Development of a microalgae biocomposite-integrated Spinning Disc Bioreactor (SDBR) for bioprocess intensification of light-driven CO_2 absorption

K.Boodhoo[1*], T. Ekins-Coward[1], S. Velasquez-Orta[1] and M. C. Flickinger[2,3]

[1] *Chemical Engineering, School of Engineering, Merz Court, Newcastle University, Newcastle Upon Tyne, NE1 7RU, UK*

[2] *Chemical and Biomolecular Engineering, Engineering Building 1, North Carolina State University, Raleigh, North Carolina, 27695,USA*

[3] *Golden LEAF Biomanufacturing Training and Education Center, BTEC, North Carolina State University, Raleigh, North Carolina, 27695, USA*

*Corresponding/presenting author (kamelia.boodhoo@newcastle.ac.uk)

We report the development of an entirely new, scalable, solar energy driven microbial gas absorber-converter technology by a novel combination of advanced photoreactive biocomposite materials with a continuous thin film flow absorber design based on a spinning disc concept. A methodology was developed to integrate *Chlorella vulgaris* microalgae cells into a porous paper biocomposite for the first time with the addition of the common natural biopolymer, chitosan which acts a biopolymer bridging structure and charge neutralizer to significantly improve the integration of the *C. vulgaris* cells within the paper matrix. A comprehensive study was undertaken to assess and understand the effects of the main constituent components of "fresh" *C. vulgaris* biocomposite paper highlighted that increases in chitosan dosage, MFC content, and the total cell loading had the greatest positive impact on the photoactivity of the immobilised microalgal cells measured via a fluorescence technique. Interactions between chitosan dosage and basis weight and between cell loading and MFC content were also deemed significant. For instance, highest Fv/Fm values of the order of 0.6 were achieved with the highest total cell loading of $2.4x10^{13}/m^2$ of biocomposite surface and low MFC content (<20%) or with high chitosan levels (75 mg) and low basis weights (50 g/m^2). The microalgal cells in the biocomposite have also been shown to thrive after exposure to long periods of desiccation and shear stress where higher recovery of photosynthetic reactivity was achieved at high chitosan levels and high total cell loading.

The proof of concept of employing an immobilized *C. vulgaris* biocomposite paper on a spinning disc for CO_2 capture has been demonstrated over a period of 15 hours. Using a biocomposite paper containing 75 mg chitosan, 10% MFC, $8.8x10^{12}$ cell loading/m^2 of biocomposite surface and a basis weight of 95 g/m^2, high photoactivity was maintained at a spin speed of 300 rpm throughout the duration of operation, more so in the presence of bicarbonate in the liquid medium and 5% CO_2 in the gas environment (Experiment 1 in Table 1). The immobilised microalgae in the biocomposite preferentially consumed the dissolved CO_2 over HCO_3^-, as the dissolved CO_2 was consistently significantly lower during the SDBR runs with the *C. vulgaris* biocomposite when compared to the control blank for Experiment 1 in Figure 1. On average the liquid medium contained 54.9±0.9 % less dissolved CO_2 when compared to the blank SDBR runs. The CO_2 biofixation rate was estimated to be 144.05 mg hr^{-1} when calculated from the average difference in dissolved CO_2 per hour between the biocomposite and blank. Nayak et al. [1][50] reported a corresponding value of 41.6 mg L^{-1} hr^{-1} (996.4 mg L^{-1} d^{-1}) or 83.2 mg hr^{-1} for their 2 L reactor volume when simultaneously supplying supplementing 1% (v/v) CO_2 and $NaHCO_3$. Given that the result reported by Nayak et al. was from a

[1] Nayak, M., et al., Enhanced carbon utilization efficiency and FAME production of Chlorella sp. HS2 through combined supplementation of bicarbonate and carbon dioxide. Energy Conversion and Management, 2018. 156: p. 45-52.

2 L flat-panel photobioreactor compared to the *C. vulgaris* biocomposite surface area on the disc of 62.2 cm^2, a considerable enhancement of CO_2 biofixation is evident in the present study. Interestingly, with the biocomposite paper securely fixed to the disc surface using a pH neutral spray adhesive, practically all *C. vulgaris* cells in the biocomposite successfully remained attached to the disc throughout the 15 hour rotational period at 300 rpm (equivalent to 5× g at disc edge). This is a significant achievement in the context of rotating biofilm technologies which generally must operate under gentle rotations below 20 rpm typically to prevent the microbial cells employed in wastewater treatment from detaching from the surface of biofilm structure. Overall, the increased biofixation for a much reduced spinning surface area and the high cell retention in the spinning biocomposite highlights the process intensification potential of the SDBR.

***Keywords**: bioprocess intensification; spinning disc bioreactor; biocomposite; microalgae; C. vulgaris; CO_2 biofixation*

Table 1. Effect of carbon source on photosynthetic activity of *C. vulgaris* biocomposite in SDBR

	Carbon source		Maximum quantum efficiency of PSII photochemistry (F_v/F_m)	
Experiment	**$NaHCO_3$ (gL^{-1})**	**Composition of gas**	**Initial (t=0)**	**Final (t=15 hours)**
1	2	5% CO_2 in air	0.368±0.004	0.514±0.072
2	2	Ambient Air (0.03% CO_2)	0.344±0.07	0.520±0.067
3	0	5% CO_2 in air	0.305±0.06	0.099±0.02

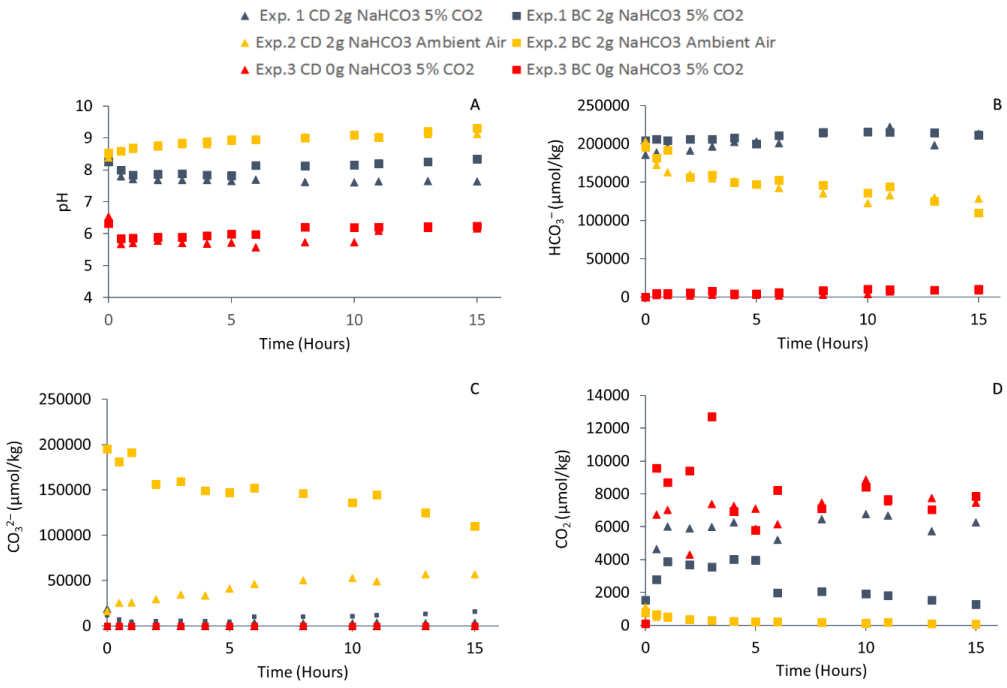

Figure 1. Results for experiments 1,2, and 3 conducted on a SDBR with a control blank disc (CD) and the *C. vulgaris* biocomposite (BC) A) The pH B) Bicarbonate (HCO_3^-) C) Carbonate (CO_3^{2-}) D) Dissolved carbon dioxide (CO_2)