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Phycoremediation of sewage wastewater and industrial flue gases for biomass generation from microalgae

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A B S T R A C T

Phycoremediation or microalgae cultivation using sewage with industrial flue gases is a promising concept for integrated nutrient removal and sequestration respectively with subsequent biomass generation in order to control environmental pollution. In the present study sewage wastewater (SWW) and industrial flue gas was supplied in batch and continuous mode for cultivation of microalgae *Chlorella vulgaris*. *Chlorella vulgaris* was very effective in reduction of chemical concentrations (COD, NO_3, SO_4, and PO_4) in SWW along with flue gas (CO_2, NOx and SOx). COD removal was achieved up to 78% in batch mode and 42% in continuous mode. The other nutrients from the sewage wastewater were removed up to 75% whereas, with continuous mode 55%. Concerning the flue gas treatment studies, *Chlorella vulgaris* removed CO_2 up to 64% in batch mode and when grown in continuous mode it was up to 72%. The SOx and NOx concentrations were reduced up to 62% and 63% respectively in batch mode and the removal efficiencies of the same were 59% and 55% in continuous mode. Both batch and continuous mode showed the maximum biomass productivity in hetero and mixotrophic cultivations. While average biomass productivity in mixotrophic continuous mode was higher as 1.0 g/L. Fourier infrared spectroscopy examination of algal biomass revealed the presence of −OH, −COOH, NH2, and = O organic compound groups. It was concluded from the results that *C. vulgaris* was very effective in the treatment of SWW and industrial flue gas on the other hand the biomass obtained is a sustainable green energy source.

1. Introduction

In the present era our world is suffering through various economic and environmental issues among which conventional energy depletion, global warming and water pollution are of more concern. These problems are affecting the whole society in different ways. Even though many alternatives to fossil fuels are available, but they have some limitations due to which major focus has been developed worldwide on renewable bio-fuel production (Batan et al., 2010). Microalgae cultivation with phycoremediation process can be suitable answers to these problems in economical and sustainable way. Phycoremediation is the use of macro- or microalgae for the reduction or biotransformation of pollutants, including nutrients and harmful chemicals from wastewater (Mulbry et al., 2008; Olguin, 2003). In microalgae cultivation, algae is used as a resource of food, fuel, stabilizing agent, manure, compound and in waste water treatment as well as in power plants to lessen CO_2 discharge. An alga generates a large amount of biomass and energy. Certain species of algae gather up to 60% intracellular lipid of their overall biomass, it enhance their heat of combustion and energy value (Gaikwad et al., 2016). The use of microalgae for wastewater treatment has recently attracted increased interest due to the effective nutrient removal abilities of such microorganism, and additional benefits of biofuel production. Microalgae also have the advantages of high growth rates with high biomass production,

Abbreviations: APHA, American Public Health Association; BOD, Biological Oxygen Demand; OD, optical density; COD, Chemical Oxygen Demand; NO_3, Nitrites; SO_4, Sulphates; PO_4, Phosphates; SOx, Sulphur oxide; NOx, Nitrogen oxide.

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high cellular lipid productivities, and capability to bio-sequester carbon dioxide, at the same time it can remove pollutants from wastewater and produce biofuels (Wai et al., 2016). In addition to the combination of wastewaters for microalgae cultivation, flue gas cultivation has also been recommended and received much research attention in recent years. This approach can further reduce the cultivation cost, and most importantly contribute to carbon dioxide bio sequestration. To achieve the largest possible micro algal productivity in a cost-effective way, selection of a microalgae mode of cultivation is of vital importance. Three modes of microalgae cultivation can be adopted, namely photo-autotrophic, heterotrophic and Mixotrophic (Wang et al., 2014). In heterotrophic nutrition, the simpler carbohydrates enter the cell and are subsequently converted to lipids and participate in other metabolic pathways such as respiration. Heterotrophic nutrition takes place both in the presence and absence of light. In photo heterotrophic nutrition, light acts as an energy source, but the source of carbon remains organic only. Heterotrophic growth in the dark condition is supported by a carbon source replacing the light energy. This unique ability is shared by several species of microalgae (Perez-Garcia and Basha, 2015). Mixotrophic cultivation is another growth mode where microalgae simultaneously use inorganic CO_2 and organic carbon sources in the presence of light therefore, photo-autotrophy and heterotrophy occur simultaneously. Mixotrophic cultivation is a combination of autotrophy and heterotrophy and can result in increased growth and resource utilization by the microalgae (Burkholder et al., 2008; Wan et al., 2011). Many studies have demonstrated that heterotrophic and mixotrophic growth for various microalgae species yields greater biomass and lipid content as compared to photoautotrophic cultivation (Vonshak et al., 2008; Chojnacka and Facundo, 2004; Chojnacka and Andrzej, 2004).

Hence, the main focus of this study was on waste to energy concept and to examine the Phycoremediation process for improving the biomass along with sewage wastewater treatment and flue gas reduction by using mixotrophic and heterotrophic cultivation of microalgae *Chlorella vulgaris* in batch and continuous mode.

2. Materials and methods

2.1. Isolation and identification of microalgae

The microalgae samples were collected from the contaminated lake of Hyderabad. Microscopic examinations were conducted to check for the availability of lipid producing green microalgae. The morphology based identifications of the microalgae species were conducted using Olympus CX21 compound microscope under 400× magnification. (Fig. 1). The samples were subjected to serial dilution followed by streaking the cells in sterile Petri dishes half-filled with BG 11 medium containing 1–1.5% agar as solidifying agent. After streaking, the Petri dishes were sealed with parafilm wax strip and incubated under white fluorescent lights in a culture rack at a temperature maintained at 24 °C for 4–8 days. After the incubation, the individual colonies were picked through sterilized wire loop and placed on the glass slide to observe under the compound microscope. Pure colonies of individual species were identified. The desired colonies were repeated for streaking to achieve pure new colonies. These new colonies were then inoculated into broth medium. Further confirmation of the species was carried out using microscopic examination under Olympus CH20i - TR biological microscope at 1000× magnification. The images were captured through the eyepiece using Canon power shot G10 digital camera. The algae species examined under the microscope were identified corresponding to the morphological properties based on the standard books and monographs. The purity of the cultures was safeguarded by repeated plating and regular microscopic examinations (Fig. 2).

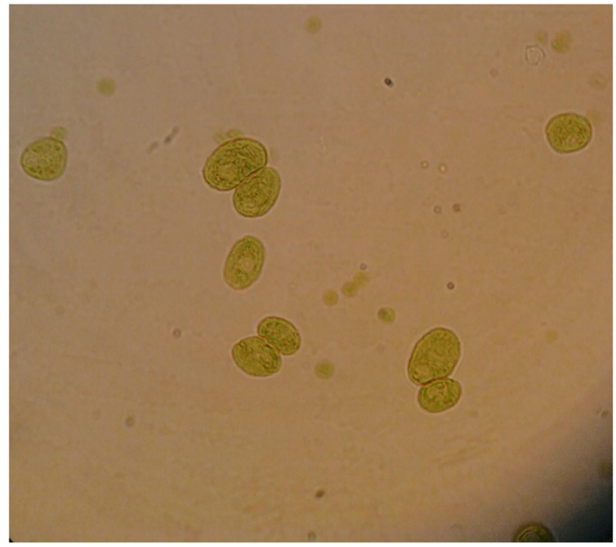

Fig. 1. Microscopic observation of the micro algae strain *Chlorella vulgaris*.

2.2. Sewage wastewater source and characterization

Sewage wastewater was collected from the university (Jawaharlal Nehru Technological University Hyderabad). The sewage wastewater sample was filtered to remove coarse particles. Its initial characterization was done according to standard methods for water and wastewater characterization APHA et al. (2005). And given inTable 1.

2.3. Flue gas sample collection

Flue gas sample was collected in canisters from a coal burning boiler outlet from nearby Industry, Hyderabad . A pipeline was connected from the boiler chimney outlet to the inlet of a vacuum pump to suck the flue gases into the canisters connected to the vacuum pump outlet through thin tubing (Fig. 2).

2.4. Composition of the flue gas and analysis

The flue gas was analyzed for the percentage of CO_2 using a gas chromatography (GC-4890, Agilent Technologies, and USA)

Table 1
Initial characterization of the sewage waste water

S.No	Parameter	Observation
1	pH	8.77
2	Phosphate (mg L⁻)	1.189 ± 0.008
3	Nitrates (mg L⁻)	3.840 ± 0.017
4	Sulphates (mg L⁻)	13.550 ± 0.105
5	Chlorides (mg L⁻)	53.25 ± 0.28
6	COD (mg L⁻)	520 ± 5.03
7	Alkalinity (mg L⁻)	250 ± 5.29
8	Total hardness (mg L⁻)	200 ± 5
9	Ca hardness (mg L⁻)	160 ± 5.0
10	Na (mg L⁻)	120 ± 5.0
11	K (mg L⁻)	135 ± 2.6
12	DO (mg L⁻)	3.5 ± 0.2
13	TS (mg L⁻)	780 ± 5.0
14	TDS (mg L⁻)	690 ± 5
15	BOD (mg L⁻)	80 ± 5.0