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Microalgae and bacteria dynamics in high rate algal ponds based on modelling results: Long-term application of BIO_ALGAE model

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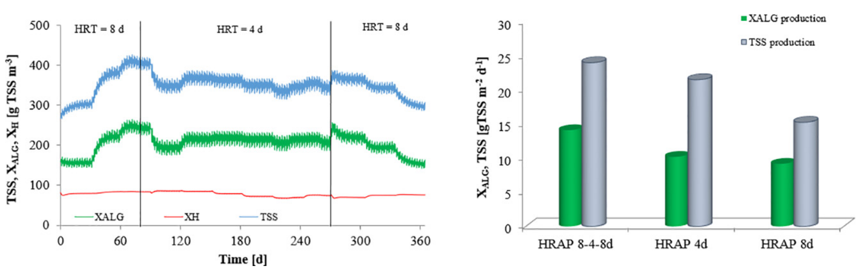
HIGHLIGHTS

- BIO_ALGAE mechanistic model was validated over two seasons of the year.
- HRAP performance was compared using different HRT operating strategies.
- Prediction of microalgae/bacteria proportion and biomass production over a year cycle
- Ammonium removal efficiency was evaluated as function of different HRT operating.
- Microalgae production and nitrogen removal optimization

GRAPHICAL ABSTRACT



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ABSTRACT

The mechanistic model (BIO_ALGAE) for microalgae-bacteria based wastewater treatment systems simulation was validated in the long-term (months) using experimental results from a pilot high rate algal pond (HRAP) treating municipal wastewater. Simulated results were compared with data gathered during two different seasons (summer and winter), and with the HRAP operating at different hydraulic retention times (HRT, 4 and 8 days, respectively). The model was able to simulate with a good degree of accuracy the dynamics of different components in the pond, including the total biomass (bacteria and microalgae). By means of practical study cases, the influences of different HRT operating strategies and seasonal variations of temperature and irradiance were investigated for the relative proportion of microalgae and bacteria, and biomass production over a year cycle. Model predictions show that the proportion of microalgae in the microalgal/bacterial biomass is quite similar in warmer months if the pond is operated with 8-day HRT (76–78%) or 4-day HRT (60–75%). Significant differences were observed in colder months (4-day HRT (27–33%) and 8-day HRT (65–68%)). The model identified a scenario in which overall microalgae production and ammonium removal efficiency were optimized. By operating the HRAP with lower HRT (4 days) in warmer months and higher HRT (8 days) in colder months, the average annual microalgae production increased up to 14.1 gTSS m-2d-1, in contrast with 10.2 gTSS m-2d-1 and 9.2 gTSS m-2d-1 operating with constant HRAP (4 and 8 days, respectively) over a year cycle.

1. Introduction

High rate algal pond (HRAP) technology for wastewater treatment was developed in California by Prof. Oswald in the 1950s as an alternative to conventional waste stabilization ponds (WPS) (Oswald and Gotaas, 1957). The smaller footprint of

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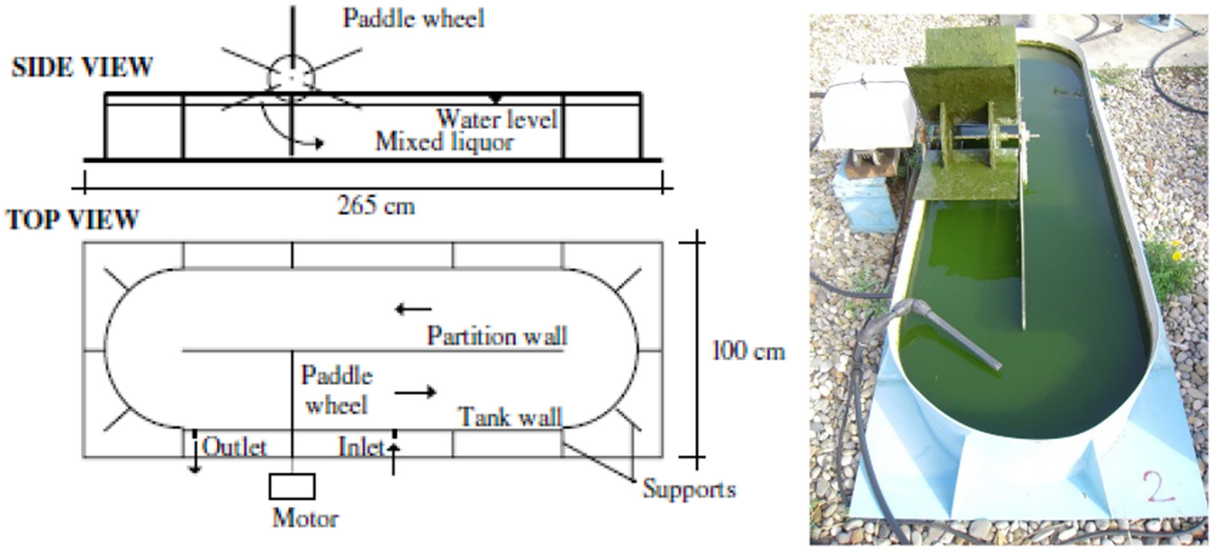

Fig. 1. Diagram of top and side views of the pilot HRAP on the left and a picture on the right. The system was located roof of the Group of Environmental Engineering and Microbiology (GEMMA) building (Universitat Politècnica de Catalunya-BarcelonaTech, Barcelona, Spain).

HRAP systems coupled with the benefit of production of valuable products (e.g. biofuels, bioplastics) from microalgae feedstock makes them more attractive over WPS (García et al., 2000a; Faleschini et al., 2012).

HRAPs are based on microalgae and bacteria interactions in wastewater exposed to light. Microalgae photosynthesis provides oxygen necessary for the degradation of organic compounds present in wastewater by aerobic bacteria. During bacterial oxidation of organic matter, carbon dioxide (CO_2) is produced and is available for both photosynthesis and nitrification (Oswald, 1988). The many processes that occur in microalgae-bacteria systems are quite difficult to control (García et al., 2006; Awuah, 2006; Fuentes et al., 2016). Moreover, these processes depend on ever-changing environmental variables such as solar radiation and temperature.

Although these systems have been studied for many years, still today the physical, chemical and biochemical reactions that occur in microalgae-bacteria systems are less well known than processes in conventional technologies, such as activated sludge. In fact, it is still very challenging to understand which are the main factors affecting microorganisms growth and production (i.e. microalgae and bacteria), and how their interactions affect the relative proportion of microorganisms. Recently, variations of biomass production over a year in pilot-scale HRAPs were experimentally evaluated by Mehrabadi et al. (2016). These authors observed that changes in microalgae concentration were clearly linked to seasonal fluctuations in temperature and light intensity in the absence of nutrient limitation. Other studies have shown that HRAP operating conditions play an important role on biomass composition, and of course the efficiency for removing pollutants. In a study conducted by Park and Craggs (2011), hydraulic retention time (HRT) clearly influenced microalgae proportion dynamics. A low hydraulic retention time (HRT, 2 days) yielded much more microalgae biomass than bacteria (80% of average of total biomass), while high HRT (8 days) had lower microalgae proportion (56% of average of total biomass). Note that these authors estimated microalgae proportion indirectly by measurements of chlorophyll-a concentration. At present time is not trivial to have a direct measure of microalgae and bacteria proportion in such mixed cultures.

Mathematical models have proven to be useful tools to understand and optimize the functioning of biological wastewater treatment systems, including microalgae-bacteria systems (Park and Craggs, 2011; Zhou et al., 2014). Solimeno et al. (2017a) developed the mechanistic BIO_ALGAE model to understand the internal functioning of complex microalgae-bacteria systems. One relevant feature of the model is that it allows microbial biomass concentration prediction, and thus evaluation of the relative proportions of microorganisms (Solimeno et al., 2015, 2017a, 2017b).

The River Water Quality Model 1 (RWQM1) (Reichert et al., 2001) and the ASM3 model (Iacopozzi et al., 2007) (International Water Association, IWA) were selected to describe microalgae and bacteria processes, respectively. Inorganic carbon as a limiting substrate for the growth of microalgae is one of the major innovative processes of BIO_ALGAE. Moreover, temperature, photorespiration, pH dynamics, solar radiation, light attenuation and rate of transfer of gases to the

Table 1
a) Maximum and minimum water temperature and irradiance recorded. b) Average (and standard deviation) of influent HRAP water quality parameters during the two periods considered for validation (Period I: July 21st–October 14th, 1993; Period II: November 10th, 1993–February 8th, 1994). These data were used as constant input values to run simulations. $n = 30$ for each period.

a)

	Water temperature [°C]		Irradiance [μmol m^{-2} s^{-1}]	
	Min	Max	Min	Max
Period I	11.1	29.7	0	1000
Period II	2.2	16.1	0	610

b)

Parameters	Influent wastewater Period I	Influent wastewater Period II
pH	7.7 (0.8)	7.8 (0.6)
COD_{TOT} (g O_2 m^{-3})	180 (84)	195 (50)
NH_4^+-N (g m^{-3})	39.8 (25)	43.7 (28)
PO_4-P (g m^{-3})	6.0 (2.5)	6.0 (1.7)
Alkalinity (g $CaCO_3$ m^{-3})	388 (48)	421 (54)

Note: S_S, X_S, X_H, X_I, X_{AOB} and X_{NOB} influent concentrations were estimated from COD_{TOT} concentration (see text).