Simple approaches towards the design of an attached-growth sponge bioreactor (AGSB) for wastewater treatment and reuse

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Abstract Wastewater treatment and reuse is being emphasized due to the shortage of water sources and the continuous deterioration of the aquatic environment. In this study, a novel sponge bioreactor was studied as a low cost, high efficiency alternative for an attached growth biological system. This was designed by combining of number of sponge trays. This emerging technology has many beneficial properties in wastewater treatment and reuse. The approaches towards the conditions for system design were: (i) selection of sponge types; (ii) selection of sponge shapes; and (iii) selection of designated slope of sponge tray. They were determined through a series of experiments using a laboratory-scale unit with synthetic wastewater. It was then tested with a pilot-scale unit at the predetermined optimum conditions. The results indicate that the highest biomass growth was found at the sponge type with a cell count of 70–90 cells/in^2 (6.45 cm$^{2)}$ The relationship between biomass growth and biological oxygen consumption was well established. The prism-shaped sponge (triangular polyurethane sponge of 70–90 cells/in^2 with designated slope of sponge tray at 10 degrees) led to the best performance in terms of both organic and nutrient removal efficiency.

Keywords Attached growth sponge bioreactor; biomass growth; oxygen consumption rate; slope of sponge tray; sponge type and shape; wastewater treatment and reuse

Introduction

Water reclamation and reuse are considered an unavoidable stage not only for alleviating the contradiction of growing water demand in connection with limiting water resources, but also for protecting existing water sources from being polluted. Reuse of wastewater has become most important in small and isolated communities where alternative sources of freshwater are neither available nor cost-effective. Several methods are presently used to treat wastewater to obtain water of recyclable quality. Biological processes often demand a large land area due to the requirement for high hydraulic retention time (HRT). For example, a conventional activated sludge system requires 4–8 h, while an extended aeration process requires 24–40 h of retention time. Further, they require high energy input for aeration. Often, sludge management is a problem in these processes. To overcome most of these problems, attached growth bioreactors using specific material bioreactors have been used. Polyurethane foam (PUF) was used as a porous support to hold the biomass, which increases the possibility of contact between microorganism and the organic substrate. It has the advantages of high internal porosity and specific surface area, high stability to hydrolyses, light and low cost (Pascik, 1990). PUF hanging curtains are good in treating strong wastewater from brewery and piggery (Henry and Thomson, 1993). The wastewater can obtain oxygen from the air by diffusion and expired carbon dioxide throughout the PUF curtain (Agrawal *et al.*, 1997). A treatment system, namely a downflow hanging sponge-cubes (DHS) aerobic treatment unit, was constructed by tilting

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right-triangular prism polyurethane foams onto both surfaces of a vertical plastic rectangular sheet (Machdar *et al.*, 2000). This system was used to treat the sewage effluent from an upflow anaerobic sludge blanket reactor with a BOD_5 of 50–60 mg/L. Long-term, continuous experimental study indicated that this system can remove significant quantities of organics (BOD_5), solids, and ammonia nitrogen.

To enhance further the performance, a novel attached-cultures sponge bioreactor (AGSB) was developed at the University of Technology, Sydney. This study emphasizes the approaches towards making an alternative system that is compact, cost effective, and low maintenance in a wide range of applications.

Materials and methods

In this study, two types of wastewater were used. One was synthetic wastewater and the other was biologically-treated sewage effluent from a water reclamation plant. The synthetic secondary sewage effluent contains organic compounds such as humic acid, tannic acid, lignin, polysaccharide, and other high molecular weight carbohydrates. The synthetic wastewater TOC is 12 mg/L and pH is 7.6. The characteristics of the biologically-treated wastewater used are shown in Table 1. The sponge used was a reticulated, flexible polyester-polyurethane sponge (PPS), which has a unique three-dimensional, uniform open cell structure. The specifications of the different grades of sponge are shown in Table 2.

A laboratory-scale ACSB consisting of a number of trays was used. The length of the tray was 91 cm (Figure 1). The unit was equipped with a commercial PPS, feeding pump, and influent distribution tank. Each tray was designed to hold 27 rows of sponge. Different shapes of SB, namely semi-circular, semi-hexagon, and triangular forms, were used in this study. In these experiments, the synthetic wastewater was fed to an influent channel equipped with overflow weirs. The influent then flows under gravity onto the SB surface, which was placed at an inclination of different degrees (0, 30, 45, 60, and 90). The effluent was collected at the outlet located at the lower part of the system. The suitable sponge type and shape for the ACSB system was selected through the investigation on biomass growth onto the sponge at a predetermined flow rate (or HRT). The trace analysis using NaCl (conductivity as indicator) was used to calculate the actual HRT of the ACSB. The biomass growth in sponge with time was measured from batch experiments with aeration.

Table 1 Specific characteristics of biologically-treated wastewater used

Parameter	Range
Total organic carbon (TOC)	1.6–3.8 mg/L
Turbidity	0.8–6 NTU
Orthophosphate (PO_4^{-3})	0.5–12 mg/L
Ammonia nitrogen (NH_4-N)	1.2–5.6 mg/L
Suspended solid (SS)	2–15 mg/L

Table 2 Specifications of different grades of the polyester-polyurethane sponge (PPS) used

Grade	S28–30R	S28–45R	S28–60R	S28–80R
Density	28–30 kg/m^3	28–30 kg/m^3	28–30 kg/m^3	28–30 kg/m^3
Tear resistance	800 N/m min	780 N/m min	760 N/m min	740 N/m min
Tensile strength	110 kPa min	120 kPa min	135 kPa min	150 kPa min
Cell count	30 cells/in^2	45 cells/in^2	60 cells/in^2	80 cells/in^2

S = polyester-polyurethane; 28–30, 28–45, 28–60, and 28–80 = density (kg/m^3) of foam/no of cells in sq. inch; R = reticulated

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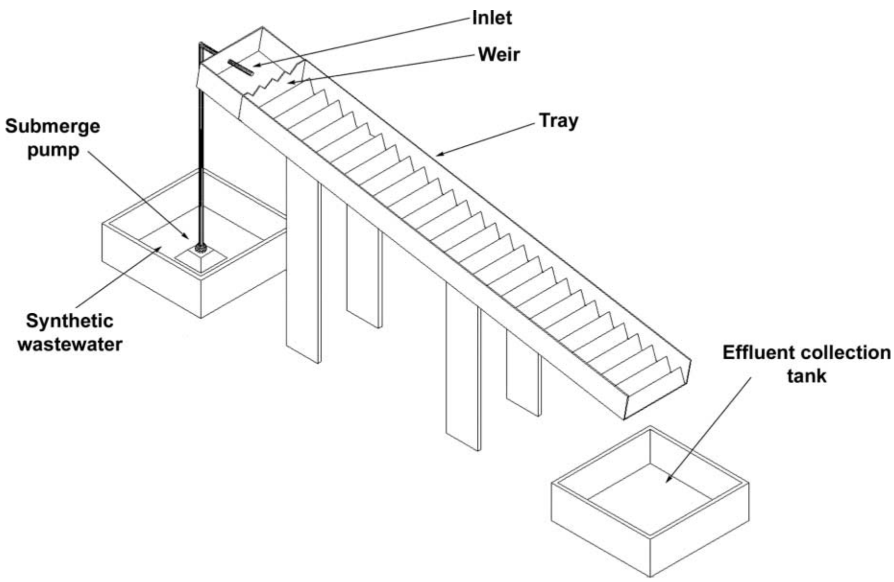

Figure 1 Experimental setup of lab-scale ACSB

The experiments were also conducted using pilot-scale ACSB at a water reclamation plant (Figure 2). A biologically-treated wastewater was fed into the SB system via a collection tank that pumped the wastewater at a steady rate to the top of the system. Each tray in this system was about 1.5 m in length and 1 m in width. Twenty-eight rows of polyurethane sponge were fixed to the surface of each tray. Individual sponge rows were 30 mm in width and 15 mm in height. This system was set up to run the trays at a 10-degree inclination. The HRT was kept at 2 h.

The performance of ACSB was evaluated in terms of total nitrogen, ammonia, orthophosphate, and chemical oxygen demand (COD).

Figure 2 Experimental setup of pilot-scale ACSB at a water reclamation plant

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Results and discussion

Effect of sponge type

Both biomass and biological DO consumption were conducted to evaluate the development of the microbiological community in different densities of polyurethane sponge. The biomass was measured as MLVSS and represented in mg/L of biomass per one unit of volume of sponge used. PPS with four grades (S28/30R, S28/45R, S28/60R, and S28/80R) were immersed into an aeration tank that was filled up with simulated synthetic wastewater. Sponge size was 3 × 3 × 2.5 cm. The growth of biomass was then measured with time. A biological oxygen monitor was used to measure the consumption rate of dissolved oxygen by microorganisms attached to sponge. The biomass was placed in a closed container and the oxygen consumption by microbial metabolism was measured by a probe for 30 min. As can be seen in Figure 3, the rate of oxygen uptake was proportional to the biomass. Their relationship could be expressed as the following equation:

$$\mathrm{OUR} = 0.1026 \times \mathrm{B} \quad (R^2 = 0.913) \qquad (1)$$

where, OUR = oxygen uptake rate (%) and B = biomass (mg/L)

Figure 4 showed that biomass was developed rapidly for the first 22 days and started to slow down at the latter stage. The higher degree of sponge fineness (S28/60R and S28/80R) led to higher biomass growth. The biomass growth was found to be the highest on a sponge with a cell count of 70–90 cells/in^2 (6.45 cm^2) (e.g. 314 mg/L after 32 days). As a result, the PPS with S28/80R grade was selected and used in subsequent experiments.

Effect of sponge shape

Figure 5 shows the sponge sizes with different shapes in HRT operated at the flow rate of 330 mL/min. The semi-circular sponge had the longest HRT compared to the others (5.7 min when the length of sponge was 91 cm at a flow rate of 330 mL/min (Figure 3)). As can be seen in Figure 6, HRT of three different shapes decreased with an increase in the inclination slope of the sponge tray.

The average biomass of these sponge shapes after 24 days were 184.4 mg/L (semi-circular), 304.4 mg/L (triangular), and 219 mg/L (semi-hexagonal), respectively. Thus, the sponge with a triangular shape was selected for subsequent experiments.

Effect of the inclination slope of the sponge tray

The slope of the sponge tray is the angle between the sponge tray and the horizontal base line. In this study, the effect of different inclination slopes of the tray at 0, 10, 30, 60, and 90 degrees was investigated. The results indicate that the higher slope of the tray led

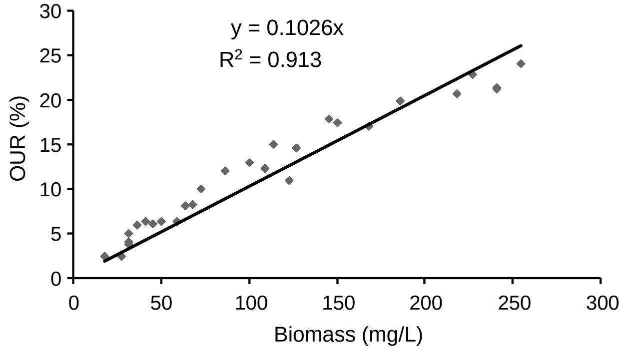

Figure 3 Relationship between oxygen consumption and biomass

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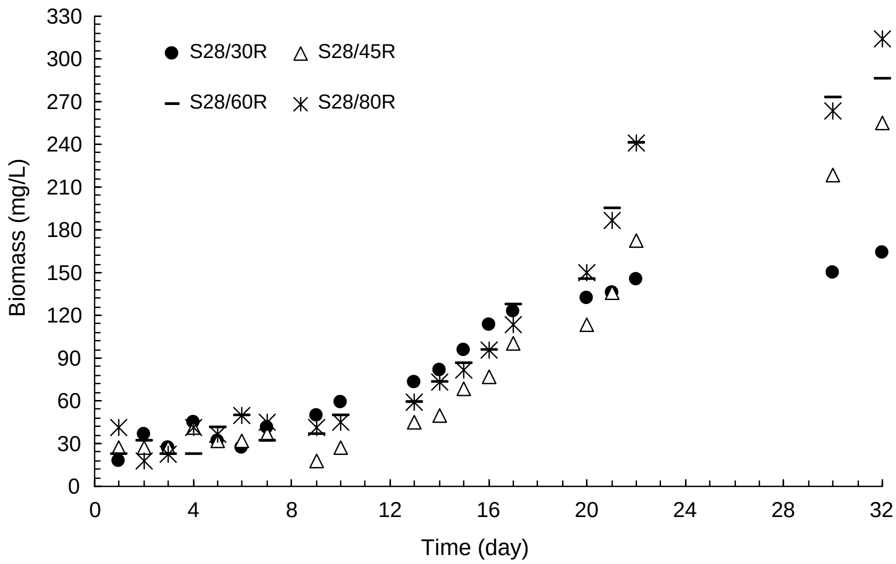

Figure 4 Biomass growths at different sponge with time

to faster flow of wastewater over the tray, and more oxygen diffused into the system. However, a low angle of inclination can increase HRT, which enables the biomass to have more time to consume the pollutants (Table 3). The lower the angle, the less diffusion of dissolved oxygen, which leads to anoxic conditions. Since it is desirable to utilize the benefits of both conditions, an inclination of 10 degrees was selected.

Evaluation of the ACSB with the selected conditions

The lab-scale experiments were conducted with three different sponge shapes (triangular, semi circular, and semi-hexagonal) at a HRT of 2 h. The results indicate that the triangular sponge led to superior effluent (NH_4-N <0.04 mg/L, PO_4-P and COD with apparently zero value most of the time) (Table 4).

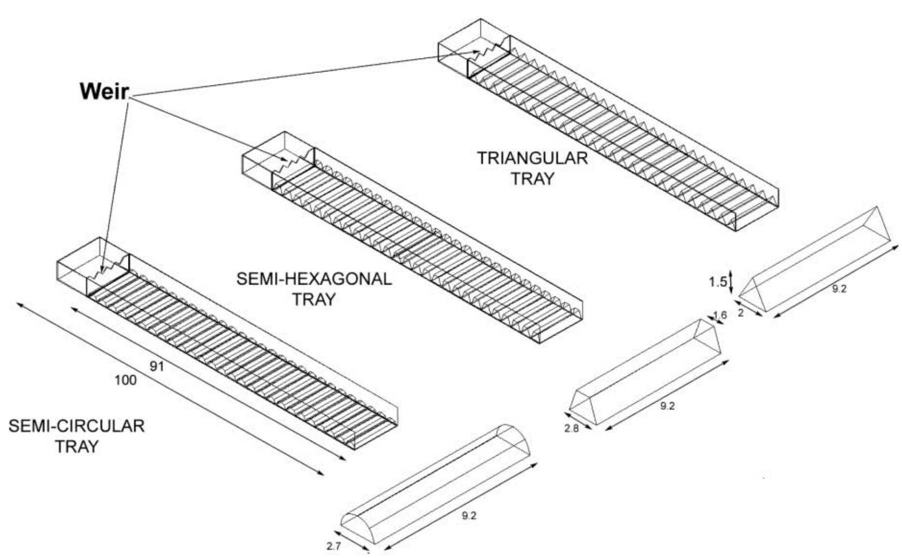

Figure 5 Sponge sizes of different shapes used

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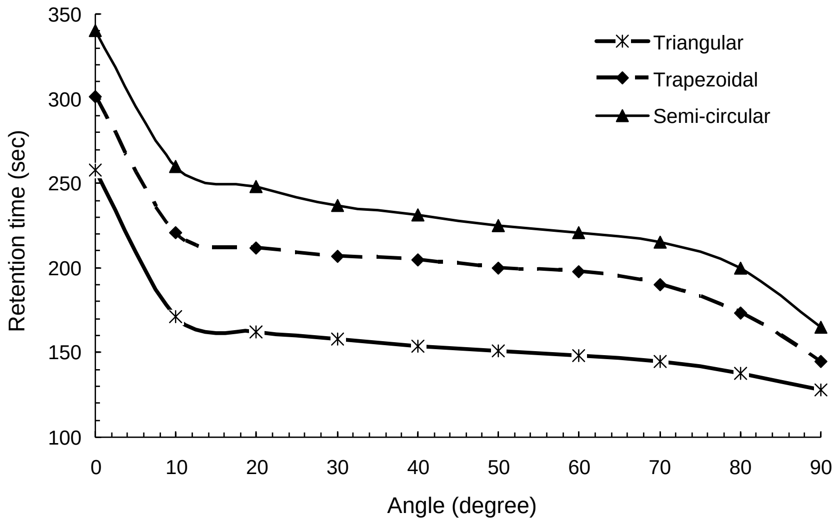

Figure 6 Comparison of hydraulic retention time at different sponge shape and inclination slope of sponge tray

Table 3 Decrease rate of HRT with inclination slope of sponge tray (Q = 330 mL/min)

Angle (degrees)	HRT (sec)	Decrease rate (%)
0	258	0.00
10	171	33.72
20	162	37.21
30	158	38.76
40	154	40.31
50	151	41.47
60	148	42.64
70	145	43.80
80	138	46.51
90	128	50.39

The lab-scale experiments were also conducted with the selective conditions of PPS (S28/80R type triangular and inclination slope of tray at 10-degree angle) to treat the high strength of recirculating synthetic wastewater (79 mg/L as N). The total nitrogen removal efficiency was up to 89% after 2 days of operation using a seeded triangular sponge unit. Total nitrogen concentration dropped to less than 5 mg/L, and after that it remained constant until the end of the operation time (10 days). This was due to particulate organic matters on the sponge surface and inside the sponge gradually decomposing and providing denitrifiers, as well with the available carbons as electron donor. With the concurrent presence of nitrifiers and denitrifiers in the sponge sludge, the denitrification can proceed in an anoxic condition.

Table 4 Performance of ACSB of different shapes of sponge

Sponge shape	Average removal efficiency (%)		
	NH_4-N	PO_4-P	COD
Triangular	85	99	99
Semi-circular	75	95	97
Semi-hexagon	80	98	95

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The performance of a pilot-scale ACSB was evaluated at the selected conditions of ACSB (S28/80R type triangular and inclination slope of tray at 10-degree angle) with HRT of 2 h. The results indicate that the ammonia nitrogen removal efficiency of the SB system was remarkable. During the 18-day operation of a seeded sponge bioreactor unit, the highest NH_4-N removal was about 90%, with an effluent concentration of less than 0.04 mg/L. The removal efficiency decreased when the influent had lower NH_4-N. A high orthophosphate removal was observed (< 0.01 mg/L). The COD removal efficiency varied in the range of 20–100%.

Conclusions

The selected prism-shaped PPS with (i) a sponge type of 70–90 cells/in^2 and (ii) a designated slope of sponge tray at 10-degrees led to the highest pollutant removal. The sponge bioreactor could be applied effectively in an economical manner to produce a high quality effluent that meets the standards of a wide range of water reuse (e.g. NH_4-N = 0.04 mg/L, PO_4-P < 0.01 mg/L and COD < 1 mg/L).

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