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Treatment of Domestic/Municipal and Industrial Wastewater Using Microalgae: Review

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Abstract. Levels of organic and inorganic compounds in wastewater can have significant effects on its treatment costs. Despite the emergence of many technologies, treatment methods can be expensive and energy intensive. These treatment methods are mostly based on separation or precipitation. However, there is still a need for different approaches and costs effective treatment methods to remove efficiently contaminants from wastewater. This calls for sustainable treatment methods to reduce high concentrations of contaminants in wastewater to acceptable levels at lower costs, with less use of energy while being environmentally friendly and meeting the discharge standards. Microalgae use for wastewater bioremediation is examined in this article. There is a great potential for treatment of industrial and domestic wastewater despite some weaknesses. Microalgae act as bio-accumulators or bio- absorbers of contaminants and can easily reduce the contaminant load from wastewater. This review aims to highlight the capacity and possibility for algae bio-remediation of industrial and domestic wastewater. The methodological approach and results generated in previous studies are an indication of possible breakthrough in the future. However, more studies on process optimization are required to get to the effectiveness of the process.

Keywords*:* Microalgae, bio-removal, industrial wastewater, domestic wastewater

1. Introduction

Wastewater contains wastes from domestic, commercial or industrial facilities. Untreated water from domestic sewage and industrial activities may have high levels of organic and inorganic material, pathogenic organisms, nutrients and many toxic elements including heavy metals. This makes wastewater (domestic or industrial) being an environmental and health hazard requiring that wastes be removed from production sources and treated appropriately before disposal [1]. An immediate intervention is needed to be implemented in order to avoid an environmental threat when dealing with wastewater. This can only be achieved through adequate management and appropriate treatment of wastewater streams from domestic or industrial activities. The primary objective of wastewater management is to protect the environment and public health through achieving quality environmental standards and solving some related socio-economic concerns. Wastewater management is becoming vital because of diminishing water resources, increasing wastewater disposal costs and strict discharge regulations that have lowered possible contaminant levels in water bodies. The importance of treating wastewater and using clean water has become irrefutable for human life, water is the most precious natural resource needed for domestic and industrial uses on a daily basis. The imperative to protect this important natural resource has led to the fact that it is becoming a conservation priority globally. Although there are many treatment methods already in use, however, some of them generate large amounts of sludge that need off-site disposal. In addition, many of the wastewater treatment activities cannot efficiently be used, due to variations in the composition of the wastewater or the ambient temperature at different times of the year. This means that a particular treatment method may be efficient at certain times but not at other times. In this paper algal bioremediation for wastewater is being analyzed.

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Algae have interesting advantages over conventional methods of wastewater treatment. Algae-based water treatment is cost effective, requires low energy, reduces the formation of sludge, and generates useful algal biomass [2]. Algae can be used in wastewater treatment for a range of purposes, including the removal of coliform bacteria, reduction of chemical (COD) and biochemical oxygen demand (BOD), removal of Nitrogen and/or Phosphorous related compounds such as nitrates, nitrites phosphates, ammonia, and removal of heavy metals.

2. Use of Algae for Wastewater Treatment

The photosynthetic ability of algae being used for the treatment of wastewater can be considered as an attractive option due to lower operating and capital costs and the quality of effluent generated after treatment. Algal systems can treat human sewage, livestock, agro-industrial, industrial wastes and effluents from food processing factories. Also algae bioremediation systems for the removal of toxic elements such as lead, cadmium, mercury, scandium, arsenic and bromine are being developed nowadays. Algal systems have traditionally been used as a tertiary process. They are now being proposed as a potential secondary treatment system. The concept of algae-bacteria culture as an engineered system in domestic and industrial wastewater treatment has witnessed increased momentum over the past decades. This system works well in regions experiencing high solar radiation and temperature because the contaminants removal is a natural process. When solar radiation falls on algae, it reacts by producing oxygen which aerobic bacteria will use for the biodegradation of contaminants or pollutants, whilst the algae take in the carbon dioxide (CO_2) released from bacterial respiration [3]. In this manner, the algae provide an affordable and safe alternative to mechanical aeration. Additionally, the process contributes to carbon dioxide mitigation. This technology is efficient because nitrogen and phosphorous compounds can accumulate in the algae bacterial biomass during the removal process. The disadvantage of adopting this technology is the requirement to harvest the biomass through separation such as with centrifugation which is energy intensive and adds up to the costs. Incorporating an immobilization with the technology is a possible solution; however, all media are expensive and ineffective over a long period of operation. Therefore, there is a need to adopt an efficient biomass harvesting strategy such as a settleable algae-bacteria system. Although previous studies were completed on identification and biometry of the dominant algal species, they lacked sufficient information about the bacterial community associated with the process [3]. According to Barsch (1961) [4] algae play an important role in the natural self-purification of contaminated water. This phenomenon, for natural algal treatment, moreover, cannot happen without biological intervention. Early studies comment that this kind of association qualifies as an interrelationship or mutual “symbiosis” between algae and bacteria. It was reported that bacteria and algae are the most dominant organisms among the planktonic biota from oceans with their associated metabolism [4]. This helps them to control pelagic energy flow and nutrient cycling in aquatic environments [4]. Therefore, it is understood that at the center of this natural biological process there is the cyclic synergistic relationship between algae and bacteria. Algal growth due to photosynthesis and bacterial decomposition constitute the main mechanism taking place within algal-bacterial ponds. The processes including oxidation, settling, sedimentation, adsorption, disinfection in ponds are results of synergetic relation between algae and microorganisms [5].

2.1 Details on algae-bacteria interrelationship for the breakdown of contaminants in wastewater

Heterotrophic microbial mineralization of incoming organic materials generates carbon dioxide (CO_2), ammonia-nitrogen (NH_3-N), phosphates (PO_4^{3-}) and essential vitamins. All these by-products are stable, inorganic and oxidized. Afterwards, the autotrophic algae utilize the synthesized products of bacterial/microorganisms metabolism for their own development and growth through photosynthesis. In addition, the splitting of the wastewater molecules by the microorganisms during the course of algal photosynthesis allows the supply of oxygen to aerobic microorganisms giving birth to oxidative decomposition of wastewater contaminants which are mainly organic for domestic wastewater or both organic and inorganic for industrial/ agricultural wastewater. Thus, the process continues in this “positive feedback” cycle. The aquatic chemistry accounts for the diurnal shifts in dissolved oxygen (photosynthesis and respiration), pH (carbonate-bicarbonate) seen in most waste stabilization ponds (WSPs). Fig. 1 is an overview of the algal-bacteria interrelationship as reported by [4] in his study regarding algae as a source of oxygen. The figure shows the “cyclic symbiosis” between algae and bacteria within a WSP environment.

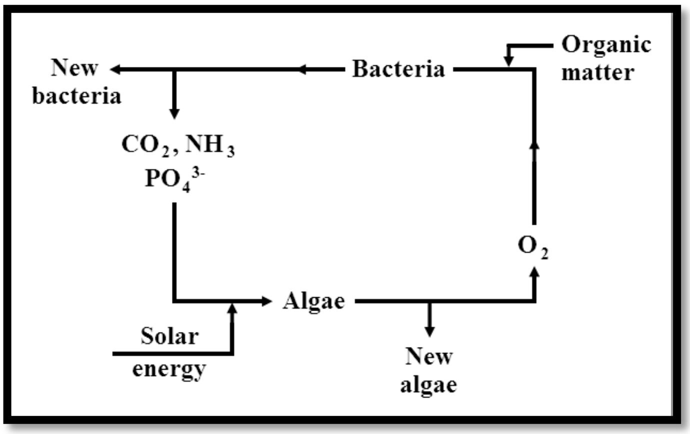

Fig. 1: Process overview of algae-bacteria interrelationship

2.2 Ponds and algal bioremediation treatment

Wastewater can be treated in many types of ponds: oxidation ponds are known as units involving stabilization of dissolved substances and suspended solids under aerobic conditions. If stabilization is taking place under anaerobic or facultative conditions these ponds take the name of waste stabilization ponds (WSP). Stabilization ponds are evaluated based on their types: facultative, anaerobic, aeration and maturation ponds. Generally, common pond type that uses algae is considered as facultative stabilization ponds. The design of Facultative ponds aims to reduce the retention time of wastewater during treatment, achieve effective treatment with high removal efficiencies and viable growth for the algal culture. Municipal wastewaters are generally treated in high rate algal ponds (HRAP) with aeration being done mechanically and they are equipped with paddle wheels for mixing purposes. These pond types are sometimes more effective than conventional systems with the same removal efficiency.

2.3 Advantages of algal treatment process for domestic wastewater

As mentioned earlier, using algae based wastewater treatment is cost effective; it requires low energy, reduces sludge formation, reduces emission of greenhouse gases (GHG) and generates significant algal biomass as compared to traditional wastewater treatment methods [3]. In addition, algae can make bio-ethanol, bio-butane, bio- hydrogen and vegetable oil [2]. In the case of bio-hydrogen production, a species such as *Chlamydomonas reinhardtii* (green algae) would at times produce oxygen and switch to bio-hydrogen production. In addition, algae can generate significant amounts of biomass which can be used for heat and electricity [3]. The technology used for algae-wastewater treatment can be applicable to domestic wastewater and industrial wastewater in various industries including poultry, dairy, aquaculture, textiles, pulp, distillery, leather, foods, petrochemicals, pharmaceuticals, chemicals and mining.

2.4 Weaknesses and factors affecting the performance algae based wastewater treatment technology

Treatment of wastewater using algae is more effective in tropical countries due to the hot climate (high temperature) and presence of abundant sunlight as mentioned earlier. These factors have a significant influence on algae growth but it is a real challenge to maintain them at the optimum. Furthermore, there are also biological and operational issues such as algae contamination, auto-inhibition and grazing to be resolved during mass cultivation of microalgae. However, contamination by bacteria and other algal species can be prevented by sterilization and ultra-filtration of the culture medium while grazing can be prevented by chemical treatment. Some of the key challenges are: light requirements, temperature, and rainfall, mixing harvesting, contamination, and oxygen depletion [2]. Table 1 summarizes the main advantages and disadvantages of algae based wastewater treatment.

Table 1: Summary of pros and cons regarding algae based wastewater treatment

Pros	Cons
Produce oxygen with low input in terms of energy	Algae do not settle well
Remove easily soluble nitrates and phosphates related compounds	Failure to meet suspended solids limits (~45 mg/L)
Can achieve high removal efficiencies for heavy metals	Algae based treatment for wastewater can interfere with disinfection
Production of biomass to be used for many industrial application	Costly biomass harvesting
Capture CO_2 to be used for algae growth	Risk of contamination and inhibition if the culture is exposed to harmful bacteria
Cost effective way of wastewater treatment when using oxidation ponds	
Reduction of greenhouse gases	
Allows BOD and COD removal	
Coliforms inhibition	

2.5 Conventional wastewater treatment versus algae-based wastewater treatment

2.5.1 Facts analysis

Wastewater treatment aims to remove solid particles known as sludge and stabilize contaminants in order to upgrade the quality of the effluent. Conventional treatment has always involved physical, chemical and biological treatment in order to get an effluent that can comply with discharge standards. This is structured into preliminary, primary, secondary or tertiary stages to remove the contaminants efficiently. Preliminary and Primary treatments aims to remove floating materials or large objects that can settle out due to gravity. Therefore, physical processes such as screening, grit removal, and sedimentation are undertaken during these two stages. Secondary treatment is achieved by biological processes and it aims to remove soluble organic contaminants and some suspended solids not removed during preliminary and primary stages. Tertiary process is based on chemical processes; during this stage denitrification can take place as well as precipitation of non-soluble compounds such as nitrates and phosphates, also, disinfection is part of this stage [6]. However, capital and operating costs to run a wastewater treatment plant can be expensive [7]. This is explained by the fact that conventional wastewater treatment plants require a huge investment for its commissioning and a regular routine maintenance which is one of the key aspects for high performance. If the plant is not maintained effectively its performance will be affected, the quality of required effluent will not be achieved as per requested standards. Also, in terms of energy consumption, conventional wastewater treatment plants can be energy consuming units because of the use of pumps and blowers for aeration and reticulation purposes. Energy optimization for a wastewater treatment plant is still a milestone to be achieved in order to run efficiently a wastewater treatment plant. Regarding the use of algae as an alternative, microalgae can play a significant role in the removal of contaminants from wastewater. Bioremediation allows auto-purification of wastewater and fresh resources [8]. Furthermore, it has been proved in many studies that algae can remove nutrients such as nitrogen and phosphorus, algae bioremediation of wastewater have achieved high removal efficiencies for heavy metals, pesticides, organic and inorganic toxins, pathogens from wastewater. The removal process is accomplished through bio-accumulation or biosorption of compounds within the algae cells [9, 10]. These studies referred to the capacity of algae to get nutrients from the water in which they survived. The exceptional ability of algae to extort compounds and elements from wastewater effectively is well organized because algae have a high potential to absorb pollutants from water. It is also important to stress on the fact algae are also good indicators of water resources pollution. Species such as *Euglena, Oscillatoria, Chlamydomonas, Scenedesmus, Chlorella, Nitzschia and Navicula*, are easily used as indicators of water pollution, but also the following species including *Lemanea, Stigeoclonium, Staurastrum, Pinnularia, Meridion and Surirella* may indicate that the level of pollution of the water course is very low or close to cleanness state.

2.5.2 Novel conceptual approach

Analyzing Fig. 2 and Fig.3 algae-based wastewater treatment can be incorporated in a conventional wastewater treatment plant. From the flow charts represented in Fig. 2 and Fig.3, it is suggested that algae-based wastewater treatment can be incorporated in the secondary treatment within a conventional treatment plant, this can be a new conceptual approach to be used for wastewater treatment if effective species can be used to remove efficiently contaminants from wastewater and produce effluent that complies with discharge standards. As a result, the necessary oxygen to feed the microorganisms will not be provided by blowers or pumps as it is in the case in conventional treatment systems but will be supplied by algae species. In this case algae will provide a way to uptake nutrients and supply required oxygen to aerobic bacteria through photosynthesis. Consequently, this can reduce energy consumption as the source of oxygen is no longer the blowers or pumps but the algae. Aeration process is known as an energy demanding for any wastewater treatment plant. Generally, aeration accounts for 45 to 75% of the total energy costs of wastewater treatment plants [11]. However, the challenge of the algae system is its capacity to produce continuously and consistently the required oxygen for microorganisms to accomplish their work in short periods of time. The weakness of algae based treatment will be the a longer treatment time compared to conventional system as it is a slow process; ponds can be an eloquent example though acceptable results can be achieved in terms of removal but it takes longer than activated sludge process. Therefore, the combination of both conventional and algae based wastewater treatment can be an option that need to be deeply examined and explored because it is energy saving and environmentally viable. Furthermore, the excess of oxygen needed to strengthen the treatment performance can be provided by algae when dealing with the combined option, it saves energy as mentioned before and will have a high impact on the contaminants removal efficiency. In this situation algae-based treatment is used as a passive treatment and the conventional system as an active treatment as per normal. In this combination the process efficiency will be enhanced, however, the costs related to maintenance will be increased. The increase is also due to algae handling and harvesting when there is need to add a new culture. It is important to stress on the fact that algae used for wastewater treatment is at the level of microalgae. It has a growth period that generally can go up to 20 days or even more depending on the species, thereafter many cells will die and there will be a need to add a new culture made up with new biomass or pellets to carry on with the treatment. Because microalgae will never settle easily during sedimentation process, if the combined option is undertaken, the separation between the biomass and clean water requires a supplementary process such as membrane filtration, flocculation or coagulation. These processes will constitute an added cost on the overall treatment process. The choice of the species is very important for algae based wastewater treatment because some species can produce toxic substances during growth. These substances can accumulate and reach higher concentrations. Consequently, inhibiting growth and prevent treatment of the wastewater in which they are growing; it is named auto-inhibition

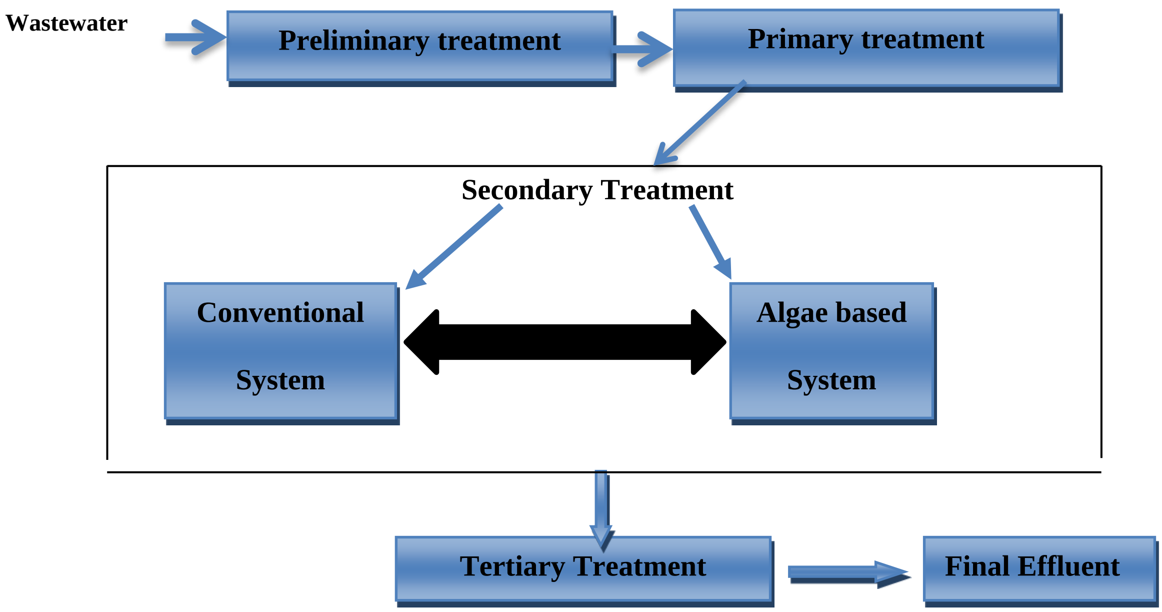

Fig. 2: Systematic chart locating the strategic position of algae based wastewater treatment (adapted from Oligae, 2013).

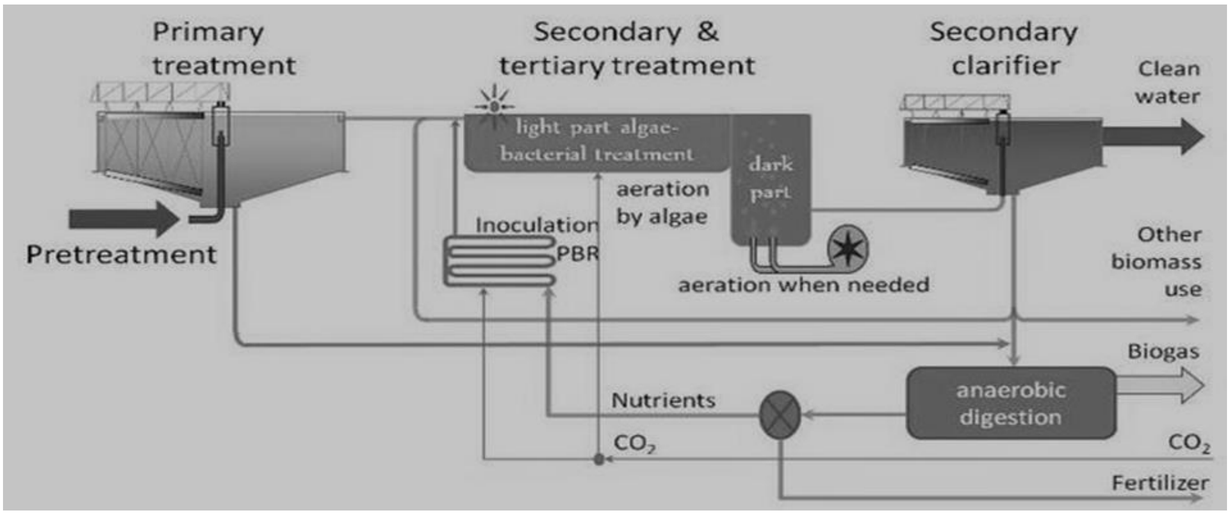

Fig. 3: Example of Flow chart incorporating algae based treatment as part of secondary treatment in a conventional wastewater treatment plant

3. Factors Affecting Removal Efficiencies when Using Algae Bioremediation of Wastewater

Many studies have shown that algae bioremediation of wastewater has potential to accomplish high removal efficiencies; the potential removed substances include nitrates, phosphates, soluble inorganic compounds and heavy metals as indicated in Table 2. This is mostly depending on the type of species or strain and its ability to absorb or accumulate in the cells contaminants from wastewater. Generally, to achieve high removal efficiencies using algae bioremediation, the operating conditions for effective algae growth need to be set properly and monitored regularly. These operating conditions require the following: the presence of light, in most cases sunlight is used as the most affordable option for photosynthesis, a temperature of the growing culture between 15 to 25 ^{o}C which is considered as the best range for optimum growth [12], the pH at neutral range which is an indicator stable growth, generally, it increases during growth period, it is also a warning parameter indicating if there is any risk of inhibition. The increase of pH may cause phosphates precipitation and the removal of compound such as ammonia and hydrogen Sulphur. Furthermore, it has been reported that high pH in algal ponds leads to pathogen disinfection [13]. In addition, there are nutrients that are needed to feed algae cells in order to allow rapid and effective algae growth. These nutrients can be supplied to the growing medium, but in the case of domestic or municipal wastewater, some of them are already contained in the wastes, the case of nitrates, phosphates, as well as heavy metals or any other compound. Also, CO_2 and HCO^{3-} are supplied to the growing algae as carbon source to fasten growth, therefore, enhancing the uptake capacity of algae. Therefore, algae bioremediation of wastewater requires a strict monitoring and compliance to growth operating conditions. The removal of contaminants can be successful if the algae growth is taking place successfully.

4. Conclusion

Algae bioremediation can efficient to remove organic and inorganic compounds from domestic and industrial wastewaters due to its many advantages. It is cost effective; there is production of oxygen taking place with low energy requirement, high removal efficiency for nitrates, phosphates, COD, BOD, heavy metals and the reduction of greenhouse emission due to consumption of CO_2 by algae during growing period. However, more studies need to be conducted regarding algae settling because algae rarely settle well; this could be a challenge to meet suspended solids limits in effluents. Future studies can focus on optimizing the design of algae based wastewater treatment systems combined with conventional systems for an efficient treatment process. The future studies will focus on scaling up from laboratory scale to large scale, to investigate on other strains that have greater potential to remove pollutants and process simulation and relevant design options, costs analyses and optimization of all aspects pertaining to the performance of the technology in order to be competitive compared to conventional one.

Table 2: Some previous work completed using algal bioremediation of wastewater

Wastewater type	Species and Parameters	Removal efficiencies	References
Domestic wastewater	Species: *C. vulgaris* Parameters: COD , BOD, NO_3, and PO_4	80.64%, 70.91%, 78.08% and 62.73%, respectively	Ayodhya and Kshirsagar (2013) [14]
Industrial wastewater (dairy effluent)	Species : *Nostoc sp* Parameters: TSS, TDS, PO_4 ,COD and BOD	53.93 %, 20.21 %, 21.08 % ,40.25 %, and 40.44 % respectively	Kotteswari M., Murugesan S. and Ranjith Kumar R (2012)[15]
Domestic wastewater	Species: *S. quadricauda* Parameters: COD , BOD, NO_3, and PO_4	70.97%, 89.21%, 70.32% and 81.34% respectively	Ayodhya and Kshirsagar (2013) [14]
Industrial wastewater	Species: *Tetraselmis Chuii* Parameters : Cd, Pb, Cu and Zn	97.3 % , 80.3 % , 94.5 % , and 96.2 % respectively	Oligae report (2013) [2]
Industrial wastewater	Species: c.vulgaris Parameters : TDS, Ca, Mg, Na, K, NH_3, NO_2,NO_3,TKN, PO_4 , BOD,COD	50%, 63 %, 50%, 14%, 18% , 80% , 89%, 29%, 73%, 94% , 22% and 38% respectively	Hanumantha Rao et., al (2011) [16]

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6. References

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