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Research paper

Bioremediation and nutrient removal from wastewater by *Chlorella vulgaris*

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ABSTRACT

The capability of the microalgae *Chlorella vulgaris (Cv)* for biomass production and nutrients removal under different wastewater quality has been studied. *Cv* was cultivated in a standard medium (*Marine labs American society of microbiology-derived medium*, MLA) blended with primary wastewater (P_{WW}), secondary wastewater (S_{WW}) and petroleum effluent (P_E) in different volume ratios. Macro and micro nutrients were characterized in each solution, and the impact on the rate of biomass growth (specific growth rate, μ) and removal efficiency (RE) determined for the bulk nutrients (total nitrogen *TN* and total phosphorus *TP*) along with a range of macro- and micro-nutrients.

P_{WW}, S_{WW} and P_E media were found to provide an appropriate quantity and balance of nutrients to promote significantly more rapid algal growth than the standard medium MLA, with high nutrient *RE* achieved at the end of cultivation period. Over a 13-day period the highest biomass concentration $X_{\max}$ of 1.6 g L^{-1} was attained for P_{WW} with corresponding values of 1.2 d^{-1}, 80% and 100% for μ, and *TN* and *TP* RE respectively. μ decreased to 0.75 d^{-1} for a 75%:25% blend of P_{WW} with MLA and to 0.54 d^{-1} on further decreasing the blend ratio to 25:75 P_{WW}: MLA, with corresponding *TN* removal efficiencies of 85% and 76% respectively; 100% removal of *TP* was obtained throughout. There was a slight increase in $X_{\max}$, μ and *TN* removal of 1.16 g L^{-1}, 0.62 d^{-1} and 83% respectively for S_{WW}. The lowest $X_{\max}$ of 0.64 g L^{-1} in P_E was recorded was associated with values of 0.31 d^{-1}, 79% and 100% for μ, and removal efficiencies of *TN* and *TP* respectively.

1. Introduction

Municipal and industrial wastewaters require treatment for removal of organic carbon and nutrients (nitrogen, N and phosphorus, P) prior to discharge. Photobioreactors (PBRs) using microalgae present a potentially economically viable alternative to conventional aerobic biological methods for wastewater treatment (Rawat et al., 2011) since they offer the potential of resource recovery and recycling (Christenson and Sims, 2011). Microalgae have attracted considerable attention for this duty, with reference to their capability for bulk nutrient (N and P) removal (Table 1), combined with simultaneous CO_2 capture (Levine et al., 2010). As well as these bulk nutrients, other macro nutrients and micro nutrients, the latter commonly regarded as micropollutants, are also assimilated during algal growth (Table 2). Some micro-nutrients may be added to commercial algal cultures together with a chelating agents such as EDTA (Fogg and Thake, 1987; Whitton, 2012) to sustain algal growth.

Chlorella vulgaris (*CV*) is unicellular green algae, its photo-autotrophic growth is generally limited by depletion of nutrients (especially nitrogen), light attenuation, change in pH, carbon limitation, and accumulation of photosynthetic oxygen (Yuvraj and Singh, 2016). C. vulgaris has great potentials as future industrial bioenergy producers and for bioremediation of different wastewater qualities due to its robustness, high oil content, mixotrophic culturing condition, and high growth rate under various harsh conditions and tolerant to high levels of heavy metals (Zhigang et al., 2013).

Table 1 Whilst bulk nutrient removal capability of PBRs has received attention (Table 1), attaining consistent removal efficiency values so as to meet the increasingly stringent wastewater standards remains a challenge. Moreover, the capability of PBRs for micro-nutrient removal has received little attention (Table 2), despite the increasing focus on the fate of micro-nutrient and their abatement in wastewater treatment processes. This study aims to address this knowledge gap with reference to one of the most commonly studied algal species (*Chlorella vulgaris*, *Cv*) along with the N and P in combination with a range of macro and micro-nutrients. Specifically, the influence of different wastewater quality on the growth rate and nutrient (macro and micro) removal capability of *Chlorella vulgaris* will be investigated.

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Table 1
Reported *Chlorella vulgaris* algal growth parameters with nutrient removal efficiency for various wastewaters.

WW	*System*	X_{max}, $g\ L^{-1}$	C_d, cells mL^{-1}	Inlet CO_2 $C_{c,g}$, %v/v	P_x, $g\ L^{-1}\ d^{-1}$	CO_2 fixn. rate, R_c $g\ L^{-1}d^{-1}$	μ, d^{-1}	TP_{in}, $mg\ L^{-1}$	TN_{in} $mg\ L^{-1}$	COD_{in}, $mg\ L^{-1}$	*N/P, ratio*	RE *TP*, (%)	RE *TN*, (%)	RE *COD*, (%)	*pH, value*	*HRT*, d^{-1}	*Refs*
Artificial	PBR_B	1.98 ± 0.1	nr	2	0.32 ± 0.1	0.56	0.13	nr	nr	nr	nr	nr	nr	nr	4.5	nr	Abreu et al., (2012)
Piggery	PBR_B	0.49 ± 0.2	nr	nr	0.02	0.04	nr	13.5 ± 0.6	56 ± 2	nr	4.1:1	18	49	nr	nr	nr	Abou-Shanab et al., (2013)
Artificial	PBR_s	nr	6.4×10^6	nr	nr	nr	0.377	~0.57	~23		46:1	70.2	74.3	nr	7.2	nr	Ruiz-Marin et al., (2010)
S_{WW}		nr	5.3×10^6	nr	nr	nr	0.186	~0.57	~22	nr	46:1	80.3	60.1	nr	nr	nr	
SAnMBR	PBRs	0.595	nr	nr	0.23	0.41	0.66 ± 0.1	5.1–10.5	52.3	nr	5:10	97.8	67.2	nr	7.2	2	Ruiz-Martinez et al., (2012)
Synthetic	PBR_B	0.2	nr	0.03[a]	0.03	0.05	0.59	1.69 − 2.17	7.48 − 22.1	nr	9.7:12.9	> 95	> 95	nr	nr	5	Marbelia et al., (2014)
Aq_{WW}	$MPBR_C$	0.04	nr	0.03[a]	0.04	0.07	0.17	0.42	6.81	nr	16.2:1	82.7	86.1	nr	nr	1	Gao et al., (2016a)
Domestic	MPBR	0.2 − 0.75	nr	0.03[a]	0.06	0.1	0.17	1.69 − 2.17	7.48 − 22.1	nr	15.5:22					2 − 5	
S_{WW}	MPBR	0.95	nr	4	0.04	0.08	nr	0.8	15	5	18.75:1	85 ± 3	64 ± 6	nr	6.8 − 7.5	2	Gao et al., (2015)
	$BMPBR_C$	1.37	nr	4	0.07	0.12	nr					86 ± 2	83 ± 4				
Mww	VFPPBR	nr	6.3×10^6	0.03[a]	nr	nr	1.39	1.8	12	nr	6.6:1	> 99	> 99	nr	nr	60	Yang et al., (2016)
S_{WW}	PBR	0.64	nr	5	0.03	0.06	0.11	0.64	10.04	nr	15:1	53.8	49.6	nr	7.2 ± 0.2	nr	Sydney et al., (2011)
P_{WW}	EF	2.71	nr	0.03[a]	0.09	0.17	0.61	10	40.8 ± 0.4	242 ± 2	4.1:1	35.2	60.2	40	7.86	nr	AlMomani and
S_{WW}		1.86	nr	0.03[a]	0.06	0.11	0.52	26	44 ± 0.2	59 ± 0.5	2.4:1	11.9	55.9	30	7.53		Örmeci, (2016)
C_{ww}		2.37	nr	0.03[a]	0.08	0.14	0.25	200	130 ± 2	601 ± 4	0.7:1	25.9	33.6	61	4.86		
Artificial	CYPBR	0.62	nr	nr	0.15	0.27	0.69	nr	90	100	nr	nr	nr	15.2	nr	nr	(Canedo-López et al., 2016)
Urban		0.36	nr	nr	0.09	0.15	0.33	nr	90		nr	nr	nr	77.6	nr		

PBR = Photobioreactor; PBR_C Continuous system, PBR_s semi continuous, otherwise batch system; ww = wastewater; SAnMBR = effluent of a submerged anaerobic membrane PBR; MPBR = membrane PBR; $BMPBR_C$ = Biofilm membrane PBR; OMPBR = Osmotic membrane PBR; VFP = Vertical flat-plate PBR; C_{ww} = Centrate wastewater; EF = Erlenmeyer flask; *Mww* = Municipal wastewater; CYPBR = Cylindrical PBRs; Aq_{WW} Aquaculture wastewater; HRT = hydraulic residence time, [a]Atmospheric level, Rc = CO_2 fixation rate which estimated from Chisti ratio: $CO_{0.48}H_{1.831}N_{0.11}P_{0.01}$; $Rc = 1.88 \times P_x$, P_x = biomass productivity which estimated from $\Delta X/\Delta t$, Not reported = nr.