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REMOVAL OF COD AND NITROGEN IN WASTEWATER USING SEQUENCING BATCH REACTOR WITH FIBROUS PACKING

H. H. P. Fang, C. L. Y. Yeong, K. M. Book and C. M. Chiu

Civil and Structural Engineering Department, University of Hong Kong

ABSTRACT

An 11-litre sequencing batch reactor (SBR) filled with fibrous packing was found to be very effective for the removal of not only Chemical Oxygen Demand (COD), but also nitrogen from synthetic wastewaters with 250–1034 mg/l of COD and 22–114 mg/l of nitrogen. As compared to the conventional SBR, this system had a shorter cycle time by skipping the settling step. In addition, denitrification was efficiently conducted in the interior of the 'bio-pompons', which were formed by the attached growth of biomass on the fibrous packings, even though the bulk of the reactor was under constant aeration. The system was tested at 12 loading conditions, ranging from 0.56 to 4.51 kg-COD/m^3-day and from 0.04 to 0.49 kg-NH_3-N/m^3-day. On average, 95% of COD was removed within 2 h of aeration, while 57% of total nitrogen was removed after a retention time of 4-8 h.

KEYWORDS

Sequencing Batch Reactor (SBR); fibrous packing; nitrogen removal; COD removal.

INTRODUCTION

The first wastewater treatment using the activated sludge process reported by Ardern and Lockett in 1914 was operated in a batch mode. Wastewater was put into the reactor, which could also serve as an equalization tank, followed by aeration. After aeration, the mixed liquor was allowed to settle. The settled sludge was retained in the reactor for the next batch of treatment, while the supernatant with low levels of pollutants was discharged. Such batch operation was, however, discontinued later in favour of continuous operation for various reasons.

However, as the continuous activated sludge process became progressively more complex and sophisticated, Irvine and his co-workers (Irvine *et al.*, 1979) re-examined the fill-and-draw type of batch operation, renaming it Sequencing Batch Reactor (SBR). Work done by Irvine and others has identified a number of merits for the SBR. For a small rural wastewater treatment plant, it requires small capital investment and minimum operational skills (Irvine *et al.*, 1979). It was also found that the biomass in an SBR would be subject to high substrate tension, which provides an effective means for the control of filamentous bacteria and, thus, sludge bulking (Irvine and Busch, 1979). In addition, SBR could also be effective for the removal of not only nitrogen (Alleman and Irvine, 1980; Palis and Irvine, 1985), but also phosphorus (Manning and Irvine, 1985; Wilderer and Dettmer, 1987).

On the other hand, biological treatments of wastewater using attached growth systems, such as Rotating Biological Contactor (RBC) and Biotower, have also become popular (Peavy *et al.*, 1985). It has been reported that, as compared to activated sludge, they are more effective for nitrification, and more resistible against hydraulic surges and environmental shocks. Also, because they do not require recycling of sludge, attached growth systems are easier to operate.

Materials used for packing vary from rocks and pebbles for the conventional trickling filters, to the sophisticated Pall rings, honeycomb and corrugated plastics sheets. Specific surface area, porosity, weight and cost are among the main factors for the selection of the packing materials. A new type of packing using fibrous materials has recently been developed (Huang and Hung, 1986; Iwai *et al.*, 1990; Lessel, 1991). In this study, fibrous packing was used in an SBR for the removal of COD and nitrogen from wastewater. A conventional SBR would normally be operated in four modes: feeding, aeration, settling and discharging. However, in an SBR using fibrous packing, the settling mode could be skipped, resulting in a simpler operation and a shorter cycle time. Furthermore, during aeration the interior portion of the fibrous packing could provide an anoxic environment, favouring denitrification.

EXPERIMENTS

Figure 1 illustrates the flow diagram of the experimental set up. The reactor was an 11 l acrylic column with 124 mm inner diameter and 900 mm in height. A string of bundles of fibrous packing, as illustrated in Fig. 2, was affixed at the centre-line of the column. The bundles were evenly spaced at a 60 mm interval; each bundle was made of about 80,000 rayon fibres. The reactor was aerated by fine diffused air. To prevent premature degradation, wastewater was kept in a 4°C feed tank. It flowed through a heater to be warmed up to 20°C before feeding into the reactor. Wastewater was fed from the top of the reactor and, after aeration, discharged from the bottom. Two solenoid valves controlled by an electronic timer were used to control the feeding and discharging.

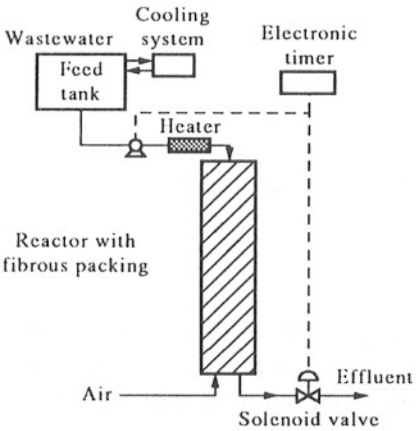

Fig. 1. Process flow diagram.

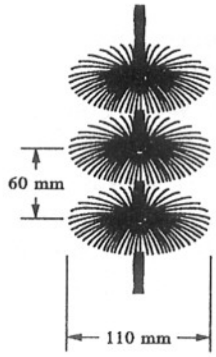

Fig. 2. Fibrous packing material.

Activated sludge from a local wastewater treatment plant was used to seed the SBR. After 2 weeks of acclimation, a total of 12 experiments were conducted at 20°C using synthetic wastewaters with constant COD:N:P ratios of 100:10:4, simulating the municipal wastewater. Synthetic wastewaters with four levels of COD were tested: 250, 500, 750 and 1000 mg/l. Table 1 shows the constituents used for making up 100 l of wastewater with 1000 mg/l of COD. Milk provided organics and all the essential nutrients; sucrose provided only a carbon source; ammonium chloride provided nitrogen; sodium bicarbonate provided alkalinity and an inorganic carbon source; and potassium phosphates provided not only phosphorus but also additional buffering capacity.

TABLE 1. Constituents Making Up of 100 l of Wastewater with a COD of 1000 mg/l

Constituents	Weight (g)
Dry milk powder	14.17
Sucrose	78.05
Ammonium chloride	38.21
Potassium dihydrogen phosphate	6.90
Potassium hydrogen phosphate	13.70
Sodium bicarbonate	75.00

At each of the four levels of COD in the wastewater, experiments at three retention times, i.e. 8, 6, and 4 h, were carried out. In this SBR operation, feeding and discharging took about 15 and 5 min, respectively; aeration covered the rest. At least 20 cycles of batch operation were carried out under each experimental condition before the run at which sampling took place. Samples of the bulk solution were taken during aeration at a constant interval of 20 min for the 4 h runs, or 30 min for the 6 h and 8 h runs. Dissolved oxygen in the bulk solution was measured *in-situ* using a YSL Model 58 oxygen meter, while the pH of the bulk solution was measured using a Hanan membrane pH meter with glass electrode. Standard methods (1985) were used for all the other analyses, including COD, ammonia nitrogen, nitrite/nitrate nitrogen, alkalinity, volatile suspended solids (VSS) and total suspended solids (TSS) of the samples.

RESULTS AND DISCUSSION

Throughout all the runs, dissolved oxygen was kept at 5 mg/l or higher to ensure effective nitrification, while the pH was between 7 and 8, and temperature was kept at 20°C. The fibrous packing had excellent affinity to the biomass. During acclimation, microorganisms were readily attached to the fibrous packing, gradually forming pompons of biomass swaying in the reactor upon aeration. These bio-pompons retained substantial amounts of solution when the water was discharged at the end of the treatment cycle. The effective volume of the reactor was only 8 l. Nevertheless, the calculated loading capacity of the reactor was based on the total volume of 11 l.

Table 2 summarizes the degrees of COD removal by the system under various operation conditions. The effluent had an average of 149 mg/l of TSS, which had good settleability and could be easily removed from the final effluent. However, since it was unnecessary to recycle settled sludge to the reactor, no effort was made to remove the SS from the final effluent in this study. The degrees of COD removal were based on the COD of the filtered samples.

TABLE 2. Removal of COD at Various Experimental Conditions

Run	Retention time (h)	Influence COD (mg/l)	COD loading (kg/m^3-day)	COD reduction after 2h (%)	Final COD reduction (%)
1	8	257	0.56	93.8	96.9
2	6	260	0.75	94.1	95.3
3	4	250	1.09	95.7	95.7
4	8	498	1.08	90.8	97.6
5	6	524	1.52	96.3	96.7
6	4	497	2.16	90.0	96.2
7	8	735	1.60	96.9	97.7
8	6	756	2.19	96.5	97.2
9	4	646	2.82	96.9	97.0
10	8	1030	2.24	97.5	98.3
11	6	1030	2.99	95.1	95.8
12	4	1034	4.51	97.8	97.8
			average	95.1	96.9

The system was very effective for COD removal under the tested conditions, i.e. wastewaters with a COD of 250-1034 mg/l and COD loadings of 0.56-4.51 kg/m^3-d. It removed an average of 95% of COD within 2 h of aeration; an additional 1.7–5.7 hours increased the total COD removal to an average of 97%. The initial COD levels in wastewater and the COD loadings appeared to have little effect on the COD removal. Figure 3 illustrates that for a given wastewater with a COD of about 1000 mg/l, the system reduced COD at the same rate at three different COD loading rates: 2.24, 2.99 and 4.51 kg/m^3-d. Similar trends were also observed for the other three wastewaters with 250, 500 and 750 mg/l of COD.

Figure 3 also illustrates that about 80% of the COD in the wastewater was removed in the first 20 min. The initial rapid COD reduction was probably due to the absorption of soluble organics by the attached microorganisms. Two additional experiments were carried out. In the first experiment, the biomass was starved for 1 h, after discharging the treated wastewater from the previous batch, before feeding. While in the second experiment, the biomass was saturated with absorbed organics before feeding: this was done by feeding a fresh batch of wastewater and discharging it at once after 1 min of aeration, before the second feeding. Aeration started immediately after feeding and samples of the bulk solution were taken every 45 sec afterwards. Should the biomass have limited absorption capacity for the soluble organics, the COD of the bulk solution in the first run was expected to be lower due to higher degrees of absorption. Figure 4, however, shows very little difference between the two experiments, indicating that the biomass had very high absorption capacity for the soluble organics in the bulk solution. Within the first 4–5 min, about 50% of COD was removed from the wastewater.

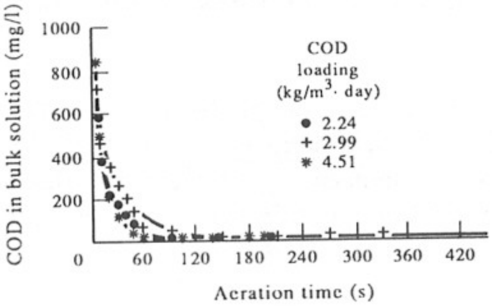

Fig. 3. COD in bulk solution vs aeration time for wastewater with 1000 mg/l of COD at three COD loading rates.

The suspended solids in the final treated effluent had very high volatile contents with an average VSS/TSS ratio of 0.92. The level of TSS in the final treated effluent increased with the COD levels in the wastewater, as expected because more biomass would have been produced. For wastewaters with COD level of 250, 500, 750, and 1000 mg/L, the TSS in final effluent were 41, 133, 210, and 211 mg/L, respectively. On the other hand, the TSS level in the final effluent decreased as retention time increased, also as expected because of more biodegradation. For retention times of 4, 6 and 8 h, the TSS in final effluent were 200, 156 and 91 mg/l, respectively.

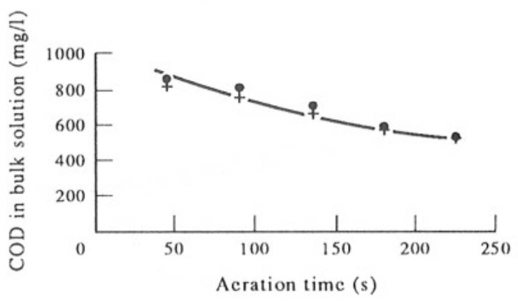

Fig. 4. COD in bulk solution during the first 4 min of aeration.

The nitrogen in the synthetic wastewater was composed of 98% ammonia nitrogen, but only 2% organic nitrogen. For simplicity, only ammonia nitrogen was measured in this study. Table 3 shows that the system on average removed 57% of the nitrogen from the wastewater. The degree of nitrogen removal in general increased with the retention time and the initial nitrogen concentration. For comparison, the average nitrogen removal was 60% for runs with 8 h of retention, whereas the average nitrogen removal was 66% for the three runs with initial nitrogen levels of about 113 mg/l.

TABLE 3. Removal of Nitrogen at Various Experimental Conditions

Run	Retention time (h)	Influent ammonia-N (mg/l)	Ammonia-N loading (kg/m^3-d)	Effluent ammonia-N (mg/l)	Effluent NO_2/NO_3 (mg/l)	Total-N reduction (%)
1	8	21.5	0.04	7.8	0.78	60.0
2	6	27.8	0.08	12.8	0.17	53.3
3	4	27.8	0.12	11.7	0.15	57.3
4	8	56.1	0.12	34.4	0.00	38.6
5	6	45.0	0.13	25.1	0.06	44.0
6	4	51.6	0.21	24.3	0.00	52.9
7	8	66.2	0.13	21.2	2.02	64.9
8	6	81.6	0.23	29.2	0.06	64.1
9	4	79.2	0.34	39.8	0.38	49.2
10	8	111.6	0.24	21.2	4.29	77.1
11	6	113.5	0.32	44.5	0.80	60.0
12	4	113.2	0.49	41.6	2.95	60.6
			average	26.1	0.97	56.9

In a conventional activated sludge system with high sludge age, nitrifiers in the mixed liquor would convert ammonia nitrogen into nitrite/nitrate. Nitrogen in such a case remains in the wastewater except that used up by the bacteria for cell reproduction. In order to further convert the nitrite/nitrate into nitrogen gas by denitrification, a separate system would normally be needed, in which aeration should be avoided to provide the desired anoxic conditions. However, in this study, an average of 57% of the nitrogen was removed while the system was under constant aeration. In addition, while the dissolved oxygen was constantly kept at 5 mg/l or higher, the average nitrite/nitrate level was only 1.0 mg/l in the final effluent. It is believed that in the interior of the bio-pompons dissolved oxygen was depleted, creating an anoxic condition. As a result, nitrite/nitrate, which were produced at the exterior aerobic surface of the bio-pompons, were readily converted to nitrogen gas when diffused into the bio-pompons.

Figure 5 illustrates the reduction of ammonia nitrogen, and the accumulation of nitrite/nitrate, against aeration time for the wastewater of 1034 mg/l of COD and 113.2 mg/l of ammonia nitrogen. Ammonia nitrogen steadily decreased to 21.2 mg/l after 7.5 h of aeration. The trend suggests that further reduction to a much lower level is conceivable by extending the time of aeration. The nitrite/nitrate levels were nil initially and gradually increased to 4.29 mg/l. Similar patterns were also observed in all the other runs.

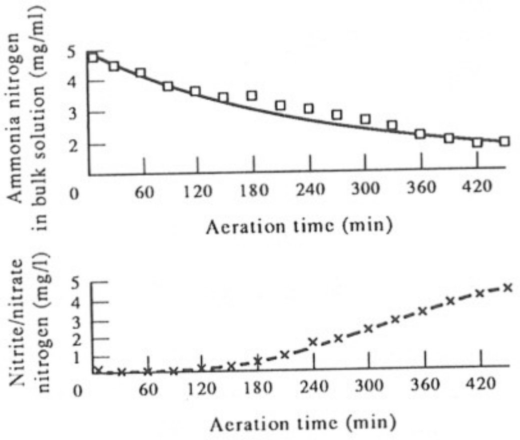

Fig. 5. Ammonia and nitrite/nitrate nitrogens in bulk solution vs aeration time for wastewater with 113 mg/l of ammonia nitrogen.

CONCLUSION

An SBR with submerged fibrous packing effectively removed both COD and nitrogen from wastewater. For wastewaters with a COD of 250-1000 mg/l and ammonia nitrogen of 25-100 mg/l, the average removals of COD and nitrogen were 97% and 57%, respectively, at COD loadings of 0.56-4.51 kg/m^3-d. The treated effluent contained low levels of nitrite/nitrate, due to effective denitrification in the interior of the bio-pompons. The treated effluent contained an average of 149 mg/l of TSS, which could be removed without much difficulties.

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