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Modelling a Novel Batch Biofilm Passive Aeration Technology Using Aquasim

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Abstract. The Pumped Flow Biofilm Reactor (PFBR) is a new biofilm-based passive aeration system (PAS) that is an example of a complex biofilm system. The PFBR is a two reactor technology that employs a unique hydraulic regime and enables aerobic, anoxic and anaerobic conditions to be sequenced. Biofilm, growing on plastic media modules within the two reactors, is aerated passively as wastewater is moved alternately between the reactors during an aeration sequence. Thus as the two reactors empty and fill a number of times during a typical aeration sequence, the biofilm is exposed, in turn, to atmospheric air and wastewater. Thus the system, while simple to design and operate, provides a particular challenge to modellers. Given its complexity, due to the passive aeration system achieved using a unique hydraulic flow regime; previous models have only been concerned with simulating the effluent from the PFBR. To date, models for the PFBR technology have not focused on the cycle performance of the PFBR, biofilm thickness or biofilm composition. It is proposed to model the PFBR using the modelling package AQUASIM in order to study the PFBR at a micro-scale level; this will enable the study of cycle performance, biofilm thickness and biofilm composition.

Keywords: Passive Aeration Systems, Pumped Flow Biofilm Reactor (PFBR), Wastewater Treatment Technology, Batch Biofilm Reactor, AQUASIM, Biofilm

1. Introduction

The PFBR is a novel batch biofilm based technology and has been previously described by O'Reilly et al. (2008) and O'Reilly et al. (2011). Biofilm-based passive aeration systems (PAS) such as the PFBR have attracted recent attention as alternative energy efficient and low maintenance technologies for the treatment of municipal wastewater. However the modelling of biofilm-based PAS offers unique challenges for modellers particularly where new technologies are not easily modelled using existing commercial modelling software.

The PFBR was previously modelled using a surrogate object in GPS-X in order to study the PFBR at a micro-scale level (Jones, 2013). In this study the PFBR model was built and calibrated using Aquasim Software, which was designed for the identification and simulation of natural and engineered aquatic systems (Reichert, 1998). The models were developed and calibrated against extensive data from field studies. A particular focus is placed on modelling individual treatment cycles as this can help optimise both technology design and operation. The work can inform model development for novel passive aeration systems and investigates the potential of modelling individual treatment cycles which can lead to more robust models and process optimisation. The model also focused on biofilm thickness and composition. An Aquasim model was built for Plant 1-Study 1 (Phase Study); the results of this were then applied to Plant 1-Study 2 (Phase Study). In order to verify the model the composite wastewater samples for both Plant 1-Study 1 and Plant 1-Study 2 were applied to the model. The results indicated that the model could be used to predict the PFBR

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performance under a variety of operating conditions. It is not practical to build a new model every time a new PFBR requires to be modelled. In order to assess the ability of the model to predict the treated effluent quality and biofilm composition for different PFBR plants, the model from Plant 1 was adapted and applied to Plant 2. The results show that once a PFBR model is built and calibrated correctly it can easily be adapted and used for a different PFBR plant.

2. Material and Methods

PFBR Description - Plant 1 and Plant 2: The field scale PFBRs involve 2 reactors position side by side and connected with a motorised valve. In Plant 1 the influent comprised a municipal wastewater and the PFBR was operated to treat 25m^3 daily (equivalent to a population equivalent – PE – of about 120). There was approximately 11.5 m^3 of stationary biofilm media modules in each reactor. In Plant 2 the average volume of wastewater treated was 115m^3/day. Each reactor chamber of the PFBR system had a working volume of 42.2 m^3. Stationary plastic biofilm modules were installed in each reactor chamber with a specific surface area of 230m^2/m^3, giving a total surface area of 15,130 m^2. In Plant 1 the PFBR was operated under 2 cycle regimes (Study 1 and 2). The model was initially calibrated using data from Study 1 and then validated against Study 2. In each study a typical treatment cycle comprised anoxic, aerobic and settle phases of varying lengths. Plant 2 was operated under 1 cycle regime (Table 1).

Table 1: Operational stages of the PFBR

	Plant 1		Plant 2
PFBR Stage	Study 1	Study 2	
Fill (t_1) (minutes)	8	12	7
Anoxic (t_2) (minutes)	134	60	30
Aerobic (t_3) (minutes)	275	360	280
Settle (t_4) (minutes)	14	8	13
Draw (t_5) (minutes)	5	5	7

Table 2: Wastewater Characteristics for Study 1 and Study 2

	Influent Wastewater Characteristics				
Parameter	Plant 1				Plant 2
	Study 1 (Phase Study)	Study 1 (Composite Study)	Study 2 (Phase Study)	Study 2 (Composite Study)	(Composite Study)
COD_t (mg/l)	-	-	-	-	143
COD_f (mg/l)	113	187	-	144	
NH_4-N (mg/l)	28	34	25	31	10.3
NO_3-N (mg/l)	0.01	0.01	0	0.03	-

Experimental and Model Wastewater Characteristics: As both PFBRs had been in operation for over 12 months the opportunity existed to gather information on 24 hour composite samples and phase study samples on flow patterns and wastewater characteristics in order to successfully model the PFBR. In Plant 1 two wastewaters of varying strengths were used and operated under two different cycling regimes (Study 1 and Study 2). In Study 1, 2 models were built, the first involved daily composite wastewater samples collected over 32 days and the second a phase study sampled over 432 minutes (1 cycle). In Study 2, 2 models were also built, the first involved daily composite wastewater samples collected over 31 days and the second a phase study sampled over 452 minutes (1 cycle). In Plant 2 a composite wastewater sample was used to model the PFBR which was operated under one cycling regime. The influent characteristics of the modelled wastewater (Table 2) were estimated using this measured data.

An Aquasim model was initially built for Plant 1-Study 1 (Phase Study); the results of this were then applied to Plant 1-Study 2 (Phase Study). In order to verify the model the composite wastewater samples for both Plant 1-Study 1 and Plant 1-Study 2 were applied to the models. The model from Plant 1 was adapted and applied to Plant 2.

Model Description: The PFBR has similar features to a sequencing batch biofilm reactor with key variations including the aeration methodology, the use of two reactors and the hydraulic pumping regime. In AQUASIM the biofilm reactor compartment (BRC) was used to model the two PFBR plants. To arrive at apparent steady-state values, the model was run until steady-state conditions were reached which was

approximately 10 days of simulated operation. The PFBR biofilm reactor was modelled using ASM1. However in the model the endogenous respiration processes from ASM3 was used instead of the decay processes in ASM1. In ASM1 a single decay process (lysis) was introduced to describe the sum of all decay processes under all environmental conditions (aerobic, anoxic). The reason was that in 1985, when ASM1 was first published, computing power was still scarce. The simplest description possible saved computation time. Today, as computation is not limiting simulation to the same extent, a more realistic description of decay processes was introduced in ASM3: endogenous respiration is close to the phenomena observed and the relevant rate constants can be obtained directly and independent of stoichiometric parameters (Henze et al, 2000). There is more or less a consensus that using endogenous respiration processes is better than using decay processes when modelling biofilms (Brockmann, 2013).

3. Results and Discussion

Kinetic and Stoichiometry Results: The stoichiometric parameter values and the kinetic parameter values were adjusted within literature ranges to calibrate the PFBR models. It is important to note that Plant 1 was initially calibrated and the model was then adjusted to calibrate Plant 2.

Dissolved Oxygen: The dissolved oxygen concentrations in the PFBR were modelled by entering an oxygen mass transfer coefficient (K_La) value and an oxygen diffusion co-efficient. The correct measurement or prediction of the volumetric mass transfer co-efficient is a crucial step in the modelling biofilm systems. A K_La value of 351/d had previously been calculated from a laboratory scale bench PFBR study. According to Garcia-Ochoa & Gomez (2009) and Ouellette (2011) scale up in bioreactors is often performed on the basis of keeping the K_La constant. The laboratory scale K_La value of 351/d was therefore used in the field scale model. It is recommended that further experimental work be carried out estimating the exact K_La of the field scale PFBR. The oxygen diffusion co-efficient used in the model was 0.00021 m^2/d rather than the theoretical one of 0.000136 m^2/d. The higher oxygen diffusion coefficient could be due to the high efficient oxygen supply within the biofilm in the PFBR system, where the biofilm is exposed to air and water alternately and this enhanced the transfer of oxygen within the biofilm.

Biomass Thickness and Composition: The biofilm thickness was assumed to be constant at 200μm (detachment rate equal to biofilm growth velocity uF) in all model studies. In order to ensure the biofilm thickness was accurately assumed an additional model was developed which represented an 'unconfined reactor type' where the biofilm could grow freely and was not constant. In order to calibrate this model the growth, decay, attachment and detachment rates were adjusted slightly. Similar results were achieved. It is recommended that additional research is conducted to determine the biofilm thickness in the PFBR tanks to minimize the uncertainty in relation to this. However Bilyk et al. reported the calibration of a biofilm model by adjusting 'assumed biofilm thickness' and according to Boltz (2010) gauging the biofilm thickness is relevant to the calibration of biofilm reactor models. The PFBR model tracked the growth of two different types of biomass, autotrophic and heterotrophic bacteria.

Experimental and Modelled Results

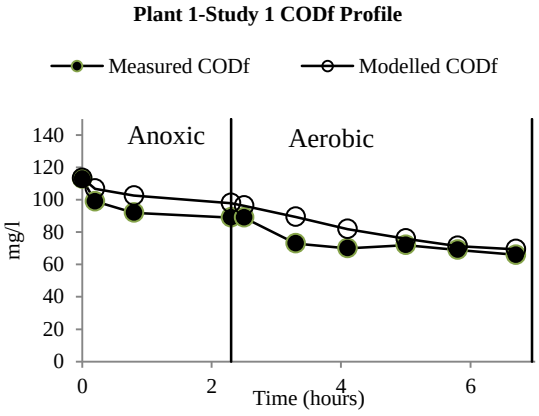

Fig. 1: Modelled and Measured COD_f results Study

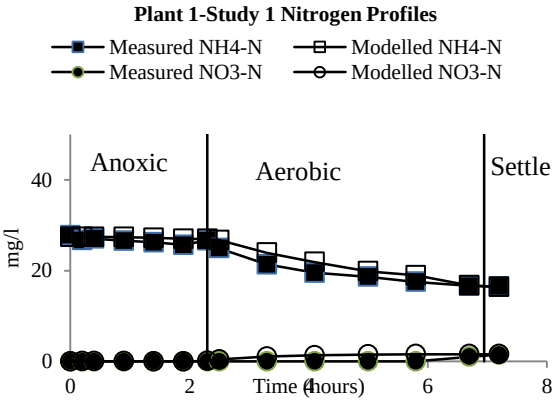

Fig. 2: Modelled and Measured N Profiles Study

Plant 1: Calibrating Plant1-Study1 (Phase Study) and applying the results to Plant1-Study 2 (Phase Study) resulted in quite accurate results indicating the model could be used for predictive modelling at different flow rates and operating conditions. Modelled COD_f profiles for Plant 1-Study 1 (Phase Study) showed a similar trend to experimental measurements (Fig. 1). Fig. 2 shows the steady state Nitrogen profile results for Plant1-Study1 (Phase Study). The NH_4-N and NO_3-N modelled profiles are close to the experimental data.

An Aquasim model was built for Plant 1-Study 1 (Phase Study); the results of this were then applied to the Plant 1-Study 2 (Phase Study) in order to validate the model. Fig. 3 shows the NH_4-N and NO_3-N results of the model for Plant 1-Study 2 (Phase Study). The Nitrogen profiles showed a good fit between measured and modelled data.

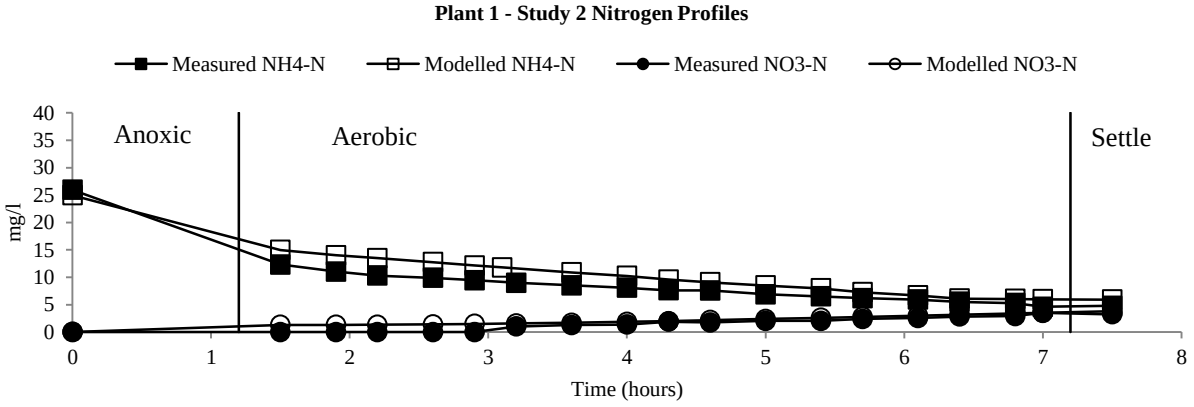

Fig. 3: Modelled and Measured Nitrogen Profiles for Plant 1-Study 2

In order to verify the model the composite samples for Plant 1-Study 1 and Plant 1-Study 2 were applied to the models. Table 3 shows excellent agreement between Plant 1-Study 1 (composite study) measured effluent results and modelled effluent results for COD_f, NH_4-N and NO_3-N.

Table 3: Measured and Modelled Effluent Results for Plant 1 – Composite Studies

	Plant 1 - Study 1 – Composite Study (Average 32 days)				Plant 1 - Study 2 – Composite Study (Average 31 days)			
	Experimental		Model		Experimental		Model	
	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
COD_f (mg/l)	187	66	187	70	144	33	144	45
NH_4-N (mg/l)	34	26	34	25	31	12	31	11
NO_3-N (mg/l)	0.01	1.2	0.01	1.6	0.03	2	0.03	1.8

Plant 2: As already stated it is not practical to build a new model every time a new PFBR requires to be modelled. The model from Plant 1 was adapted to Plant 2 to assess the ability of the model to predict the treated effluent quality and biofilm composition of Plant 2 by adapting the existing Plant 1 model. The approach to the Plant 2 model calibration consisted of making an initial fit of the model to the data to look for significant issues, followed by adjusting the model parameters and various input conditions as appropriate, which resulted in a good fit of the model to the plant data as shown in Table 4.

Table 4: Measured and modelled results for Plant 2

Parameter	Measured Data			Modelled Data		
(mg/l)	Influent	Effluent	% removal	Influent	Effluent	% removal
COD_t	143 (68.3)	24 (8.4)	83	143	29	79
NH_4-N	10.3 (2.5)	3.0 (1.2)	71	10.3	3.2	69
NO_3-N	-	5.1 (1.5)	-	-	3.3	-

4. Conclusion

The PFBR was previously modelled using a 'surrogate activated sludge unit process' in GPS-X as a surrogate for the PFBR system in order to study the PFBR at a macro-scale level. In this study, the PFBR was modelled using the modelling package AQUASIM in order to study the PFBR at a micro-scale level and enable the study of cycle performance, biofilm thickness and biofilm composition. The results show good correlation between experimental and modelled effluent results. The modelling of individual cycles offers the potential of significant process optimisation. The working PFBR model will offer many advantages such as: optimising plant efficiencies; optimising daily operations, energy saving evaluations, determining maximum flow conditions, preparing existing PFBRs for upcoming regulations such as the Water Framework Directive in Europe, testing scenarios before implementation on site, predicting the effect of influent changes. There were a number of shortcomings in the development of this model which are outlined as follows.

(i) One of the most notable one was that the PFBR was modelled as a single BRC as opposed to 2 biofilm SBR's.

(ii) A BRC was used to model the PFBR however for both the confined and unconfined BRCs available in Aquasim the reactor has a constant volume; therefore it was not possible during a cycle to empty and fill the reactor and expose the biofilm to air.

Further work will focus on improving model results, modelling experimental measurements of biofilm mass and applying the model to a range of laboratory and field scale systems.

5. Acknowledgements

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