

**PHOTOBIOREACTOR DESIGN AND DEVELOPMENT FOR SIMULTANEOUS  
WASTEWATER TREATMENT AND CO<sub>2</sub> SEQUESTRATION**

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**CENTRE FOR RURAL DEVELOPMENT AND TECHNOLOGY  
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WASTEWATER TREATMENT AND CO<sub>2</sub> SEQUESTRATION**

by

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*Submitted*

*In fulfillment of the requirement of the degree of Doctor of Philosophy*

to the



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## CERTIFICATE

This is to certify that the thesis entitled “**Photobioreactor design and development for simultaneous wastewater treatment and CO<sub>2</sub> sequestration**” being submitted by **Mr. Pushap Chawla** to the Indian Institute of Technology Delhi for the award of the degree of “**Doctor of Philosophy**” is a record of bonafide research work carried out by him. He has worked under our guidance and supervision and has fulfilled the requirement for the submission of this thesis. To the best of our knowledge, the results contained in this thesis have not been submitted in part or full to any other university or Institute for the award of any degree or diploma.

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## ABSTRACT

The present investigation was driven by the lack of coherent data, economically feasible scale up and the need to address other key issues concerning simultaneous wastewater treatment and CO<sub>2</sub> sequestration by algal cultures. In spite of several studies on algal wastewater treatment, comparison of performances is difficult due to differences in parameters such as algal culture, wastewater, photobioreactor employed, temperature, light intensity etc. Keeping this in mind, performance of various algal cultures (native and procured) was studied in progressively enhancing environment through innovative photobioreactor (PBR) designs providing a highly efficient multi-algae screening tool. We started with eleven algal cultures in three different wastewaters in stationary batch mode and compared their performances. Most of the algal cultures exhibited exemplary performance in terms of nutrient removal with removal efficiencies reaching maximum in case of isolated algal culture PA9 in dairy wastewater (COD: 93.4%, NO<sub>3</sub><sup>-</sup>-N: 82.1%, NH<sub>4</sub><sup>+</sup>-N: 92.2%, PO<sub>4</sub><sup>3-</sup>-P: 100%) and PA4 in slaughterhouse wastewater (COD: 73.2%, NO<sub>3</sub><sup>-</sup>-N: 88.5%, NH<sub>4</sub><sup>+</sup>-N: 90.3%, PO<sub>4</sub><sup>3-</sup>-P: 84.8%), respectively. In sewage treatment plant wastewater, procured culture, *Chlorella vulgaris* performed best in terms of nutrient removal efficiency (COD: 79.6%, NO<sub>3</sub><sup>-</sup>-N: 95.0%, NH<sub>4</sub><sup>+</sup>-N: 97.6%, PO<sub>4</sub><sup>3-</sup>-P: 99.3). Results clearly established that site specific solutions are required for effective wastewater treatment.

Similar comparison was made by enhancing and optimizing the growth conditions by designing the PBR specifically for wastewater treatment. Improvement in conditions (temperature, light intensity, carbon source, and agitation) led to increase in productivity of almost every algal culture and nitrogen, phosphorus removal efficiencies in this case reached to same levels as compared to stationary shake flask mode but in lesser duration. For instance, in case of PA4, peak biomass concentration in aerated PBR-II in STP (1.36 gL<sup>-1</sup>), DWW (2.3 gL<sup>-1</sup>) and SWW (1.7 gL<sup>-1</sup>)

<sup>1</sup>) was much higher than the biomass concentration in stationary batch mode in STP (0.56 gL<sup>-1</sup>), DWW (1.0 gL<sup>-1</sup>) and SWW (1.16 gL<sup>-1</sup>). Also, algal preference for carbon from CO<sub>2</sub> was observed in this case with relatively less COD removal efficiency exhibited by all the algal cultures.

In the next phase, the best performing cultures were screened for their tolerance to high CO<sub>2</sub> environment. The calculation of net carbon sequestered (71.8 mg L<sup>-1</sup> h<sup>-1</sup>) showed the exemplary performance of algae in CO<sub>2</sub> sequestration. In order to evaluate simultaneous wastewater treatment and CO<sub>2</sub> sequestration, further investigations were done using STP wastewater as nutrient source and raw biogas as a source of CO<sub>2</sub>. Significant decrease in concentration of CO<sub>2</sub> (38% to 4.35%) from biogas along with removal of nitrogen (94.7%) and phosphorus (90.5%) from wastewater were recorded.

Finally, a pilot scale photobioreactor capable of simultaneous wastewater treatment and CO<sub>2</sub> sequestration was commissioned. This 100 L PBR combined the best design features evaluated previously with a unique provision for controlling pH and CO<sub>2</sub> injection, thereby resulting in high algal growth rates. The importance of initial biomass concentration in net CO<sub>2</sub> sequestered was observed. At the operating biomass concentration of 2.2 gL<sup>-1</sup>, net CO<sub>2</sub> sequestered was 89.76 gD<sup>-1</sup>. It was conclusively proven that the growth of algal culture depends more upon the net CO<sub>2</sub> input in the system rather than the composition of CO<sub>2</sub> in gas.

Overall, several new observations on critical parameters governing algal wastewater treatment and CO<sub>2</sub> sequestration were made. Translation of these newer insights into PBR designs yielded significant improvements. In the nutshell, four fold increase in algal biomass production (2.2 gL<sup>-1</sup> from 0.56 gL<sup>-1</sup>) was achieved in scaling up from 100 ml flask studies to 100 L photobioreactor while the process time reduced from 12 days to 5 days, respectively.

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