Algal Technologies for Wastewater Treatment and Biofuels Production: An Integrated Approach for Environmental Management

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1 Introduction

The algae play very important role in mobilizing elements in the aquatic environments and received more attention in recent years as they have ability to absorb and detoxify heavy metals (Ye et al. 2012). Synthesis of phytochelatins and metallothioneins by algae helps in forming complexes with heavy metals and their detoxification (Suresh and Ravishankar 2004). Heavy metal uptake and

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accumulation in algae from wastewater depend on adsorption process and uptake metabolism (Lomax et al. 2011). For removing organic and inorganic contaminants, nutrients, and metals from wastewater different microalgae have been used (Hirooka et al. 2005; Fierro et al. 2008; Jácome-Pilco et al. 2009). Wastewater treatment by algae is more feasible due to their low cost and high efficiency as they remove contaminants by uptake and accumulation. Algae are capable of biotransforming and mineralizing nutrients and metals growth and development (Semple et al. 1999). Therefore, an integrated algal system can be utilized for wastewater treatment to remove organic matter, nutrients (N&P) from industrial effluents, sewage, and other wastes (Sivakumara et al. 2012).

Despite algal wastewater treatment being promoted as long ago as the 1950s (Oswald and Gotaas 1957), it has yet to be adopted as a conventional approach (Pittman et al. 2011).

Wastewater treatment by algae may be a sustainable option over conventional wastewater treatment which are costly and require energy for operation. There are some limitations in wastewater treatment by algae like problem in separating the algae from the treated water due to their small size (de la Noüe et al. 1992). Algal biomass is being utilized as feedstock for generation of biogas. Recently, several algae have been reported for biogas production. Biogas production potential of *Chlorella spp*. and *Chroococcus spp*. has been explored in earlier studies (Prajapati et al. 2013, Prajapati et al. 2014). Similarly, digestion studies of *Scenedesmus obliquus* and *Phaeodactylum tricornutum* under mesophilic and thermophilic temperature conditions have been conducted (Zamalloa et al. 2012). Green algae and cyanobacteria are distinct photosynthetic organisms able to rapidly convert solar energy to carbon based compounds. They are attractive raw materials for biofuel production because they are more capable to capture carbon dioxide and have less impact compared to other biofuel crops cultivation on agriculture and land availability. However, for commercialization of algal based biofuels including biomethane, high cost of nutrients is required in growing algae which may be overcome by utilizing wastewaters to provide nutrients. Recently, algae have been grown in the laboratory under volume reactor anaerobic digestion of wastewater (Kinnunen et al. 2014). The advantage of wastewater treatment by algae is the production of algal biomass which can be further used for biofuel production (Prajapati et al. 2013).

Algal biomethane process is also affected by lower activity of anaerobic microflora due to imbalanced carbon and nitrogen (C/N ratio) which may be overcome by codigestion with carbon rich substrate (Zhao and Ruan 2013). For example, a significant increase in biogas production has been observed by co-digesting Taihu blue algae with corn straw at C/N ratio of 20/1 (Zhong et al. 2012) and optimized C/N ratio to be 15/1 for co-digestion of Taihu algae and kitchen wastes (Zhao and Ruan 2013). Therefore, anaerobic digestion of algal biomass may be increased by codigestion with carbon rich substrate. Importantly, the economic value, energy, and resource efficiency of photosynthetic biofuels can be considerably improved when employing waste streams as feedstocks (Pittman et al. 2011, Samorì 2013). Nutrient resource reuse is particularly important in the face of diminishing phosphorus reserves and threats to global food security (Cordell et al. 2009). From the above discussion, it is clear that integrated approach of wastewater treatment and codigestion of resulting algal biomass for biofuel production may be a sustainable way for environmental management.

2 Wastewater Treatment by Algae

2.1 Wastewater Type and Composition

Generally water after consumption by different source is termed wastewater or water enriched with different types of compounds is known as wastewater. In wastewater different type of pollutants are present which directly or indirectly affects the health of people around the world. About more than 50% diseases are water borne. The main source of wastewater is effluent emitted from household, urban, municipal, agricultural, chemical, and industrial resource. Point and non-point sources of wastewater from different anthropogenic activities have detrimental effects on water quality when directly discharge into the river without any treatment (Rai et al. 2011). The wastewater discharge can be characterized into two types, i.e., organic and inorganic waste. Organic waste constitutes the carbon containing biodegradable substances while inorganic waste constitutes nitrate, phosphate, heavy metal, etc. As for organic waste is concern, it was degraded by the activity of microbes and oxidation processes. However, inorganic pollutant particularly heavy metals cannot be treated effectively through simple measure and persist in the environment for long time. Untreated sewage may contain different heavy metals like cadmium, zinc, nickel, lead, chromium, cobalt and copper release into the waterbodies, and sediments leads to their bioaccumulation and bio-magnification into the aquatic flora and fauna (Gochfeld 2003).

2.2 Algae Based Wastewater Treatment Technologies

Technologies have been put forth for the treatment of wastewater still could not mitigate the pollution at satisfactory level. Moreover, technologies used are high cost and are not eco-friendly. Therefore, there is a noteworthy requirement for some cost-effective green technology which can treat wastewater in a sustainable manner. In this regard plant based management of wastewater could be a boon over water pollution.

The algae based treatment systems have been reported for efficient treatment of sewage, agricultural waste, and industrial effluent (Kaplan et al. 1988; Ma et al. 1990). More frequent algal based treatment systems used are the Algal Turf Scrubber (ATS) and High Rate Algal Ponds (HRAP) (Craggs et al. 1996; Oswald

1988) for growing algal biomass of green algae (*Scenedesmus* sp., *Chlorella* sp., and *Cladophora* sp.) and cyanobacteria (*Spirulina* sp., *Oscillatoria* sp., and *Anabaena* sp.). Currently algae and cyanobacteria draw more attention towards sustainable wastewater treatment. Algae and cyanobacteria have potential to treat different types of wastewater from surrounding. Algae are small in size can grow autotrophically like green algae or heterotrophically as cyanobacteria with high tolerance to heavy metals and other water contaminants. Synthesis of phytochelatin and potential for genetic manipulation in algal cell makes them more efficient for removal of pollutants from wastewater (Cai et al. 1995). The interesting idea of wastewater treatment by algae has been launched by Oswald and Gotaas (1957) in the USA. Different algae such as *Chlorella, Ankistrodesmus, Scenedesmus, Euglena, Chlamydomonas, Oscillatoria, Micractinium*, *and Golenkinia* have been reported from waste stabilization ponds and may be utilized for water treatment (Palmer 1974).

2.3 Nitrogen and Phosphorus Removal Efficiency of Algae

Nitrogen and phosphorous are very essential for algal growth; however, they have detrimental effects at higher concentration in wastewater. Algae can thrive in wastewaters containing high concentration of nitrogen and phosphorus (Pittman et al. 2011) and which can be applied not only to remove, but also to mobilize these nutrients as fertilizer in the terrestrial environment. Algal bioremediation to remove metals and nutrients from wastewater is widely accepted as an efficient and cost-effective method (Barrington et al. 2009; Neori et al. 2004) (Table 1).

2.4 Heavy Metals Removal Potential of Algae

As for heavy metal is concern, ability of algae to accumulate heavy metals has been recognized for many years (Megharajet al. 2003; Wang et al. 1995; Bursali et al. 2009; Al-Homaidan et al. 2011). Algae particularly microalgae remove metals from

Table 1 Different potential algae used in wastewater treatment

Algae	Type of wastewater	References
Spirulina	Anaerobic effluents of pig waste	Lincoln et al. (1996)
Phormidium bohneri	Sewage	Talbot and de la Noue (1993)
Chlorella sp.	Municipal wastewater	Li et al. (2011)
Euglena	Domestic wastewater	Mahapatra et al. (2013)
Desmodesmus sp. TAI-1 and *Chlamydomonas*	Industrial wastewater	Wu et al. (2012)
Scenedesmus quadricauda	Campus sewage	Han et al. (2015)

Table 2 Potential algae used for heavy metal accumulation/removal from wastewater

Algae	Algae group	Heavy metal accumulation/ removal	References
Nitella pseudoflabellata	Red algae	Cr, Cd	Gomes and Asaeda (2013)
Cystoseira indica, *Nizmuddinia zanardini*, *Sargassum glaucescens*, and *Padina australis*	Brown algae	Ni	Pahlavanzadeh et al. (2010)
Chlamydomonas reinhardtii	Green algae	Cu, Pb	Flouty and Estephane (2012)
Chlorella vulgaris, Chlamydomonas sp.	Green algae	Pb	Golab and (Smith 1992)
Chlamydomonas reinhardtii and *Scenedesmus obliquus*	Green algae	As	Wang et al. (2013a, b)
Cladophora sp.	Green algae	Pb	Cao et al. 2015
Microcystis aeruginosa	Green algae	As	Wang et al. 2014
Laminaria hyperborea, Bifurcaria bifurcata, Sargassum muticum, and *Fucus spiralis*	Brown algae	Cd, Zn, Pb	Freitas et al. (2008)

wastewater either by metabolism dependent uptake at low concentrations or by absorption process (Matagi et al. 1998). In recent years, green algae such as *Enteromorpha* and *Cladophora* have been used to estimate metal concentrations (Al-Homaidan et al. 2011). The potential of algae for bioaccumulation and biotransformation of metals has led to their widespread utilization in ecosystem's biomonitoring studies(Mehta and Gaur 2005). The Cyanobacteria *Phormidium* has been used successfully for bioaccumulation cadmium, zinc, lead, nickel, and copper (Wang et al. 1995). The algae *Caulerpa racemosa* has been utilized for boron removal from wastewater (Bursali et al. 2009). Therefore, removal of metals and nutrients by algae may provide a cost-effective and environmental friendly method for wastewater treatment (Table 2).

The functional groups, hydroxyl (–OH), phosphoryl (–PO), amino (–NH), carboxyl (–COOH), and sulfydryl (–SH), present on algal cell which bound metals (cations) from wastewater (Xue et al. 1988; Romero-González et al. 2001). Different algae have been manipulated for overexpression of metal binding protein (metallothionein) and removal of metal from wastewater. Genetic engineering was first done with an Hg^{++} transport system for overexpressing metal binding protein (metallothionein) (Chen and Wilson 1997; Li et al. 2011).

3 Algal Biomass for Biofuel Production

Algae are fast growing and most abundant photosynthetic plants in the world and organism of bulk production of different types of products like chemicals, biofuel, lipid, EFA, and secondary metabolites (Wijffels et al. 2013). Generally algae grow in two basic system: open systems include turf scrubber and tanksetc and closed systems consisting bioreactor, biocoil, bags, etc (Borowitzka 1999). Closed system of growing algae can improve yields by protecting algal species from different contaminations and provide temperature control (Darzin and Pienkos 2010).

3.1 Biomass Production

Basically two concepts, i.e., open pond reactor and closed photobioreactor of algae production are used nowadays. Prior to biofuel preparation some common steps, i.e., cultivation, collection, harvest, and a processing steps, are being used regardless of the biomass feedstock. In the production of biodiesel lipid content is one of the important components which should be high in algae with high lipid production efficiency (Xu and Hu 2013). The algae such as *Chlorella*, *Scenedesmus*, and *Botryococcus braunii* have been reported for biodiesel production (Wang et al. 2013a, b; Nascimento et al. 2013). The lipid obtained from algal biomass contains triacyglyceride and different sterol (Pruvost et al. 2009; Pruvost et al. 2011) which may or may not affect the biodiesel production efficiency. Therefore proper fatty acid profile of the algae need to be done before the start of production process of transesterification (Xu and Hu 2013; Bogen et al. 2013). Lipids having high content of mono unsaturated fatty acids (MUFA) with low content of poly unsaturated fatty acids (PUFA) are preferred for biodiesel as they can be easily transesterified during the processes (Mandotra et al. 2014).

3.2 Harvesting

Different strategies viz. centrifugation, flocculation, and filtration have been applied for the effective removal of algae from water. In centrifugation processes algae are removed through gravitational force by rotating water sample to high speed in centrifuge and algal mass collected at the bottom of tubes. Different types of centrifuge are in used for obtaining biomass form algae which are slightly varies in mechanism to separate materials (Shuler 2002) like centrifugal force, flow rate, biomass settling rate and settling distance of centrifugation (Williams and Laurens 2010). In flocculation process chemicals like polyacrylamides are added to clump algae together and easily separated. In the closed system limiting the supply of CO_2 causes the cells to clump. Often, in the flocculation generally salt of aluminum and iron are used (Grima et al. 2003). Filtration is also the best process and algae can be filtered by applying water pressure of water to pass through a membrane. The easiest form of filtration is dead-end filtration (Fig. 1).

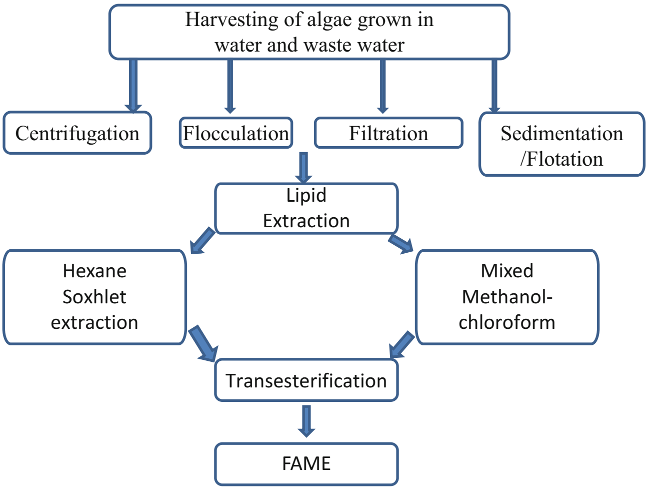

Fig. 1 Schematic representation of processes involved in biofuel production from algae

3.3 Processing

Lipid extraction is a key practice prior to transesterification. Lipid is extracted from the biomass of algae which is usually performed by the hexane Soxhlet extraction and mixed methanol–chloroform (2:1 v/v) (Bligh–Dyer method) (Bligh and Dyer 1959) process. In transesterification lipid compounds (triglycerides) react with alcohol in the presence of catalyst (Van Gerpen et al. 2004; Francisco et al. 2010). In the transesterification process propanol, butanol, methanol, ethanol, and amyl alcohol are used (Naik et al. 2006). Methanol and ethanol are utilized most frequently for transesterification process. The transesterified product is known as Fatty Acid Methyl Esters (FAME) which is known as biodiesel fuel. The main purpose of transesterification is to lower the viscosity of oil (Indhumathi et al. 2014).

4 Factor Affecting on Wastewater Treatment and Energy Production Efficiency of Algae

Algal biomass cultivation is difficult due to low survival under harsh conditions, heterotrophic species, climatic, and effluent water (Varshney et al. 2015). However, closed system improves yields by protecting algal species from water contaminants. Quality of wastewater and climate related impacts viz. rainfall, evaporation, and diurnal and seasonal temperature fluctuations affects growth, type, and abundance of algae. In case of land based aquaculture operations, wastewater treatment is often limited by strict environmental regulations around water quality of point-source discharges (Abreu et al. 2011 and de Paula Silva et al. 2008). Algae producing lipids with high content of mono unsaturated fatty acids are more suitable and efficient for biodiesel production.

5 Conclusion and Future Prospect

It may be concluded from the literature that efficient algae can be cultivated for algal biomass production utilizing wastewater containing nutrients (nitrogen and phosphorus) and metals to remove them. Additionally, the resultant algal biomass from water treatment could be utilized for biofuel production, it may be a more viable, cost-effective and eco-friendly integrated method for wastewater treatment and biofuel generation. Moreover, treated water may be utilized for irrigation in agricultural field for crop production which further strengthen the feasibility of the algae based treatment of wastewater on sustainable manner. Further, algae based biotransformation and detoxification of water contaminants may contribute to reduce the toxicity of their bioaccumulation in crops for sustainable agriculture and environmental monitoring. Therefore, an integrated approach of wastewater treatment and biofuel production by algae could be a viable method for environmental cleanup, biofuel production, and environmental management in the coming future.

References

Abreu MH, Pereira R, Yarish C, Buschmann AH, Sousa-Pinto I (2011) IMTA with *Gracilaria vermiculophylla:* productivity and nutrient removal performance of the seaweed in a land-based pilot scale system. Aquaculture 312:77–87

Al-Homaidan AA, Al-Ghanayem AA, Areej AH (2011) Int J Water Resour AridEnviron 1:10–15

Barrington K, Chopin T, Robinson S (2009) Integrated multitrophic aquaculture (IMTA) in marine temperate waters. FAO Fisheries and Aquaculture Techinical Paper No. 529. In: Soto D (ed) Integrated mariculture: a global review. FAO, Rome, pp 7–46

Bligh EG, Dyer WJ (1959) A rapid method of total lipid extraction and purification. CanJ Biochem Physiol 37:911–917

Bogen C, Klassen V, Wichmann J, La Russa M, Doebbe A, Grundmann M et al (2013) Identification of *Monoraphidium contortum* as a promising species for liquid biofuel production. Bioresour Technol 133:622–626

Borowitzka MA (1999) Commercial production of microalgae: ponds, tanks, tubes and fermenters. J Biotechnol 70:313–321

Bursali EA, Cavas L, Seki Y, Bozkurt SS, Yurdakoc M (2009) Chem Eng J. 150:385–390

Cai XH, Logan T, Gustafson T, Traina S, Sayre RT (1995) Mol Mar Biol Biotechnol 4:338

Cao DJ, Shi XD, Li H, Xie PP, Zhang HM, Deng JW, Liang YG (2015) Effects of lead on tolerance, bioaccumulation, and antioxidative defense system of green algae Cladophora. Ecotoxicol Environ Saf 112:231–237

Chen S, Wilson DB (1997) Construction and characterization of *Escherichia coli* genetically engineered for bioremediation of Hg(2+)-contaminated environments. Appl Environ Microbiol 63:2442–2445

Cordell D, Drangert JO, White S (2009) The story of phosphorus: global food security andfood for thought. Glob Environ Chang 19:292–305

Craggs RJ, Adey WH, Jenson KR, St. John MS, Green GF, Oswald WJ (1996) Phosphorous removal from wastewater using and algal turf scrubber. Water Sci Technol 33:191–198

DarzinAl, PienkosP., 2010. Current Status and Potential for Algal Biofuels Production. NREL Report T39-T2, pp 146

de la Noüe J, Laliberté G, Proulx D (1992) Algae and wastewater. J Appl Phycol 4:247–254

de Paula Silva PH, McBride S, de Nys R, Paul NA (2008) Integrating filamentous 'green tide' algae into tropical pond-based aquaculture. Aquaculture 284:74–80

Fierro S, del Pilar Sánchez-Saavedra M, Copalcúaa C (2008) Nitrate and phosphateremoval by chitosan immobilized *Scenedesmus*. Bioresour Technol 99:1274–1279

Flouty R, Estephane G (2012) Bioaccumulation and biosorption of copper and lead by a unicellular algae *Chlamydomonas reinhardtii* in single and binary metal systems: a comparative study. J Environ Manag 111:106–114

Francisco EC, Neves DB, Eduardo J-L, Franco TT (2010) Microalgae as feedstock for biodiesel production:carbon dioxide sequestration, lipid production and biofuel quality. J Chem Technol Biotechnol 8(3):395–403

Freitas OM, Martins RJ, Delerue-Matos CM, Boaventura RA (2008) Removal of Cd (II), Zn (II) and Pb (II) from aqueous solutions by brown marine macro algae: kinetic modelling. J Hazard Mater 153(1):493–501

Gochfeld M (2003) Cases of mercury exposure, bioavailability, and adsorption. Ecotoxicol Environ Saf 56:174–179

Golab Z, Smith RW (1992) Accumulation of lead in two fresh water algae. MinEng 5 (9):1003–1010

Gomes PI, Asaeda T (2013) Phytoremediation of heavy metals by calcifying macro-algae (*Nitella pseudoflabellata*): implications of redox insensitive end products. Chemosphere 92 (10):1328–1334

Grima EM, Belarbi EH, Fernández FA, Medina AR, Chisti Y (2003) Recovery of microalgal biomass and metabolites: process options and economics. Biotechnol Adv 20(7):491–515

Han L, Pei H, Hu W, Jiang L, Ma G, Zhang S, Han F (2015) Integrated campus sewage treatment and biomass production by *Scenedesmus quadricauda* SDEC-13. Bioresour Technol 175:262–268

Hirooka T, Nagase H, Uchida K, Hiroshige Y, Ehara Y, Nishikawa J, Nishihara T, Miyamoto K, Hirata Z (2005) Biodegradation of bisphenol A and disappearance of its estrogenic activity by the green alga *Chlorella fusca* varVacuolata. Environ Toxicol Chem 24:1896–1901

Indhumathi P, Syed S, Shoba U (2014) A Method for production and characterization of biodiesel from green micro algae. Int J BioSci Biotechnol 6(5):111–112

Jácome-Pilco CR, Cristiani-Urbina E, Flores-Cotera LB, Velasco-García R, Ponce-Noyola T, Cañizares-Villanueva RO (2009) Continuous Cr(VI) removal by *Scenedesmus incrassatulus* in an airlift photobioreactor. Bioresour Technol 100:2388–2391

Kaplan D, Christiaen D, Arad S (1988) Binding of heavy metals by algal polysaccharides. In: Stadler T, Mollion J, Verdus MC, Karamanos Y, Morvan H, Christiaen D (eds) Algal biotechnology. Elsevier Applied Science, London, pp 179–187

Kinnunen V, Craggs R, Rintala J (2014) Influence of temperature and pretreatments on the anaerobic digestion of wastewater grown microalgae in a laboratory-scale accumulating-volume reactor. Water Res 57C:247–257

Li Y, Chen YF, Chen P, Min M, Zhou W, Martinez B, Ruan R (2011) Characterization of a microalga *Chlorella* sp. well adapted to highly concentrated municipal wastewater for nutrient removal and biodiesel production. Bioresour Technol 102(8):5138–5144

Lincoln EP, Wilkie AC, French BT (1996) Cyanobacterial process for renovating dairy wastewater. Biomass Bioenergy *10*(1):63–68

Lomax C, Liu WJ, Wu L, Xue K, Xiong J, Zhou J, McGrath SP, Meharg AA, Miller AJ, Zhao FJ (2011) Methylated arsenic species in plants originate from soil microorganisms. New Phytol 193:665–672

Ma A.N., Cheah S.C., Chow M.C., 1990. Current status on treatment and utilization of palm oil industrial wasters in Malaysia. Special coordination meeting of the working group on environmental biotechnology, Kuala Lumpur

Mahapatra DM, Chanakya HN, Ramachandra TV (2013) *Euglena* sp. as a suitable source of lipids for potential use as biofuel and sustainable wastewater treatment. J Appl Phycol 25(3):855–865

Mandotra SK, Kumar P, Suseela MR, Ramteke PW (2014) Fresh water green microalga *Scenedesmus abundans*: a potential feedstock for high quality biodiesel production. Bioresour Technol 156:42–47

Matagi SV, Swai D, Mugabe R (1998) A review of heavy metal removal mechanisms in wetlands. Afr J Trop Hydrobiol Fish *8*(1):13–25

Megharaj M, Avudainayagam S, Naidu R (2003) Toxicity of hexavalent chromium and its reduction by bacteria isolated from soil contaminated with tannery waste. Curr Microbiol 47:51–54

Mehta SK, Gaur JP (2005) Use of algae for removing heavy metals ions from wasterwater, progress and prospects. Crit Rev Biotechnol 25:113–152

Naik SN, Meher LC, Sagar DV (2006) Technical aspects of biodiesel production by transesterification—a review. Renew Sust Energ Rev 10:248–268

Nascimento IA, Marques SSI, Cabanelas ITD, Pereira SA, Druzian JI, de Souza CO (2013) Screening microalgae strains for biodiesel production: lipid productivity and estimation of fuel quality based on fatty acids profiles as selective criteria. Bioenergy Res 6:1–13

Neori A, Chopin T, Troell M, Buschmann AH, Kraemer GP, Halling C, Yarish C (2004) Integrated aquaculture: rationale, evolution and state of the art emphasizing seaweed biofiltration in modern mariculture. Aquaculture *231*(1):361–391

Oswald W, Gotaas H (1957) Photosynthesis in sewage treatment. Trans Amer Soc Civil Eng, United States 122

Oswald WJ (1988) Large-scale algal culture systems (engineering aspects). Micro-algal biotechnology. Cambridge University Press, Cambridge, pp. 357–394

Pahlavanzadeh H, Keshtkar AR, Safdari J, Abadi Z (2010) Biosorption of nickel (II) from aqueous solution by brown algae: equilibrium, dynamic and thermodynamic studies. J Hazard Mater 175(1):304–310

Palmer CM (1974) Algae in American sewage stabilization's ponds. Rev Microbiol (S-Paulo) 5:75–80

Pittman JK, Dean AP, Osundeko O (2011) The potential of sustainable algal biofuel production using wastewater resources. Bioresour Technol 102:17–25

Prajapati SK, Kaushik P, Malik A, Vijay VK (2013) Phycoremediation coupled production of algal biomass, harvesting and anaerobic digestion: possibilities and challenges. Biotechnol Adv 31:1408–1425

Prajapati SK, Malik A, Vijay VK (2014) Comparative evaluation of biomassproduction and bioenergy generation potential of *Chlorella* spp. through anaerobic digestion. Appl Energy 114:790–797

Pruvost J, Van Vooren G, Cogne G, Legrand J (2009) Investigation of biomass and lipids production with *Neochlorisoleoabundans* in photobioreactor. Bioresour Technol 100:5988–5995

Pruvost J, Van Vooren G, Le Gouic B, Couzinet-Mossion A, Legrand J (2011) Systematic investigation of biomass and lipid productivity by microalgae in photobioreactors for biodiesel application. Bioresour Technol 102(1):150–158

Rai UN, Singh NK, Verma S, Prasad D, Upadhyay AK (2011) Perspectives in plant based management of Ganga water pollution: a negative carbon technique to rehabilitate river ecosystem. Appl Bot Abs 31(1):64–81

Romero-González ME, Williams CJ, Gardiner PH (2001) Study of the mechanisms of cadmium biosorption by dealginated seaweed waste. Environ Sci Technol 35(14):3025–3030

Samorì G (2013) Growth and nitrogen removal capacity of *Desmodesmus communis* and ofa natural microalgae consortium in a batch culture system in view of urban wastewatertreatment: part I. Water Res 47:791–801

Semple KT, Cain RB, Schmidt S (1999) Biodegradation of aromatic compounds by microalgae. FEMS Microbiol Lett 170:291–300

Shuler ML (2002) Bioprocess Engineering: Basic Concepts. Prentice-Hall, Inc, Upper Saddle River

Sivakumara G, Xu J, Thompson RW, Yang Y, Smith PR, Weathers PJ (2012) A review on integrated green algal technology for bioremediation and biofuel. Bioresour Technol 107:1–9

Suresh B, Ravishankar GA (2004) Phytoremediation: a novel and promising approach for environmental cleanup. Crit Rev Biotechnol 24:97–124

Talbot P, De la Noüe J (1993) Tertiary treatment of wastewater with *Phormidium bohneri* (Schmidle) under various light and temperature conditions. Water Res 27(1):153–159

Van Gerpen J, Shanks B, Pruszko R, Clements D, Knothe G (2004) Biodiesel analytical methods. National Renewable Energy Laboratory, Colorado, pp. 37–47

Varshney P, Mikulic P, Vonshak A, Beardall J, Wangikar PP (2015) Extremophilic micro-algae and their potential contribution in biotechnology. Bioresour Technol 184:363–372

Wang H, Gao LL, Chen L, Guo FJ, Liu TZ (2013a) Integration process of biodiesel production from filamentous oleaginous microalgae *Tribonema minus*. Bioresour Technol 142:39–44

Wang NX, Li Y, Deng XH, Miao AJ, Ji R, Yang LY (2013b) Toxicity and bioaccumulation kinetics of arsenate in two freshwater green algae under different phosphate regimes. Water Res 47(7):2497–2506

Wang TC, Ramesh G, Weissman JC, Varadarajan R, Benemann JR (1995) Bioremoval of toxic elements with aquatic plants and algae (No. CONF-950483). Battelle Press, Columbus

Wang Z, Luo Z, Yan C, Che F, Yan Y (2014) Arsenic uptake and depuration kinetics in Microcystis aeruginosa under different phosphate regimes. J Hazard Mater 276:393–399

Wijffels RH, Kruse O, Hellingwerf KJ (2013) Potential of industrial biotechnology with cyanobacteria and eukaryotic microalgae. Curr Opin Biotechnol 24(3):405–413

Williams PJLB, Laurens LML (2010) Microalgae as biodiesel andbiomass feedstocks: review and analysis of the biochemistry, energetics andeconomics. Energy Environ Sci 3(5):554–590

Wu LF, Chen PC, Huang AP, Lee CM (2012) The feasibility of biodiesel production by microalgae using industrial wastewater. Bioresour Technol 113:14–18

Xu J, Hu HH (2013) Screening high oleaginous *Chlorella* strains from different climate zones. Bioresour Technol 144:637–643

Xue HB, Stumm W, Sigg L (1988) The binding of heavy metals to algal surfaces. Water Res *22* (7):917–926

Ye J, Rensing C, Rosen BP, Zhu YG (2012) Arsenic biomethylation by photosynthetic organisms. Trends Plant Sci 17:155–162

Zamalloa C, Boon N, Verstraete W (2012) Anaerobic digestibility of *Scenedesmus obliquus* and *Phaeodactylumtricornutum* under mesophilic and thermophilic conditions. Appl Energy 92:733–738

Zhao M-X, Ruan W-Q (2013) Biogas performance from co-digestion of Taihu algae and kitchen wastes. Energy Convers Manag 75:21–24

Zhong W, Zhang Z, Luo Y, Qiao W, Xiao M, Zhang M (2012) Biogas productivity by co-digesting Taihu blue algae with corn straw as an external carbon source. Bioresour Technol 14:281–286