ROCK-BED FILTRATION PERFORMANCE EVALUATION FOR WASTEWATER TREATMENT

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Abstract

Pilot-scale experiments were conducted at a site near the biological pond of Suranaree University of Technology (SUT) to evaluate the performance of a rock-bed filtration process under different operating conditions. Experimental setup consisted of two rectangular reactor units, head tank unit, filter media, and aeration system. The reactors were fed with SUT wastewater from the biological pond by a pump through the head tank unit. During the 5 ½ months operation, the HRT, filter media size, and aeration system were changed in 3 runs consisting of eight experiments to analyze the filtration mechanism. The results showed that the maximum removal efficiency was found for particulate matter, ranging 60-90%. In case of T-BOD, removal was not significant in the beginning but reached up to 81-82% during the third run. The effluent quality improved with an increase in HRT up to 9 h and showed only minor improvement thereafter. Smaller rock size media showed best results for particulates removal. The run with 6 air diffusers and 9 h HRT had significantly improved T-BOD removal (up to 76%). The porosity of rock-beds was reduced by approximately 11% over 5 ½ months operation.

Keywords: Rock-bed filtration, biofilm, biodegradation, sedimentation, clogging.

Introduction

Natural treatment systems take advantage of the self-purification capacity of the water bodies. Rock-bed filtration is one such method which can accomplish removal of pollutants (e.g., suspended solids, dissolved organic matter, nitrogen, etc.) from the water/wastewater by two main process mechanisms: 1) sedimentation of suspended organic and inorganic matter, and 2) biodegradation of soluble organic matter by the attached biofilms at the rock's surface. As a natural process, rock-bed filtration may be considered to be more economical compared with other physicochemical treatment methods. The reason is that no chemicals are used in this natural method. Thus, not only the lower cost but it is also safe from any potential harmful effects of the chemicals.

The objective of this research was to evaluate the process efficiency, optimum design parameters, and most appropriate operating conditions of the rock-bed filtration method for water/wastewater treatment through pilot-scale experiments. Selected wastewater quality indices (DO, pH, SS, VSS, T-COD, S-COD, T-BOD, and

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NH_3-N) were analyzed in influent and effluent over a period of 5½ months. Subsequently, suitable design and operating conditions were established for the removal of suspended solids and soluble organic matter during rock-bed filtration.

Materials and Methods

Experimental setup

The experiments were carried out using two pilot-scale rock-bed filtration units. Schematic layout of the experimental setup is shown in Figure 1. Two reactor units of rectangular cross-section (3.0m. long, 0.5m. wide, and 0.5m. high) were constructed from concrete with the wall thickness of 0.1m. In each reactor, the influent was fed from one end, and the effluent was discharged through a pipe installed at the other end. Two different rock-sizes, represented by small and big with equivalent diameters of 2-4cm. and 5-7cm., respectively were used as filter media. SUT wastewater was used as influent in steady horizontal flow in the reactors through a head tank unit (consisting of one 100L volume head tank, and three storage tanks-200L each). The aeration in each reactor was provided through 6 air diffusers installed at the bottom at 0.15m., 0.4m., 0.8m., 1.2m., 1.7m., and 2.2m., respectively from the influent end.

Experimental conditions

During experimentation, the hydraulic retention time (HRT), rock size, and aeration conditions were changed to study the performance of rock-bed reactors. There were three test runs, each comprising of two separate experiments carried out simultaneously in individual reactor units. Various operating conditions selected in this study are shown in Table 1.

For all the 3 experimental runs, the two reactors designated as RBF I and RBF II were filled with small and big size rocks, respectively to investigate the effect of media size on the pollutant removal efficiency. The HRT for both reactors was kept 6 h in the first run, 9 h in the second run, and 12 h in the third run. Air was supplied through the 6 air diffusers along the reactor length during the first and the third runs. In the second run, air was supplied through only 3 diffusers during the first half period (31 days) and then through all 6 diffusers till the end of the run.

Experimental measurements

Influent and effluent flow rates, temperature, and water levels were measured daily in both reactors. Wastewater samples were collected regularly from the influent and effluent in each reactor for laboratory analysis. Eight wastewater quality indices-dissolved oxygen (DO), pH, total and volatile suspended solids (SS, VSS), total and filtrate chemical oxygen demand (T-COD, S-COD), total biochemical oxygen demand (T-BOD), and ammonia (NH_3-N) were determined for each test sample. The rock-bed porosity in both reactors was measured at the beginning of each test run.

Results and Discussion

Influent characteristics

Selected influent characteristics and their variations are summarized in Table 2. These included the average concentrations of DO, SS,

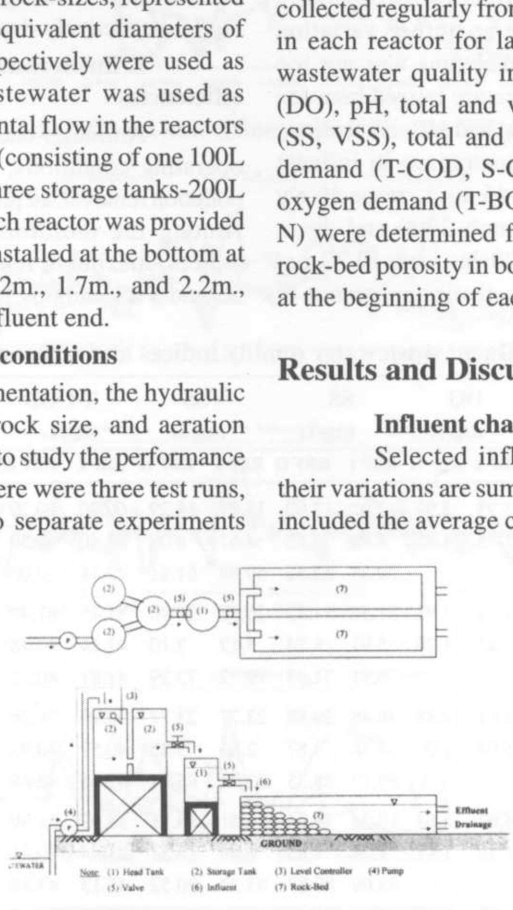

Figure 1. Schematic layout of the pilot-scale setup.

Table 1. Experimental conditions.

Experimental run	Unit	Run number	Media size	Hydraulic retention time (h)	Aeration condition (No. of air diffusers)
Run 1 (52 days)	RBF I	R11-6	Small	6	6
20 Jan - 11 March	RBF II	R12-6	Big	6	6
Run 2-I (31 days)	RBF I	R21-3	Small	9	3
14 March - 13 April	RBF II	R22-3	Big	9	3
Run 2-II (35 days)	RBF I	R21-6	Small	9	6
20 April - 24 May	RBF II	R22-6	Big	9	6
Run 3 (30 days)	RBF I	R31-6	Small	12	6
31 May - 29 June	RBF II	R32-6	Big	12	6

T-COD, S-COD, T-BOD and NH_3-N during the three test runs. The influent and effluent flow rates were nearly constant. The range of water level in the reactors varied between 35-37 cm. at inlet and outlet. During the experimental period, pH of influent were between 8.0-8.5 with the average of 8.15. Temperature variation during all the experimental runs was not too wide, and average temperature ranged between 30°C and 28°C for influent and effluent, respectively. SS and VSS concentrations in influent were 30-70 mg/L and 25-45 mg/L, respectively during the month of March 2000 and again during mid April-May 2000; but were 10-30 mg/L, and 10-25 mg/L, respectively for the rest of the period. Ammonia concentrations were 0-5 mg/L throughout the experimental period. Total COD, filtrate COD, and total BOD were in the range of 50-120 mg/L, 25-60 mg/L and 15-40 mg/L, respectively during the first two runs, and decreased to 30-50 mg/L, 15-25 mg/L and 5-15 mg/L, respectively during the third run.

Effluent characteristics and removal efficiencies.

Although each test run had different operating conditions, some general trends of pollution removal are presented in Figures 2 and 3. Among the monitored wastewater quality indices, maximum removal were achieved for SS and VSS, ranging from 60-90% on average.

Table 2. Influent and effluent wastewater quality indices and removal efficiencies.

Run	Wastewater quality	DO mg/L		SS mg/L		VSS mg/L		T-COD mg/L		S-COD mg/L		T-BOD mg/L	
		RBF I	RBF II	RBF I	RBF II	RBF I	RBF II	RBF I	RBF II	RBF I	RBF II	RBF I	RBF II
Run 1	Influent	3.93	3.93	17.02	17.02	15.29	15.29	60.70	60.70	37.66	37.66	20.02	20.02
	Effluent	1.55	1.63	4.99	6.52	4.67	6.08	42.40	40.50	27.03	23.45	15.22	15.15
	R.E. (%)	-	-	70.31	62.32	69.88	61.21	29.11	32.06	27.88	36.91	25.98	25.30
Run 2-I	Influent	4.02	3.91	31.52	31.52	26.90	26.90	81.49	81.49	43.98	43.98	24.04	24.04
(3 diffusers)	Effluent	1.25	1.28	5.91	8.74	5.17	7.10	47.24	47.48	34.43	34.02	13.49	13.70
	R.E. (%)	-	-	79.91	71.95	79.72	73.29	41.87	40.22	20.48	21.68	45.83	45.35
Run 2-II	Influent	3.01	2.88	39.88	39.88	23.77	23.77	76.26	76.26	37.72	37.72	31.19	31.19
(6 diffusers)	Effluent	1.04	1.20	3.58	3.87	2.85	3.25	40.59	40.95	29.22	29.17	7.11	7.71
	R.E. (%)	-	-	89.17	88.35	87.74	85.94	42.65	42.68	21.83	22.26	76.29	73.87
Run 3	Influent	4.67	4.64	18.24	18.24	14.51	14.51	38.99	38.99	27.24	27.24	10.05	10.05
	Effluent	1.32	1.47	1.24	1.83	0.99	1.37	21.44	20.41	18.69	20.26	1.85	1.83
	R.E. (%)	-	-	93.09	89.87	93.27	90.52	45.13	47.84	32.95	27.11	81.46	81.74

R.E. = Removal efficiency

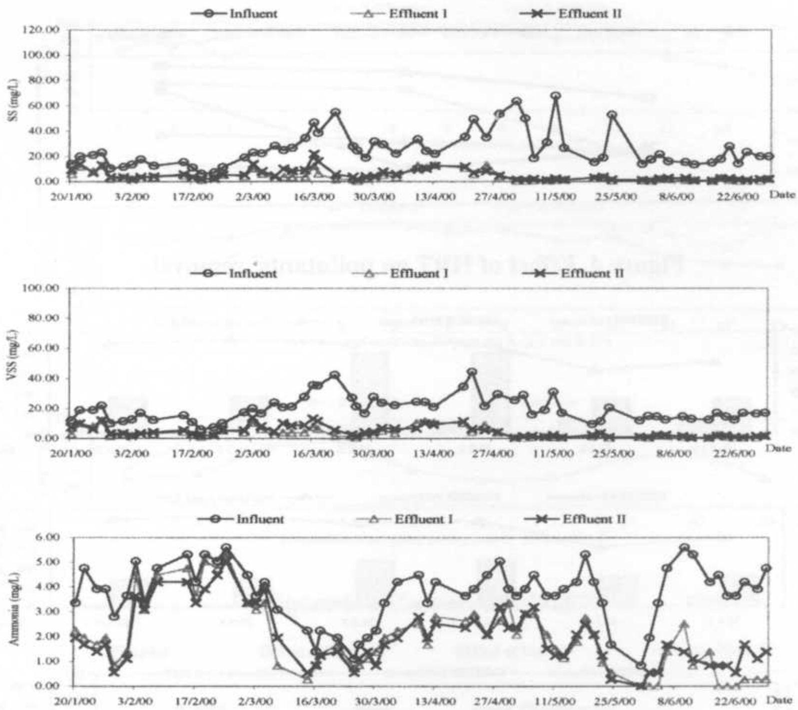

Figure 2. Variation in influent and effluent SS, VSS and NH_3-N concentrations.

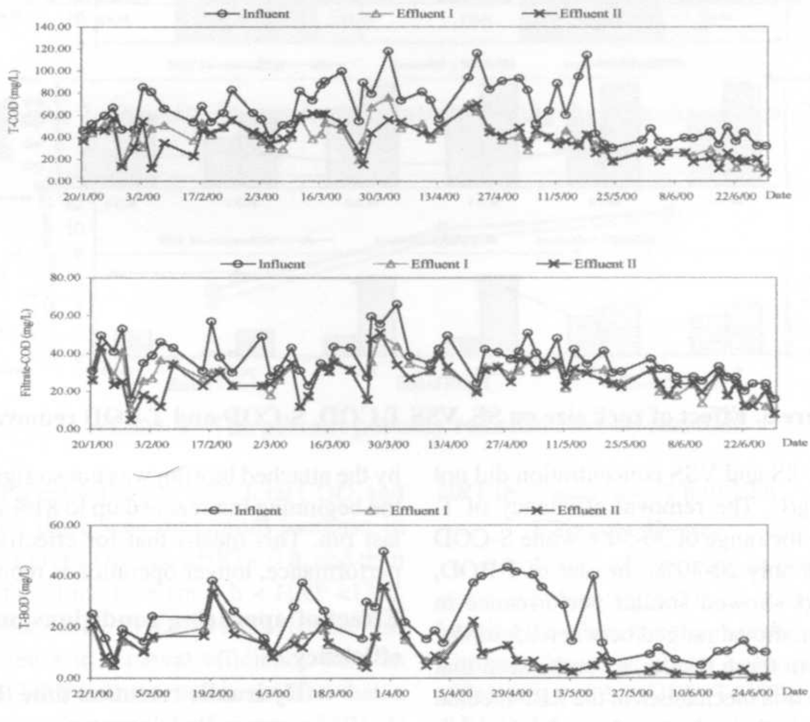

Figure 3. Variation in influent and effluent T-COD, S-COD and T-BOD concentrations.

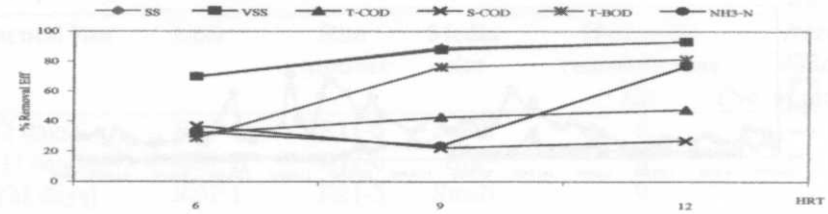

Figure 4. Effect of HRT on pollutants' removal.

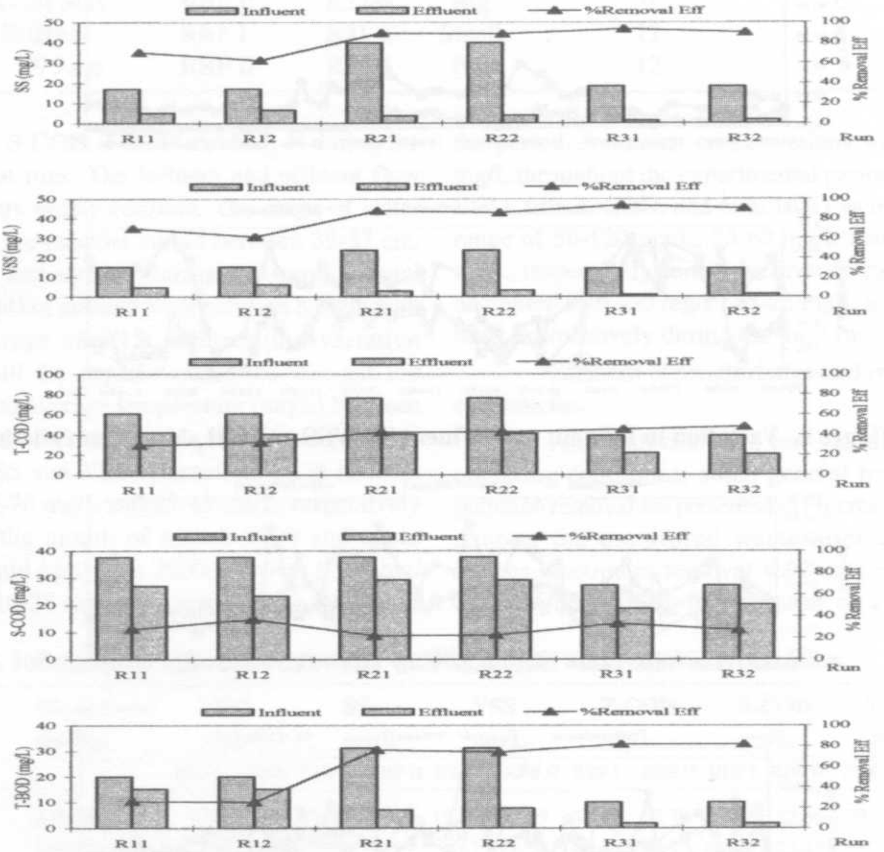

Figure 5. Effect of rock size on SS, VSS T-COD, S-COD and T-BOD removal.

The effluent SS and VSS concentration did not exceed 9 mg/L. The removal efficiency of T-COD was in the range of 30-50% while S-COD removal was only 20-30%. In case of T-BOD, both reactors showed similar performance in general and removal ranged between 25-81%.

From these results, it can be seen that the main reaction mechanism of the RBF method was sedimentation of organic and inorganic particulate matter. The soluble organic removal by the attached biofilm was not so significant in the beginning but reached up to 81% during the last run. This means that for effective biofilm performance, longer operation is required.

Effect of operating conditions on process efficiency

Hydraulic retention time (HRT)

An increase in HRT from 6 h to 12 h indicated better removal of target pollutants as

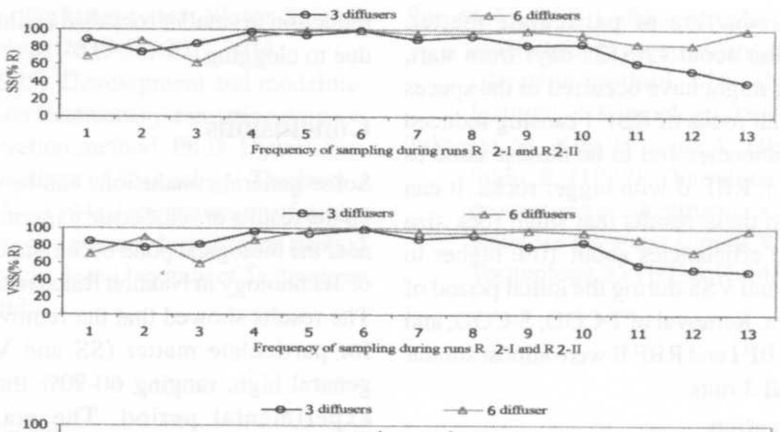

Figure 6. Effect of Aeration.

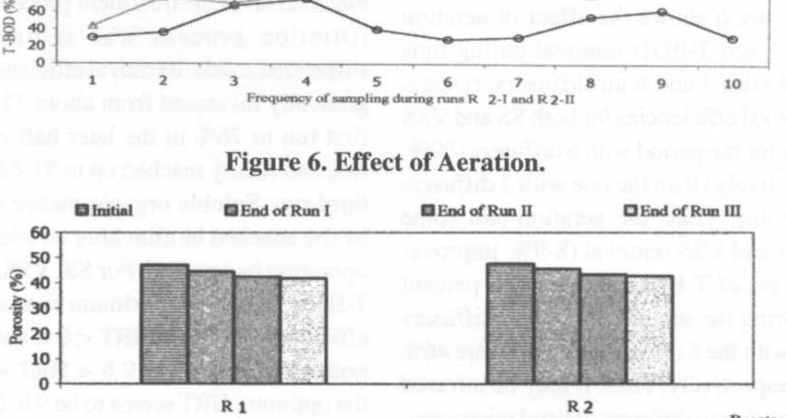

Figure 7. Porosity change in two reactors during the experimental period.

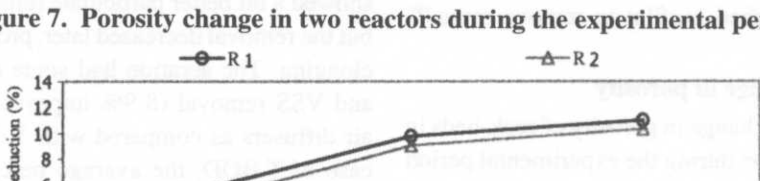

Figure 8. The percent porosity reduction in two reactors.

shown in Figure 4. For SS, VSS, total COD, and total BOD, there was maximum increase in removal efficiency for 6 h <HRT< 9 h, and then only a nominal increase for 9 h < HRT <12 h. However, for filtrate COD and NH_3-N, there was slight decrease in removal efficiency with an increase in HRT from 6 h to 9 h and after that, a sharp increase in removal efficiency of NH_3-N but only a slight increase for filtrate COD as the HRT increased from 9 h to 12 h.

Filter media size

Effect of rock size on process performance was investigated in three experiments by keeping the other operating conditions (HRT and aeration) the same. Figure 5 shows the removal efficiencies of SS, VSS, T-COD, S-COD, and T-BOD for the two rock sizes. Under similar conditions, the smaller rock size resulted in maximum reduction of particulate matter. However, after about 120-125 days from start, the clogging might have occurred in the spaces between small rocks of RBF I causing reduced removal efficiencies and to be almost same as in the reactor, RBF II with bigger rocks. It can be seen from these results that small rock size had removal efficiencies about 10% higher in terms of SS and VSS during the initial period of 120-125 days. Removal of T-COD, S-COD, and T- BOD in RBF I and RBF II were almost similar during the all 3 runs.

Aeration

Figure 6 shows the effect of aeration on SS, VSS, and T-BOD removal during runs 2-I and 2-II with 3 and 6 air diffusers, respectively. Removal efficiencies for both SS and VSS were higher for the period with 6 diffusers (89%, 88%, respectively) than the one with 3 diffusers (80% for both). Thus, the aeration had some effect on SS and VSS removal (8-9% improvement). In case of T-BOD, the average percent removal during the second run with 3 diffusers (R2-I) and with the 6 diffusers (R2-II) were 46% and 76%, respectively. Thus, it may be inferred that more aeration (6 diffusers) helped microorganisms in attached biofilm to remove more T-BOD.

Change in porosity

The change in porosity of rock-beds in the two reactors during the experimental period of 5 ½ months is shown in Figure 7. Initial overall porosities of the rock-beds were 47.08% for RBF I and 47.63% for RBF II. After one and a half months of operation (Run I), the porosity in RBF I was reduced to 44.61% and in RBF II to 45.59%. At the end of the second run, the porosities were found to be 42.48% in RBF I and 43.31% in RBF II. At the end of the last run, the porosities in RBF I and RBF II were 41.90% and 42.71%, respectively. Figure 8 shows the porosity reduction in RBF I and RBF II during experimental period. It can be seen that the porosity reduction in RBF I was only slightly higher than RBF II. Howevre, if the process was continued for longer period of about 1 year or so, much higher porosity reduction in smaller rock-bed could be expected due to clogging.

Conclusions

Some general conclusions can be drawn based on the results of pilot-scale experiments at a site near the biological pond of Suranaree University of Technology in Nakhon Ratchasima, Thailand. The results showed that the removal efficiency for particulate matter (SS and VSS) was in general high, ranging 60-90% throughout the experimental period. The main reaction mechanism in the treatment process of rock-bed filtration process was sedimentation of suspended solids. Removal efficiency for T-BOD gradually increased from about 25% during the first run to 76% in the later half of the second run, and finally reached up to 81-82% during the third run. Soluble organic matter was removed by the attached biofilm after an adequate time of operarion had passed. For SS, VSS, T-COD, and T-BOD, there was maximum increase in removal efficiency for 6 h < HRT < 9 h and then only a nominal increase for 9 h < HRT < 12 h. Thus, the optimum HRT seems to be 9 h. Smaller rocks showed a bit better particulate removal initially but the removal decreased later, probably due to clogging. The aeration had some effect on SS and VSS removal (8-9% improvement with 6 air diffusers as compared with 3 diffusers). In case of T-BOD, the average percent removal during the second run with 3 diffusers (R2-I) and with the 6 diffusers (R2-II) were 46% and 76%, respectively. Thus, it may be inferred that more aeration (6 diffusers) helped microorganisms in attached biofilm to remove more T-BOD.

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