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Microalgae: A Nano Factory for Wastewater Treatment

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Abstract: *Current global environmental problems raise inevitable challenges for our use of natural resources. fast industrialization, economic development, and population overgrowth are the key reasons accountable for the discharge of organic and inorganic substances into the environment, any resulting in environmental pollution and contamination of water. provision the human population with clean water is turning into a world problem. Microalgae are shown to be a supply of multiple bio-based product starting from high price molecules to commodities. together with their potential to supply an oversized form of products, Microalgae can even be used for the depollution of wastewaters of various origins (urban, industrial, and agricultural). Microalgae are omnipresent and very numerous microorganisms which may accumulate deadly contaminants and significant metals from wastewater, creating them superior competition to become a robust nano factory. The pH increase that is mediate by the growing Microalgae additionally induces phosphorus precipitation and ammonia uncovering to the air, and will additionally act disinfecting on the wastewater. Furthermore, they're versatile, comparatively convenient, and straightforward to handle, together with varied alternative benefits akin to synthesis are often performed at low temperature with bigger energy efficiency, less toxicity, and low risk to the environment. The Microalgae even have the ability to repair the surplus greenhouse gas gift within the setting and unharness the oxygen and solve the matter of worldwide warming. Consistent with the varied study, the nutrients removal potency of Microalgae based mostly waste treatment system is incredibly high because it removes 78-99% of nitrogen and phosphorus. The treatment system additionally succeeds to get rid of 40-65% of COD, BOD and alternative impurities present in wastewater. The Microalgae treatment system is economical, green, and environmental friendly choice of wastewater treatment.*

Key Word*: Micro Algae; Wastewater; Nutrient uptake, Sunlight, Temperature, Biomass, Bioremediation*

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I. Introduction

Worldwide economic and community development has led to increased water demand along with a scarcity of water. Reports project that by the year 2030, at current water utilization practices, globally, there could be a 40% water shortfall [1]. Today, although the strategic importance of fresh water is universally recognized more than ever before, and although issues concerning sustainable water management can be found almost in every scientific, social, or political agenda all over the world, water resources seem to face severe quantitative and qualitative threats. The pollution increase, industrialization and rapid economic development, impose severe risks to availability and quality of water resources, in many areas worldwide [2]. Microalgae has long been recognized as a critical microorganism in wastewater and sewage treatment. Early studies of these systems were able to be identified that Microalgae played an essential role in wastewater treatment: directly through the uptake of organic and inorganic nutrients from waste and indirectly through the oxygenation of wastewater for aerobic microbes to further breakdown the waste. Microalgae have multiple potential applications, of which the most promising future objective on a large-scale is their use as a biofuel feedstock. A number of Microalgae-based products are already well established in other high-value markets, for example as a human dietary supplement (nutraceuticals) and as a component in animal feed. Nevertheless, considerable advances in the field of biology and substantial processing improvements are required to achieve economic, environmental, and energetic sustainability in the production of Microalgae biofuels [3]. Wastewater constitutes a good chance for Microalgae because it will be thought of as a medium for growing them at an affordable and as a replacement in potential market. Through their various modes of nutrition (phototrophy, heterotrophy, mixotrophy), Microalgae will effectively take away a broad vary of chemicals from liquid matrices. Amongst the assorted methods attainable for economical large-scale production of microalgal biomass, a coupling of sewer water treatment with Microalgae farming is presumably the foremost smart because of the similar scale and production facilities that each industries think about [3]. The pollution of municipal, agricultural, and industrial wastewater with a huge number of organic and inorganic contaminants, such as microplastics, xenobiotics, heavy metals, and high concentrations of nitrates, phosphates, and carbon (C) compounds, puts a strain on the food chain and thus the basis of human life. Wastewater treatment (WWT) is a global issue that cannot be managed by a single technology because of the extremely variable scales, types of contaminants, and regional conditions involved (Figure 1) [4].

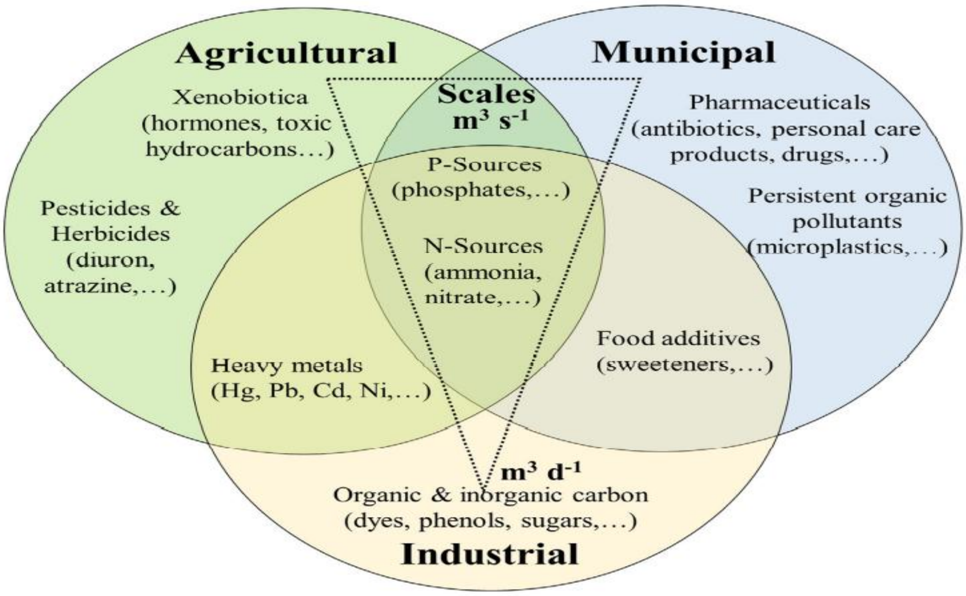

Figure 1: Wastewater sources and their typical impurities

In wastewater treatment system, the removal of principle pollutants such as suspended solids, biochemical oxygen demand (BOD), nutrients (organic and inorganic), toxicity, and coliform bacteria is the main goal to get purified wastewater [5,6]. A conventional wastewater system includes the removal of dissolved organic matter and suspended solids by sedimentation process. 'e preliminary treatment of sewage removes 60 percent of large solid materials through a well-designed sedimentation tank and approximately 35 percent of BOD delivered by sewers responsible for obstructing the flow through the plant or damage equipment. Materials such as heavier grit particles, rags, fecal materials, and woods can be removed by passing the sewage through screen bars. The secondary treatment process aims to reduce 85 percent of suspended solids and BOD exerted by reducing organic matter [7]. Microalgae have the ability to remove nutrients, heavy metals, organic and inorganic toxic substances and other impurities present in the wastewater by using the sunlight, CO_2, and various nutrients. The main advantage of using algal system is that it absorbs solar radiation in the form of energy in its chloroplast cell and takes CO_2 along with nutrients from wastewater to synthesis their biomass and produce oxygen. The released oxygen from Microalgae is enough to meet the most aerobic bacterial requirements while metabolizing the residual organics in the treated wastewater. Algae also release a large amount of simpler organic compounds that can be assimilated in aqueous system. The bacteria, in turn constitute an essential source of CO_2 required for algal growth, stimulate the release of vitamins & organic growth factors and change the pH of the supporting medium for algal growth [8].

The Microalgae system can treat various types of wastewaters like, domestic sewage, industrial waste water etc and reduce the nutrients (Nitrogen, phosphate and other minerals) from the waste water. Removal of Nutrient is an important part of wastewater treatment because rich nutrient effluent discharged into water bodies can result in eutrophication in water bodies [9]. The figure: 2, shows the Basic operation principles for the microalgal production combination with wastewater treatment. This paper is a compilation of reported experiences from wastewater treatment with Microalgae. The intention is principally to clarify the most significant factors that affect microalgal growth and to provide some opinion on design and operation of algal treatment steps.

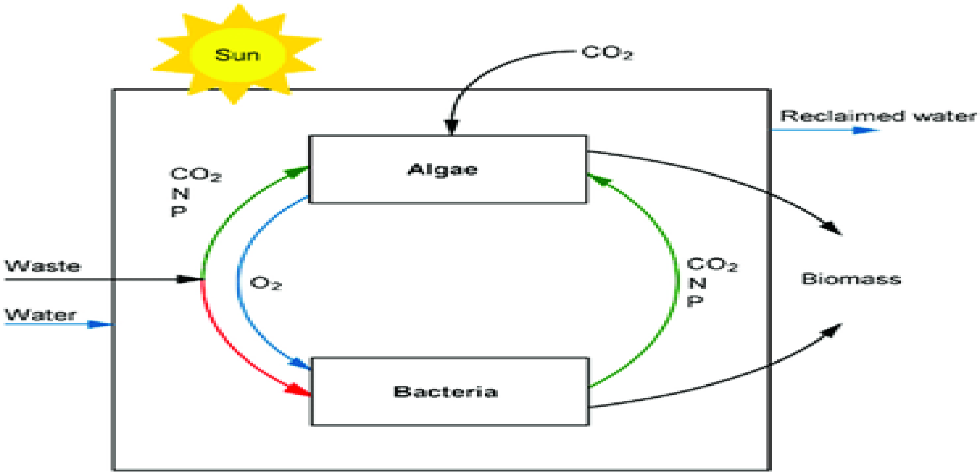

Figure 2: Wastewater sources and their typical impurities

II. Microalgal Treatment of Wastewater

The history of the viable use of algal cultures spans about 75 years with application to wastewater treatment and mass production of different strains such as Chlorella and Dunaliella. Currently significant interest is developed in some advanced world nations such as Australia, USA, Thailand, Taiwan and Mexico [10]. Microalgae based treatments have a number of unique benefits. As an aquatic species, they do not require arable land for cultivation. It means the cultivation of Microalgae does not need to compete with agricultural commodities for growing space. In fact, Microalgae cultivation facilities can be built on minimal land that has few other uses. The water used in algae cultivation can be fresh water or saline, wastewater, and salt concentrations up to twice that of seawater can be used effectively. However, the major factors of selecting a suitable strain or a mix-consortia for wastewater treatment would be (i) characteristics of wastewater, (ii) the desired level of treatment efficiency required, (iii) the cost and energy requirement of biomass harvesting, and (iv) the application of the harvested biomass. Wastewater could contain several compounds at elevated concentrations that inhibit biological (e.g., microalgal) growth [12]. Similarly, the turbidity and pH of wastewater could inhibit microalgal growth [13]. Physicochemical pretreatment of wastewater would improve the conditions for microalgal growth and reduce wastewater’s strength [14]. Microalgal biomass cultivation in such pretreated wastewater could also reduce residual nutrients and turbidity from the treated wastewater [15]. Lin et al. (2017) adopted a three-step strategy for efficient treatment of textile industry water (TWW): adsorption of toxic compounds by granular activated carbon, followed by anaerobic digestion to produce electricity and reduce the load of the TWW before cultivating Microalgae in the partially treated TWW [16]. A pretreatment would be required to reduce the ammonium concentration in wastewater, or wastewater should be diluted to a tolerable limit where the selected strain could grow efficiently [17].

III. Microalgal Nutrient Uptake Efficiency

Algae are autotrophs, i.e. they can synthesize organic molecules themselves from inorganic nutrients. A stoichiometric formula for the most common elements in an average algal cell is $C_{106}H_{181}O_{45}N_{16}P$, and the elements should be present in these proportions in the medium for optimal growth [18]. The use of municipal and industrial wastewater effluent as a nutrient feedstock to produce Microalgae has environmental and economic benefits. Wastewater nutrients are fed Microalgae by different nutrients like nitrogen, phosphor, ammonia, sulphur, iron, toxins and all the metals in wastewater to production of Microalgae biomass [19]. Phosphorus and Nitrogen are the most essential nutrients for the Microalgae growth. Besides carbon, nitrogen is the second most important nutrient to Microalgae. Phosphorus is another macro-nutrient essential for growth, which is taken up by algae as inorganic orthophosphate [18]. Table: I. shows the major nutrient removal efficiencies by Microalgae cultivation [20]. The rate at which an algal cell takes up a specific nutrient depends on the difference between the concentration inside and outside the cell, and also on the diffusion rates through the cell wall. The thickness of the unstirred layer of water just outside the cell wall also plays a role, where thicker layers give slower diffusion rates. To avoid such thick boundary layers to enhance mass transfer rates of nutrients and metabolites, turbulence in the water is essential [26].

Table no 1: Summary of major nutrient removal efficiencies by algal cultivation

Algae Species	Wastewater Characteristics	N (%)	P (%)	Carbon	Retention Time	References
Algal–bacterial symbiosis (Chlorella + Nitzchia)	Settled domestic sewage	92	74	97% BOD, 87%COD	10 h	20
Chlorella pyrenoidosa	Settled domestic sewage	93.9	80	NA	13 days	21
Cyanobacteria	Secondarily treated domestic effluent + settled swine wastewater	95	62	NA	1 day	22
Chlorella vulgaris	Diluted pig slurry (suspended solids content to 0.2%)	54-98	42-89	BOD_5 98%	4.5 days	23
Chlorella pyrenoidosa	Domestic sewage and industrial wastewaters from a pig farm and a palm oil mill	60-70	50-60	80-88 % of BOD, 70-82 % COD	15 days	24
Mixed culture of Chlorella and diatom species	Wood-based pulp and paper industry wastewater			58 %	42 days	25
NA : Not Applicable						

The artificial wastewater medium was used to analyze the amount of nitrogen incorporated into *Scenedesmus obliquus* (*S. obliquus*) biomass and the loss of nitrogen in the form of ammonium. *S. obliquus* was cultivated in an artificial medium with the daily replacement of 50% and 70% of the cell suspension with the fresh medium. The result of this study concluded that only lesser amount of nitrogen in the form of nitrate were utilized from the medium by *S. obliquus* and the remaining form of nitrogen is lost by ammonia stripping [27]. Several studies were performed to analyze the capability of Microalgae consortium along with symbiotic bacteria for nutrient removal capacity from wastewater. One such study was the analysis of euglenophyt, cyanobacterium, green Microalgae and two types of indigenous Microalgae consortium along with symbiotic bacteria for the nutrient removal capability from diluted (1:4 & 1:8) piggery wastewater. The result of this study showed that the unialgal cultures like *Euglena viridis (E. viridis), Chlorella sorokiniana (C. sorokiniana)* were able to grow in both types of diluted wastewater, while *Scenedesmus obliquus (S. obliquus)* and consortium 2 were able to grow in eight times (1:8) diluted wastewater, whereas consortium1 and *Spirulina platensis* showed no growth. In case of phosphorus and nitrogen removal capacity, *E. viridis* and *C. sorokiniana* showed more nitrogen removal in both the dilutions; on the other hand, *C. sorokiniana, S. obliquus* and *E. viridis* showed phosphorus (20 - 65%) removal in eight times diluted wastewater [28]. Nutrients in wastewater have been removed mainly by activated sludge in a conventional biological process. However, this kind of bacteria-based treatment has limited capability for nitrogen and phosphorus removal. Therefore, nitrogen and phosphorus have been removed additionally by advanced treatment processes before discharge of the wastewater [29]. The bacteria living in activated sludge are expected to help the microalgal growth. Algae and bacteria, when they were co-cultivated, could remove N, P, and COD simultaneously [30].

The treatment of wastewater having low nitrogen to organic carbon ratio (C/N) is challenging. In such wastewater, supplementation of organics is often practiced improving bacterial nutrient removal efficiency as a source of energy. On the contrary, Microalgae could utilize sunlight, the soluble inorganic carbon dioxide, nitrogen, and other nutrients to increase their cell numbers while treating wastewater. Depending on the strain type, microalgal cellular nitrogen content could range from 3-10% [31,32]. A variety of inorganic (e.g., ammonium, nitrate, nitrite, atmospheric nitrogen) and organic (e.g., urea, glycine, etc.) forms of nitrogen could be assimilated by microalgal/cyanobacterial strains, although the efficiency would again vary among strains and growth conditions. From a cost perspective, microalgal removal of phosphorus from wastewater could be a superior choice over chemical precipitation and engineered wetland-based phosphorus removal [33,34]. Microalgae could also selectively consume nitro and amino groups from different aromatic compounds (e.g., aminonaphthalenes and nitrobenzonates) as nitrogen source-thereby reducing the toxicity of the original pollutants [35]. Microalgal nutrients' removal efficiencies from different wastewaters are listed in Table 2 [36].

Table no 2 : Microalgal nutrient removal efficiencies from different wastewater

Wastewater	The Concentration of Contaminants in Wastewater (mg/L)			Strain	Operating Conditions		Removal Efficiency		
	TN	TP	TOC		pH	vol (L)	TN	TP	TOC
Municipal sewage water	116.1	212	-	*Chlorella sp.*	-	25	94	89.1	-
	130	15	-	*Spirulina sp.*	7.7	0.25	79	93.3	-
	40.6	5.66	-	*Chlorella sp.*	-	0.1	82.4	50.9	-
Produced water	52.4	0.21	720.3	*Chlorella sp.*	7.0	1	92	73	-

Agro-industry wastewater	1570	154	-	Microalgal consortia	-	0.6	49	70	-
	44	88	495	*Scenedesmus obliquus*	8.6	0.5	34	65	42
	44	88	495	Algal consortia	8.6	0.5	36	13	46
Pharmaceutical wastewater	729.5	54.5	-	*Chlorella sorokiniana*	7.5	0.25	70	89	-
	44	5	-	Microalgal consortia	-	9600	74	92	-
Landfill leachate	1650	5.42	-	*Chlorella vulgaris*	6.6	0.5	69.3	100	-
	1084	1.78	-	*Acutodesmus obliqus*	-	-	30	93	-
	1786	4	-	Microalgal consortia	-	0.4	90	95	-
Aquaculture wastewater	6.81	0.42	-	*Chlorella vulgaris*	-	5	86.1	82.7	-
	41.3	4.96	-	*Tetraselmis suecica*	-	40	49.4	99	-
	9.8	1.56	14	algal-bacterial flocs	-	400	58	89	71
Aqueous phase wastewater from biomass to energy generation process	4223	504.7	13,917	*Tetraselmis sp.*	-	1	98.5	98	-
	6900	1100	13,800	*Picochlorum sp.*	-	1	95.4	97.2	94.3
	9650	343	-	*Chlorella vulgaris*	-	0.15	59.9	94.6	-
Wastewater from mines	56	15.6	176	*Micratinium reisseri*	-	0.2	97	83	62

IV. Microalgae Impact with Sunlight, pH and Temperature

Microalgae are phototrophs, which means that they obtain energy from light. However, some algae can grow in the dark using simple organic compounds as energy and carbon source. The light energy is converted to chemical energy in the photosynthesis, but large parts are lost as heat. Oswald (1988) reports that in outdoor ponds, more than 90 % of the total incident solar energy can be converted into heat and less than 10 % into chemical energy [37]. Fontes (1987) reports a conversion efficiency of sunlight energy into chemical energy of only 2 %. There are several strategies used by Microalgae to remain near the water surface to catch enough light. These strategies aim to decrease the specific gravity and thereby minimize the sinking rate. Examples of this are fat accumulation, mucilage production, selective accumulation of ions (monovalent ions have a lower specific gravity) and buoyancy among some cyanobacteria which float due to gas vacuoles [18]. Microalgal growth rate and treatment of wastewater may also be affected by pH of the waste water. Availability of inorganic carbon also affected by pH, even if pH is high for other reasons than photosynthetic CO_2-exhaustion, the pH regulates what species of inorganic carbon that is available [18]. Increasing dissolved oxygen concentration and pH cause for phosphorus sedimentation and also ammonia and hydrogen sulphur removal. High pH in algal ponds also leads to pathogen disinfection [19]. Fontes et al (1987) observed that optimal productivity of the cyanobacterium *Anabaena variabilis* were obtained at pH 8.2–8.4, being slightly lower at 7.4–7.8, decreasing significantly above pH 9, and at pH 9.7–9.9 the cells were unable to grow well [18]. Nitrogen absorption by the algae also affects pH in the medium. Assimilation of nitrate ions tend to raise the pH, but if ammonia is used as nitrogen source, the pH of the medium may decrease to as low as 3, which is too acid to support growth [38]. High pH can lead to precipitation of phosphate in the medium by formation of calcium phosphates, but these may redissolve if pH drops, e.g. during night. If the concentration of ammonia is high at high pH, the photosynthesis will be inhibited. High pH may also induce flocculation of some algae, which in turn lead to reduced nutrient uptake and growth, but this flocculation can, on the other hand, facilitate harvesting [18].

Generally, temperatures around 15-25ºC seems to suit most algal species, even those which are adapted to growth at colder temperatures. To enable higher temperatures in algal cultures, greenhouses may be a solution at higher latitudes [39]. Temperature is proportional to the availability of sunlight and has little effect when light is limiting. When light availability is not limiting, increase in temperature can increase the rate of photosynthesis, growth/doubling rates are consequently [19]. At low temperatures, Microalgae easily get photo-inhibited by high light intensities. This sensitivity to bright light at low temperatures may pose an operational constraint on outdoor wastewater treatment in cold climate. At temperatures near optimum for growth, Microalgae can better tolerate high light intensities before getting inhibited [40]. Although microalgal removal of a couple of pharmaceuticals and personal care compounds (PPCCs) (e.g., benzothiazole, diclofenac, OH-Benzothiazole, etc.) were affected by seasonal variation (temperature), the removal of most common PPCCs (e.g., caffeine, acetaminophen, ibuprofen, etc.) in wastewater was minimally affected by the variation in temperature [41].

V. Microalgal Biomass mediated Bioremediation of Wastewater

Microalgal biomass has the potential to be a sustainable alternative feedstock compared to the feedstock typically generated from the terrestrial plant. Water and nutrients supply are two factors that would influence microalgal biomass production’s cost and energy; in this regard, the cultivation of Microalgae in wastewater could offer additional benefits, although this would limit the application of produced algae biomass. Potential applications of Microalgae biomass grown in different industrial wastewaters were reviewed recently.

A schematic of the microalgal bioremediation of wastewater and the potential applications of the produced biomass is shown in Figure 3 [1].

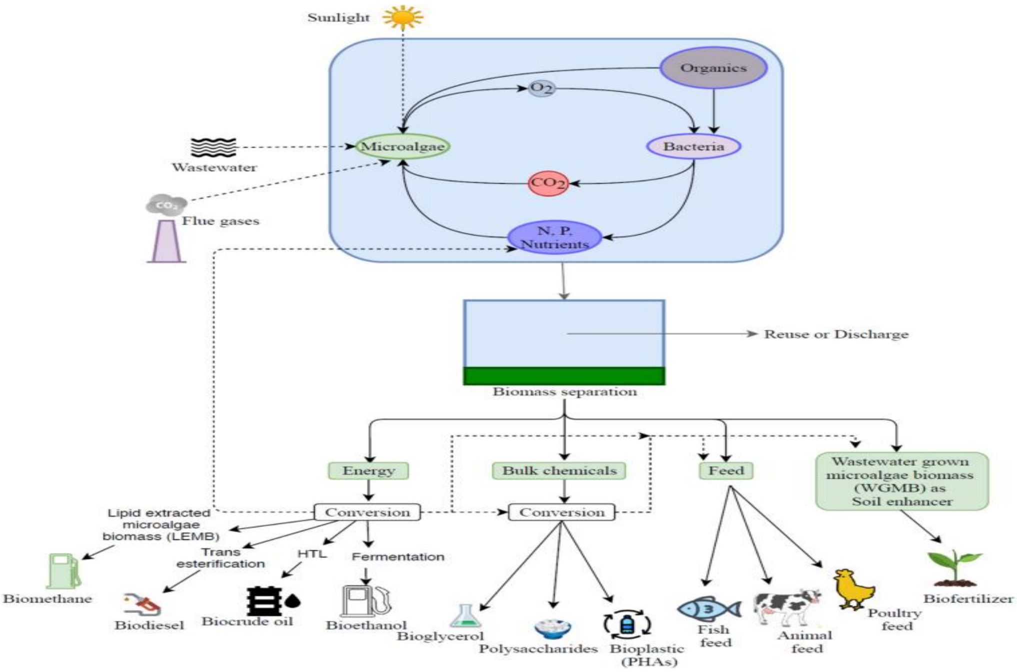

Figure 3: Microalgal bioremediation of wastewater and the potential applications of the produced biomass.

The major metabolites of microalgal biomass are protein, lipid, and carbohydrate; the relative composition of these metabolites could vary among strains and the prevailing growth conditions (i.e., nutrient composition and concentrations, duration of cultivation, light intensity, temperature, pH, salinity, etc. [42]. Several Microalgae could accumulate various high-value pigments (phycocyanin, phycoerythrin, β-carotene, lutein, astaxanthin etc.) [43].

VI. COD and BOD Reduction

As stated before, there are many amalgams and microorganisms could be detected in wastewater, which is capable of causing the pollution of a water-course. Pollution of wastewater may be manifested in three broad categories, namely organic materials, inorganic materials in addition to microbial contents. The organic compounds of wastewater comprise a large number of compounds, which all have at least one carbon atom. These carbon atoms may be oxidized both chemically and biologically to yield carbon dioxide. If biological oxidation is employed the test is termed the Biochemical Oxygen Demand (BOD), whereas for chemical oxidation, the test is termed Chemical Oxygen Demand (COD). In other words, BOD exploits the ability of microorganisms to oxidize organic material to carbon dioxide and water using molecular oxygen as an oxidizing agent. Therefore, biochemical oxygen demand is a measure of the respiratory demand of bacteria metabolizing the organic matter present in wastewater. Excess BOD can deplete the dissolved oxygen of receiving water leading to fish kills and anaerobiosis, hence its removal is a primary aim of wastewater treatment [2]. BOD is removed in the aerobic and anaerobic ponds in a WSP system. In the aerobic ponds, the algae produce oxygen that is used by the aerobic bacteria for the breakdown of complex organic matter. The residual BOD is removed in the anaerobic pond by heterotrophic bacteria including denitrifying bacteria. A final maturation pond plays a crucial role in the removal of human pathogens [44]. The consortia of Microalgae and aerobic bacteria have been used to remove COD from domestic wastewater. However, the use of COD as a wastewater quality parameter has received lesser attention than BOD despite the advantages of the former over the latter. Hammouda et al. [45] reported 84% in BOD and 89% in COD removal, using *C. vulgaris* and *Scenedesmus sp.* in batch system. Govindan [46] reported BOD reduction from 75% to 95% and COD reduction from 72% to 91%, respectively, in a system with dairy wastewater in admixture with sewage. Rana [47] reported 89% in BOD and 88% COD reduction using C. vulgaris at 30°C during 48 hr. The wastewater treatment utilizing the algal-bacterial system [48] was capable of removing about 80% COD. A relatively lower efficiency of COD removal in the range between 59.2% and 79.4% was reported by Wood et al. [49] by combining the high-rate algal pond, using filamentous green algae and an artificial wetland. Biological treatment of domestic wastewater using algae indicated 68.4% BOD and 67.2% COD removal, respectively [50].

VII. Conclusion

The use of Microalgae for wastewater treatment has long been considered a viable method of treating waste streams while producing high value added microalgal biomass. Research into the use of Microalgae for waste treatment systems spans over a century and has been closely linked to political and economic events. Although large-scale processing plants have not yet been widely adopted, a combination of technological advancements and socio-political pressure is expected to lead to the development of these facilities in the near future. Cultivation of Microalgae on wastewater offers new perspectives for the Microalgae industry and the wastewater treatment industry. The use of wastewater for the cultivation of Microalgae is necessary to reduce the production costs of Microalgae. This is a prerequisite for Microalgae to enter the energy market via biofuels. The wastewater treatment industry faces challenges that encourage the development of other alternatives. The processes linked to Microalgae can be an interesting alternative to the conventional activated sludge process.

Despite these opportunities, several analysis and development challenges have still to be overcome to learn from the total potential of the mix of Microalgae production and waste product treatment, specifically within the development of robust, productive wastewater-adapted microalgal species, and in the improvement and innovation of cultivation and downstream process systems which is able to yield higher growth, gather and conversion of the Microalgae biomass. A prolific growth rate, ability to adapt in several wastewaters and uptake nutrients or take away pollutants from wastewater, including the assimilation of carbon dioxide, might build microalgal bioremediation of wastewaters terribly promising.

Therefore, more detailed studies would be needed to select the appropriate strain (s) from a wider range of algae species and to understand the efficiency of the treatment along with the long-term biomass productivity in a large-scale outdoor installation in varying environments and wastewater properties. Microorganisms in Microalgae bacteria or Microalgae-Microalgae consortia require a better understanding of long-term field operations. The development of an application-specific, energy-saving biomass sorting and harvesting is a prerequisite for the bioremediation of sewage Microalgae; With this in mind, a freestanding strain or consortia of bio-flocculating strains need to be developed. In addition, the harvested Microalgae biomass should be evaluated in a multi-product biorefinery approach in order to improve the economic efficiency and environmental compatibility of biological wastewater treatment.

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