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THE EFFICIENCY OF A SEQUENCING BATCH BIOFILM REACTOR (SBBR)
IN ORGANIC CARBON AND PHOSPHORUS REMOVAL

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ABSTRACT

A laboratory sequencing batch biofilm reactor (SBBR), operated for a period of 158 days, was used to treat domestic-strength synthetic effluent. The biofilm reactor comprised a bulk fluid reactor, a biofilm plastic module, a synthetic wastewater feed tank and pneumatic devices with pneumatic controls. The reactor cycle time was 8 hours and its operation consisted of 5 phases--feeding (59 minutes), mixing (1 minute), anoxic/anaerobic (3 hours), aerobic (3 hours) and settling (1 hour). At total chemical oxygen demand (COD_T) loading rates of 8.8 g COD_T m⁻² d⁻¹ and 1.2 kg COD_T m⁻³ d⁻¹, expressed in terms of the plastic module surface area and reactor volume, respectively, the SBBR had average removal rates of 8.3 g COD_T m⁻² d⁻¹ and 1.1 kg COD_T m⁻³ d⁻¹, or

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94%. Total ortho-phosphorus ($\text{PO}_4\text{-P}_T$) and filtered ortho-phosphorus ($\text{PO}_4\text{-P}_F$) removals were 44% and 50%, respectively.

Keywords: Sequencing batch biofilm reactor (SBBR); carbonaceous oxidation.

INTRODUCTION

In the last few decades, high running costs of wastewater treatment plants have resulted in the search for new technologies for treating wastewater. Sequencing batch biofilm reactor (SBBR) systems, operated in a fill-and-draw mode, have been successful in the treatment of wastewater.^[1, 2] The unit processes involved in the SBBR and continuous flow biofilm systems are similar. Aeration and clarification are carried out in both systems; however, in the SBBR, the processes are carried out sequentially in the same tank. One of the main advantages of SBBR systems is that anaerobic and aerobic phases can be included in the same tank by splitting the cycle time of the SBBR up into phases; this is especially useful for biological phosphorus removal.

Most SBBR systems have a cycle with five phases that are carried out in sequence as follows: fill--the reactor basin fills with wastewater; react--the reactor can be anoxic, anaerobic or aerobic; settle--the basin contents are allowed to settle; draw--the effluent is withdrawn from near the top of the tank; idle--time is provided in a multitank system for flexible operation and sludge wasting. Sludge wasting is an important step in the SBBR operation that greatly affects performance. The amount and frequency of sludge wasting

is determined by performance requirements; the length of time it remains in the reactor is the sludge retention time (SRT).

The carbonaceous oxidation and nutrient removal efficiency of SBBRs have been well documented.^[1, 2, 3, 4] Rodgers et al.^[2] operated a laboratory vertically moving SBBR, loaded at $3.7 \text{ g COD}_T \text{ m}^{-2} \text{ d}^{-1}$ and $0.7 \text{ kg COD}_T \text{ m}^{-3} \text{ d}^{-1}$, treating domestic-strength synthetic effluent in an 8-hour cycle, comprising fill, anoxic, aerobic, settle, and draw phases, and reported COD_T and SS removals of 95% and 93%, respectively. Similar results were reported by Di Iaconi et al.^[1], who used an SBBR to successfully treat tannery wastewater at organic loading rates of 2.1 to $3 \text{ kg COD}_T \text{ m}^{-3} \text{ d}^{-1}$. Using a laboratory-scale SBBR unit with a specific surface area of $450 \text{ m}^2 \text{ m}^{-3}$, operated at a temperature of 30°C , average COD_T and $\text{NH}_4\text{-N}$ removals of 93% and 99%, respectively, were measured.

SBBRs have also been used to treat high-strength wastewaters; Cho et al.^[3] used 24-hour cycle SBBRs, set up in replicate at an average temperature of 20°C and with an organic loading rate of 0.3 to $0.6 \text{ kg m}^{-3} \text{ d}^{-1}$, to treat industrial wastewaters with an average COD_T , SS, and Tot-N concentration of 7150 mg L^{-1} , 358 mg L^{-1} , and 250 mg L^{-1} , respectively. Using plastic porous media (specific area = $50\text{ -}130 \text{ m}^2 \text{ m}^{-3}$) subject to anaerobic, aerobic, anoxic, reaeration, setting, and draw phases, 83%-87% removals of COD were measured and effluent Tot-N was less than 10 mg L^{-1} .

During the anaerobic phase of the SBBR cycle, phosphorus is released to the bulk fluid in the reactor. Subsequently, when the reactor is aerated, phosphorus is taken up by phosphorus-accumulating organisms (PAOs). Gieseke et al. ^[4] investigated a SBBR operated at an 8-hour cycle time, comprising filling, anaerobic, aerobic and draw phases, and containing 8 mm diameter plastic elements as support material for biofilm, and found that, on account of the competition for available oxygen, phosphorus removal and nitrification occurred in a sequential action, with PAOs being the dominant competitor for oxygen. In their experiment, they found that PO₄-P removal, nitrification and limited denitrification took place in the SBBR.

The aim of this paper was to investigate the organic carbon and phosphorus removal performance of a laboratory SBBR with an 8-hour cycle time in treating domestic-strength synthetic effluent.

MATERIALS AND METHODS

A laboratory SBBR unit, illustrated in Figure 1, was constructed after Rodgers ^[5] to test the removal of organic carbon and phosphorus. The unit was placed in a temperature-controlled room at an average temperature of 10°C and consisted of a bulk fluid reactor, a biofilm plastic module, a synthetic wastewater feed tank and pneumatic devices with pneumatic controls. The feed tank and the reactor tank were made from plastic waste disposal bins. Both bins were 0.55 m in height and had internal dimensions at the top and bottom of 0.28 m x 0.34 m and 0.28 m x 0.295 m, respectively. The outlet pipe from the

reactor tank was a 0.032 m diameter MARLEY pipe and was 0.36 m from the bottom of the tank, giving a bulk fluid volume of 27.6 L.

In the reactor tank, a module of cross-flow corrugated plastic BIOdek media (Munters, UK), with a specific surface area of $240 \text{ m}^2 \text{ m}^{-3}$ and with dimensions of 0.29 m by 0.21 m in plan and a depth of 0.26 m, was moved vertically in and out of the wastewater in cycles using a pneumatic piston, limit switches and timers. The surface area of the module was 3.80 m^2 and the corrugation angle on the media was 30° to the horizontal. The module was supported in a stainless steel frame that was connected to the pneumatic piston.

The piston was powered by a compressed air system and travelled a vertical travel distance of 0.4 m at an average vertical velocity of 0.2 m sec^{-1} . Limit switches controlled the movement of the media blocks and the return action of the piston withdrew the media from the wastewater. The dipping cycle was 4 secs in the air, 2 secs travelling down, 4 secs in the water and 2 secs travelling up. As a result, the module had an overall motion of 5 cycles per minute. In order to control the SBBR for each step of operation, a solenoid valve and a programmable timeswitch were fitted to the compressed air supply line. When the air supply to the piston was shut off, the BIOdek module stayed submerged in the reactor and when it was switched back on again, the module moved in and out of the reactor.

The unit was started by seeding it with 500 ml of waste sludge from another experimental biological PO₄-P removal system, and with 3 litres of return sludge, which contained nitrifiers, from a local wastewater plant. Synthetic effluent, after Odgaard and Rusten^[6] and with composition as in Table 1, was prepared daily and kept mixed in the feed tank by two pumps.

The cycle time of the reactor was 8 hours and its operating sequence consisted of 5 phases – feeding (59 minutes), mixing (1 minute), anoxic/anaerobic (3 hours), aerobic (3 hours) and settling (1 hour) (Table 2). The draw and idle phases were ignored in this study because the synthetic wastewater entered the bottom of the SBBR tank, pushing the clear effluent at the top of the tank through the outlet and into the waste pipe. A peristaltic pump, activated 3 times per day at 8-hour intervals for a total loading period of 177 minutes a day, was used to feed the reactor at a rate of 9.36 L hr⁻¹ (27.6 L d⁻¹).

In Table 2, the anoxic/anaerobic period (3 hours) allowed P-removing microorganisms time to synthesise the influent substrate into volatile fatty acids (VFAs) to form storage products and to release PO₄-P. The aerobic period (3 hours) allowed the microorganisms time to oxidise these storage products and to take up available PO₄-P. The contents of the reactor were mixed twice during the anoxic/anaerobic phase by automatically switching on the air which caused the module to move into and out of the reactor for 1 minute every hour.

Throughout the duration of operation of the unit (158 d), samples were taken after the reactor was fed and mixed (AF in Table 3), at the end of the anaerobic phase (AAN in Table 3), at the end of the aerobic phase (AA in Table 3) and at the end of the settlement phase (AS in Table 3).

The water quality parameters measured were: total and filtered COD (closed reflux, titrimetric method), ammonia-N ($\text{NH}_4\text{-N}$) (ammonia-selective electrode method), nitrate-N ($\text{NO}_3\text{-N}$) (nitrate electrode method), total and filtered $\text{PO}_4\text{-P}$ (ascorbic acid method) and suspended solids (SS) (total suspended solids dried at 103-105°C). Samples of biofilm were taken from the top, bottom and side of the module and tested for growth and $\text{PO}_4\text{-P}$ concentration. All water quality parameters were tested in accordance with the Standard Methods.^[7] The system reached a near steady-state after 20 days of operation and all data are quoted at near steady-state until day 91, when the plastic module clogged.

RESULTS AND DISCUSSION

Carbon Oxidation and SS Removal

The average COD_T loading rates in the reactor, expressed in terms of the surface area of the BIOdek module and reactor volume, were $8.8 \text{ g COD}_T \text{ m}^{-2} \text{ d}^{-1}$ and $1.2 \text{ kg COD}_T \text{ m}^{-3} \text{ d}^{-1}$, respectively, and average removal rates were 94% until day 91, when clogging occurred in the plastic module (Table 3). This was similar to Di Laconi et al.^[1], who reported COD_T removals of 93%, when a SBBR was loaded at $3 \text{ kg COD m}^{-3} \text{ d}^{-1}$. During

the aerobic phase, carbonaceous oxidation occurred and COD_F decreased dramatically from $300 \pm 28 \text{ mg L}^{-1}$ to $83 \pm 19 \text{ mg L}^{-1}$; at the end of this phase, COD_T was $1566 \pm 392 \text{ mg L}^{-1}$ due to the high concentration of solids in suspension in the reactor after mixing. The average COD_T in the treated effluent after settlement was $65 \pm 14 \text{ mg L}^{-1}$. Testing conducted subsequent to the occurrence of clogging indicated that there was no significant reduction in the COD removal capacity of the unit.

The SS in the reactor tank remained constant during most of the anoxic/anaerobic phase, because the reactor was only mixed once every hour. The SS increased during the aerobic phase to $543 \pm 92 \text{ mg L}^{-1}$ because the contents of the tank were totally mixed by the module being moved into and out of the reactor. The SS decreased during the settlement phase to a concentration of $128 \pm 51 \text{ mg L}^{-1}$.

When the module was submerged in the reactor, it was overlain by 0.03 m of treated water. This small height of water above the module meant that the SS fell directly on top of the module. Rodgers et al. ^[2] found that, using a greater clearance of 0.05 m from the reactor to the water surface, the solids were flushed to the bottom of the reactor tank and there was no clogging problem.

PO₄-P Removal

The PO₄-P_T loading rates on the reactor were $0.34 \text{ g m}^{-2} \text{ d}^{-1}$ and $0.083 \text{ kg PO}_4\text{-P}_T \text{ m}^{-3} \text{ d}^{-1}$ and the average removal rates of PO₄-P_T and PO₄-P_F throughout the study were 0.2 g

$\text{PO}_4\text{-P}_T \text{ m}^{-2} \text{ d}^{-1}$ ($0.36 \text{ kg m}^{-3} \text{ d}^{-1}$) and $0.2 \text{ g PO}_4\text{-P}_F \text{ m}^{-2} \text{ d}^{-1}$ ($0.36 \text{ kg m}^{-3} \text{ d}^{-1}$), respectively; this was equivalent to a reduction of 44% and 50%, respectively, for both parameters.

During the anaerobic phase, the $\text{PO}_4\text{-P}_T$ and $\text{PO}_4\text{-P}_F$ concentrations were $36 \pm 5 \text{ mg L}^{-1}$ and $27 \pm 4 \text{ mg L}^{-1}$, respectively. This was similar to the findings of other studies.^[4] There was 'luxury uptake' of the $\text{PO}_4\text{-P}$ from the bulk fluid into the solids during the aerobic phase, as indicated by the $\text{PO}_4\text{-P}_T$ and $\text{PO}_4\text{-P}_F$ concentrations, $39 \pm 9 \text{ mg L}^{-1}$ and $24 \pm 4 \text{ mg L}^{-1}$, respectively.

Nitrification/Denitrification

The wastewater effluent was not fully nitrified by the SBBR throughout the study duration. The $\text{NH}_4\text{-N}$ concentration rose from an average concentration of $63 \pm 5 \text{ mg L}^{-1}$ in the feed tank to $86 \pm 14 \text{ mg L}^{-1}$ after the synthetic wastewater was applied to the reactor. Following the anaerobic/anoxic phase of the cycle, $\text{NH}_4\text{-N}$ fell from a concentration of $86 \pm 14 \text{ mg L}^{-1}$ to $75 \pm 10 \text{ mg L}^{-1}$ at the end of the aerobic phase and $\text{NO}_3\text{-N}$ rose from a concentration of $4 \pm 4 \text{ mg L}^{-1}$ to $8 \pm 7 \text{ mg L}^{-1}$. Generally, the pH of the wastewater in the SBBR remained between 7 and 8, the desirable pH for the growth of nitrifying bacteria.

[8]

Biofilm Analysis

From day 1 growth of biofilm commenced on the module; this caused the module to clog after 91 days of operation (Figure 2). At the end of the study, samples of biofilm were

removed from the module and tested. The biofilm on the SBBR module increased during the study to a final thickness of 3.21 mm and the average moisture content of the biofilm was 96.2%. The maximum total solids of the biofilm was 42.2 g L^{-1} , which contained 33 g L^{-1} of volatile solids and 9.2 g L^{-1} (21.8%) of inert solids. The $\text{PO}_4\text{-P}$ content of the biofilm was tested on 3 occasions; on day 55, 61 and 97 and it increased from 2.7% on day 55 to 2.9% on day 61 to 3.7% on day 97.

CONCLUSIONS

The average COD_T removal in the SBBR was 94%, with an average COD_T concentration in the effluent of $65 \pm 14 \text{ mg L}^{-1}$, which was below the Urban Wastewater Treatment Directive^[9] value of 125 mg L^{-1} . The average COD removal rates in the SBBR were $8.3 \text{ g m}^{-2} \text{ d}^{-1}$ and $1.1 \text{ kg m}^{-3} \text{ d}^{-1}$, expressed in terms of the module surface area and reactor volume, respectively. The SBBR had good $\text{PO}_4\text{-P}$ removal; throughout the study, $\text{PO}_4\text{-P}_T$ and $\text{PO}_4\text{-P}_F$ was removed by 44% and 50%, respectively. Excessive biofilm growth on the biofilm caused it to block; this could be avoided if a greater volume of water was above the module.

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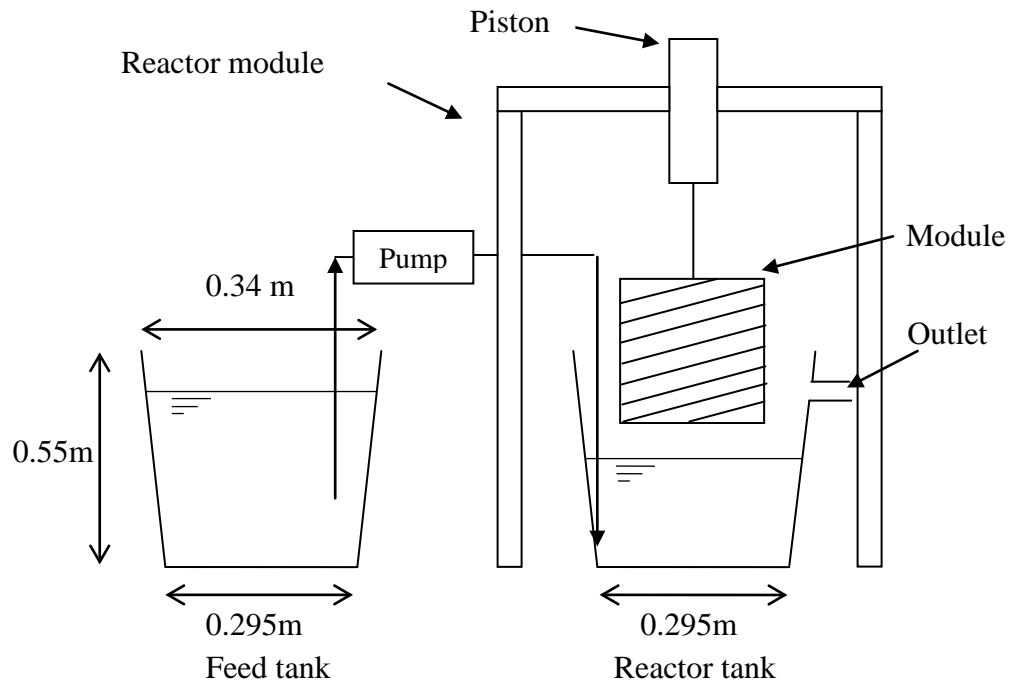
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FIGURE CAPTIONS

Figure 1. Illustration of the laboratory SBBR used in this study.

Figure 2. The mass increase of the module during the laboratory SBBR study.



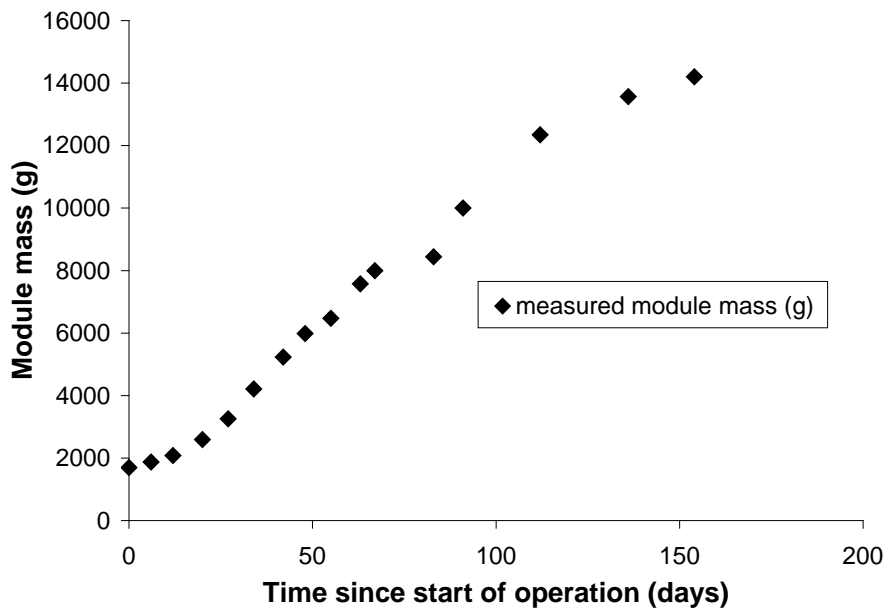


Table 1. Chemical composition of the synthetic effluent used in the SBBR study.

Constituents	Amount	
	ml	g
C ₂ H ₄ O ₂	37	
NaOH	70	
Yeast		2.0
Dried milk		7.9
NH ₂ CONH ₂		5.9
NH ₄ Cl		11.8
Na ₂ HPO ₄ .12H ₂ O		19.7
KHCO ₃		3.3
NaHCO ₃		8.5
MgSO ₄ .7H ₂ O		3.3
CaCl ₂ .6H ₂ O		0.1
MnSO ₄ .H ₂ O		0.1
FeSO ₄ .7H ₂ O		2.6

Table 2. Operating sequence of the SBBR

Phase	Module position	Operating sequence
Feeding	Down in tank	59 minutes
Mixing	Moving in and out of tank	1 minute
Anoxic/Anaerobic	Down in tank	3 hours
Aerobic	Moving in and out of tank	3 hours
Settling	Down in tank	1 hour
