Combination of a UASB reactor and a curtain type DHS (downflow hanging sponge) reactor as a cost-effective sewage treatment system for developing countries

I. Machdar, Y. Sekiguchi, H. Sumino, A. Ohashi, and H. Harada

Department Environmental Systems Engineering, Nagaoka University of Technology, Kamitomioka-machi 1603-1, Nagaoka, 940-2188 Japan. *Fax.: +81-258-47-9600, Email: machdar@stn.nagaokaut.ac.jp*

Abstract The second generation of our originally proposed sewage treatment system, which consists of a UASB reactor as an anaerobic pre-treatment unit and curtain-type DHS (downflow hanging sponge) reactor as an aerobic post-treatment unit, was installed at a municipal sewage treatment site. A 550-day continuous experiment demonstrated that the whole combined system successfully achieved 94–97% of unfiltered-BOD removal, 81–84% of unfiltered-COD removal, and 63–79% of SS removal, at an overall HRT of 8 h (6 h for UASB and 2 h for DHS units). The combined system performed an excellent organic removal as well as a fairly efficient nitrification, i.e. 52–61% of ammonia-nitrogen removal. Our proposed combined system possesses prominent advantages: requiring neither external aeration input nor excess sludge withdrawal.

Keywords Aerobic post-treatment; appropriate technology; developing countries; DHS reactor; sewage treatment; UASB reactor

Water Science and Technology **Vol 42 Nos 3–4 pp 83–88** © IWA Publishing 2000

Introduction

The use of an upflow anaerobic sludge blanket (UASB) technology for sewage treatment has been explored as a feasible option in many developing countries like Colombia, Indonesia, Brazil, China, and India (Alaerts *et al*., 1993). However, to meet the future effluent requirement of many developing countries, anaerobic effluents need to be improved. As a cost-effective and an easy-maintenance sewage treatment process for developing countries, we originally proposed a novel system which consists of a modified UASB as a pre-treatment and an aerobic post-treatment named the downflow hanging sponge (DHS) cube reactor (Machdar *et al*., 1997). Our proposed DHS reactor has a unique design concept: each module is 2–4 m vertical lengths, composed of hundreds of series-connected hanging sponge-cubes, as shown in Figure 1. Wastewater is supplied at the top end of each module, and is trickling down toward the lowest end of the module. Therefore, the most important feature of the DHS reactor is no requirement of external intended aeration.

In the previous study, the whole system (UASB unit plus cube-type DHS unit) gave an excellent reactor performance, achieving over 97% of total-BOD (unfiltered-BOD) removal at an HRT of only 8.3 h (7 h in UASB and 1.3 h in DHS). Furthermore, the cube-type DHS unit did 73–78% nitrification and some extent of denitrification. However, from a practical viewpoint, the cube-type DHS reactor seemed to have some drawbacks in area requirement and in influent uniform distribution. To improve these drawbacks, in this study we developed the second generation DHS called, a curtain-type DHS reactor. The objective of this study is to evaluate the efficiency of organic removal in the combination of the UASB process and the curtain-type DHS process. This paper describes a long-term experiment to assess the process performance of the whole combined system receiving actual sewage, with an emphasis on nitrification behavior of the DHS post-treatment unit.

Downloaded from https://iwaponline.com/wst/article-pdf/42/3-4/83/428415/83.pdf
by guest

Materials and methods

Description of pilot plan and process

Our proposed system was installed at a municipal sewage treatment plant site in Nagaoka City, Japan. The schematic diagram of the experimental setup, consisting of UASB pre-treatment unit and curtain-type DHS post-treatment unit, is shown in Figure 1. For reference, the cube-type DHS reactor used in the previous study is also given in this figure. The UASB reactor has 155-litre working volume (a 120-litre column portion and a 35-litre gas/solid separator), and detailed configuration was described elsewhere (Agrawal *et al*., 1997). The curtain-type DHS was constructed by tiling right-triangular prism polyurethane foams (side: 3 cm and length: 75 cm) onto both surfaces of a vertical plastic-made rectangular-sheet (75 cm in width by 200 cm in length). Raw sewage was supplied to the UASB reactor (6 h HRT) and the effluent stream was further forwarded for polish-up to the aerobic DHS reactor.

The DHS was operated in two different flow modes by partitioning the total experimental duration of 550 days into two phases. For the first-half period (until day 262, referred to as phase I) two units of the DHS curtain-sheet were in parallel operated at a nominal HRT of 2 h for each unit. For the second-half period (day 288 through day 550, referred to as phase II) two DHS-curtain sheets were connected in series so as to make the total vertical flow length double that of the phase I. To maintain an identical HRT (2 h) for both DHS modes, the feeding flow rate to phase II was set at twofold as large as that to phase I. All operational conditions other than the flow rate were maintained at similar to the previous experiment. The combined system (UASB plus DHS) was kept at 25˚C to simulate the annual average ambient temperature in most developing countries in subtropical regions. The DHS was seeded with activated sludge mixed liquor for one day prior to the start-up of phase I.

Batch experiment

Separate batch experiments were conducted by using sludge harvested from the DHS. Appropriate amounts of sludge were collected by squeezing out from sponge materials located at three different heights: 10 cm, 100 cm, and 195 cm from the inlet. The collected sludge was, after washing by centrifugation, resuspended in a 10 mM phosphate buffer solution (pH 7.0), which contained either 25 mg NH_4-N/L, or 20 mg NO_2-N/L, or 50 mg NO_3-N/L plus 100 mg glucose/L, as a final batch-liquid concentration, for determination of

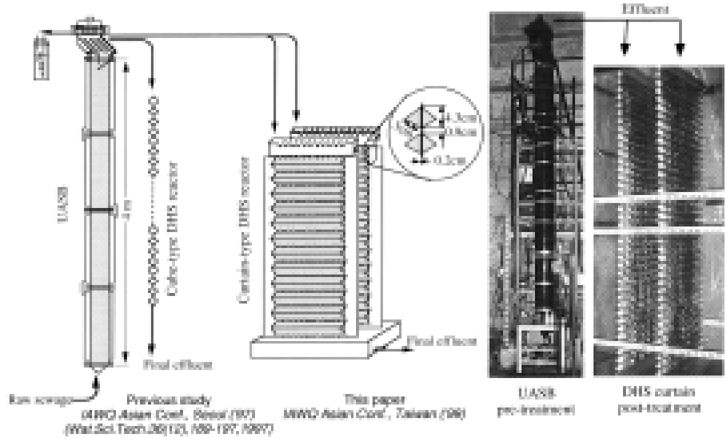

Figure 1 Schematic diagram and photograph of an experimental setup (USAB unit plus certain-type DHS unit) installed at a sewage treatment site. For reference the cube-type DHS process used in the previous study is also presented in the figure

Downloaded from https://iwaponline.com/wst/article-pdf/42/3-4/83/428415/83.pdf
by guest

the ammonia-oxidation, or the nitrite-oxidation, or the denitrification rate, respectively, along with trace elements. The sludge suspensions were kept fully either at aerobic conditions by magnetic stirrer during the ammonia- and nitrite-oxidation tests, or at anoxic conditions by N_2 purging during the denitrification test.

Dissolved oxygen profile measurement

A Clark-type dissolved oxygen microelectrode was used to measure (1) the profile of DO in the downward flowing liquid along the DHS reactor vertical distance (from inlet to exit point), and (2) the DO profile within sponge-material inward depth. The DO microelectrode was fabricated in our laboratory, which has a tip end with 50 µm – 100 µm in diameter, and a 90% response time of less than 30 s. Detailed procedure as for application of the DO microelectrode to on site DHS process was described in the cube-type DHS study (Araki *et al*., 1999).

Results and discussion

Organic removal in UASB and curtain-type DHS

The UASB reactor was installed in March 1995 at a municipal sewage treatment plant in Nagaoka, Japan, and has been continually operated since then. A successful performance of the UASB from March 1995 to June 1996 (Sekiguchi *et al*., 1996) encouraged further investigation to improve the UASB effluent quality by adding a simplified and cost-effective post-treatment unit. In this context, the cube-type DHS, as the post treatment unit, was started in June 1996. The whole combined system (UASB unit plus cube-type DHS unit) gave an excellent performance with respect to organic removal and some extent of nitrogen removal (Machdar *et al*., 1997). Afterwards, the second generation of DHS reactor, i.e. the curtain-type DHS unit, started in operation in October 1997.

Figure 2 gives the time courses of total BOD (unfiltered-BOD) of raw sewage (the influent to the UASB unit), of the UASB effluent (the influent to the curtain-type DHS) and of the DHS effluent. Table 1 summarizes the process performances of the UASB pre-treatment unit solely, of the curtain-type DHS post-treatment solely, and of the whole combined system, throughout both phases. Similarly to the previous study (Sekiguchi, Machdar), the UASB unit exhibited a fairly satisfactory organic removal at an HRT of even 6 h, accomplishing 58% (SD±14%) of total- (unfiltered-) COD removal and 64% (SD±11%) of soluble- (filtered-) COD removal. Particulate COD of the raw sewage accounted for 55% of the total influent strength, and the UASB pre treatment unit functioned well for solid-organic removal, achieving 61% (SD±20%) of SS removal.

The curtain-type DHS produced superior effluent quality in terms of BOD: on average, 4–10 mg/L (for phase I and II, respectively) of total-BOD, and 1–3 mg/L of soluble-BOD (see Table 1). The high COD/BOD ratio for the final effluent from the DHS are likely attributable to residual organic refractory fractions present in the sewage. No substantial difference in BOD and in COD removals by the DHS was observed between the phase I and II period. However, the phase II DHS unit showed somewhat lower performance in SS removal, likely due to two-times higher liquid velocity. The whole combined system (UASB plus curtain-type DHS) exhibited an excellent ability in removing organic materials: achieving 84–81% of total-COD removal (averaged for phase I and II, respectively), 97–94% of total BOD removal at an overall HRT of 8 h (6 h for UASB unit and 2 h for DHS unit). Compared with the first generation (cube-type) DHS reactor, the second generation (curtain-type) DHS showed inferior capability in trapping particulate organics due to the occurrence of uneven wastewater distribution within curtain-type sponge material. However, it should be noted that the curtain-type DHS unit still proved a satisfactory organic removal performance.

Downloaded from https://iwaponline.com/wst/article-pdf/42/3-4/83/428415/83.pdf
by guest

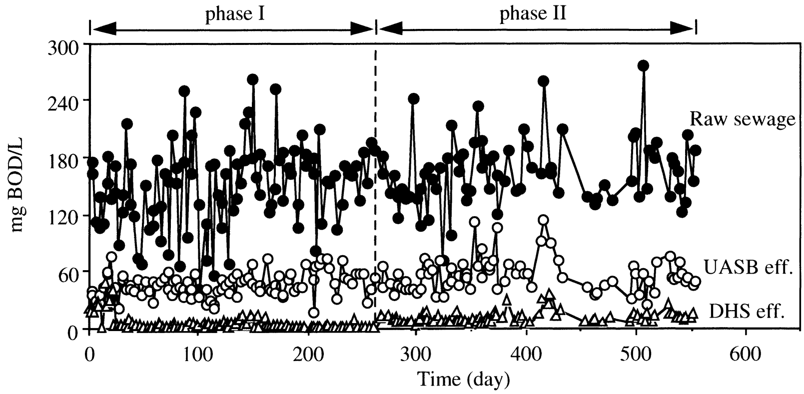

Figure 2 Time course of total-BOD of raw sewage, of UASB effluent, and of curtain-type DHS effluent during the phase I and the phase II experiments

Nitrogen removal in the curtain-type DHS

Ammonia-nitrogen removal in the curtain-type DHS attained on average 52% (SD±16%) and 61% (SD±14%) during phase I and II, respectively. Figure 3 presents the relationship between the removal of total (unfiltered) Kjeldahl-nitrogen and the production of oxidized-nitrogen in the DHS unit. The observation that the elimination of total Kjeldahl-nitrogen all the time exceeded considerably the formation of oxidized-nitrogen suggested the concurrent occurrence of nitrification and denitrification in the DHS unit. The proportion of nitrogen eliminated per total nitrogen fed to the DHS unit was estimated to be 25% (SD±12%) and 31% (SD ±9%), respectively, during phase I and II (see Table 1). A major part of nitro-

Table 1 Summary of process performances of USAB unit, of certain-type DHS post-treatment unit, and of the whole combined system

Parameter	UASB Pre-treatment (from DHS curtain started)		Effluent from DHS uni		Total system	
	Raw sewage	Effluent	phase I (262 days)	phase II (288 days)	phase I	phase II
Total-COD (mg/L)	393 (78)	161 (49)	65 (33)	68 (28)		
Soluble-COD (mg/L)	178 (39)	61 (14)	27 (9)	25 (8)		
Total-BOD (mg/L)	157 (46)	51 (16)	4 (8)	10 (6)		
Soluble-BOD (mg/L)	75 (23)	17 (8)	1 (3)	3 (2)		
Total-N (mgN/L)	53 (10)	51 (10)	40 (8)	38 (8)		
Total-Kjeldahl (mgN/L)	53 (10)	51 (10)	22 (9)	23 (9)		
Soluble-Kjeldahl (mgN/L)	53 (10)	51 (10)	22 (9)	23 (9)		
NH_4-N (mgN/L)	32 (8)	39 (8)	20 (8)	15 (7)		
$N0_2$-N (mgN/L)	ND	ND	0.8 (1)	1 (1)		
$N0_3$-N (mgN/L)	ND	ND	18 (6)	14 (5)		
SS (mg/L)	138 (48)	56 (32)	28 (24)	46 (24)		
VSS (mg/L)	119 (40)	46 (27)	23 (18)	34 (18)		
DO (mg/L)	0–1.9	0	6.34–8.08	5.11–7.19		
pH	6,87–7.88	6.35–7.63	7.2–7.6	6.21–7.98		
ORP (mV)	(–90)–(–302)	(–68)–(–315)	(–54)–(216)	(–94)–(83)		
Total-COD removal (%)	58 (14)		59 (18)	62 (11)	84 (9)	81 (11)
Soluble-COD removal (%)	64 (11)		55 (13)	60 (8)	84 (7)	85 (6)
Total-BOD removal (%)	66 (13)		91 (16)	83 (8)	97 (6)	94 (4)
Soluble-BOD removal (%)	76 (13)		94 (14)	88 (7)	98 (5)	97 (2)
NH_4-N removal (%)			52 (16)	61 (14)	52 (16)	61 (14)
Total-N removal (%)			25 (12)	31 (9)	25 (12)	31 (9)
SS removal (%)	61 (20)		51 (29)	39 (23)	79 (16)	63 (20)

( ) *standard deviation* *ND = not detectable*

Downloaded from https://iwaponline.com/wst/article-pdf/42/3-4/83/428415/83.pdf
by guest

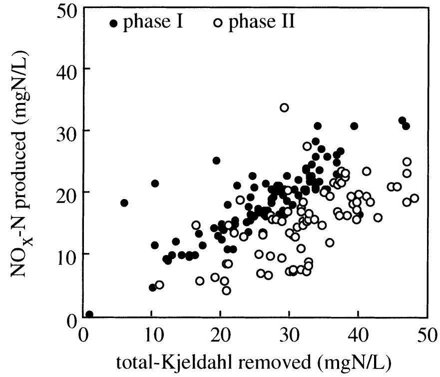

Figure 3 Relationship between the removal of total (unfiltered) Kjeldahl-nitrogen and the formation of oxidized-form nitrogen in the DHS unit during phase I and phase II

gen eliminated could be attributed to denitrification because nitrogen accumulated in the DHS reactor through assimilation was negligible at a very long SRT.

Figure 4 gives representative examples of nitrogen species and soluble-COD profiles along DHS reactor vertical distance during phase I and II. At the upper portion of the DHS reactor there was no substantial occurrence of nitrification (accumulation of nitrate) in both phases. This can be ascribed to heterotrophs being outcompeted in oxygen over nitrifiers at the upper DHS portion where sufficient amount of organic is available.

Activities of the DHS-reactor sludge

Table 2 presents microbial activities of retained sludge at three different curtain-DHS heights, with respect to ammonia oxidation, nitrite oxidation and denitrification, given on sludge basis ($kgN.kgVSS^{-1}.d^{-1}$) and sponge-volume basis ($kgN.m^{-3}$ $sponge.d^{-1}$). For comparison, some activity data regarding cube-type DHS sludge in the previous study (Araki *et al.*, 1999) are also given in the figure. At 10 cm DHS locations, volume-basis ammonia oxidation rate of the curtain-type DHS significantly differed from that of the cube-type DHS, i.e., 0.05 versus 9.46 $kgN.m^{-3}.d^{-1}$. A similar difference in nitrite oxidation activity at 10 cm locations was also observed between curtain-type DHS (0.57) and cube-type DHS (4.69 $kgN.m^{-3}.d^{-1}$). With the exception of the 10cm location, the curtain-type DHS sludge acquired somewhat efficient nitrification potential, for instance 0.074 to 0.087 $kgN.kgVSS^{-1}.d^{-1}$ of ammonia oxidation, at 100-cm and 190-cm locations, where organic loading becomes insignificant. In this study the new configuration (curtain-type) of the

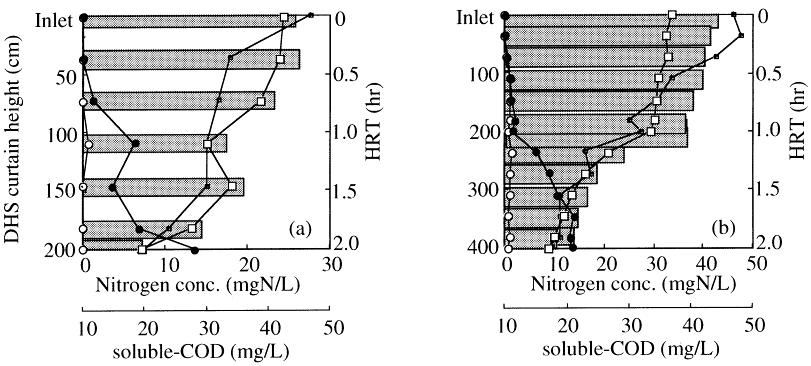

Figure 4 Profiles of nitrogen species and soluble-COD along the curtain-type DHS reactor height. (a) phase I (day 107); (b) phase II (day 63).
Legend: —o— NO_2-N —●— NO_3-N —□— NH_4-N ▢ s-Kjeldahl —▪— s-COD

Downloaded from https://iwaponline.com/wst/article-pdf/42/3-4/83/428415/83.pdf
by guest

Table 2 Nitrogen conversion activities of curtain-type DHS unit at three different locations, expressed on VSS basis and on sponge-volume basis. For comparison, the previous study (cube-type DHS) data are also presented

Location from the inlet (cm)	VSS retainment (mg VSS/cm^3)		Ammonia oxidation				Nitrate oxidation				Denitrification (curtain-type)	
	curtain-type	cube-type	curtain-type		cube-type		curtain-type		cube-type		(curtain-type)	
			(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
10	26	84	0.002	0.05	0.113	9.46	0.022	0.57	0.056	4.69	0.037	0.96
100	21	14	0.074	1.55	0.036	0.50	0.091	1.91	0.031	0.44	0.026	0.55
195	22	7	0.087	1.91	0.024	0.17	0.104	2.28	0.019	0.13	-	-

Cube-type data from Araki *et al*. (1999)

(a) kgN.kgVSS^{-1}.d^{-1} (b) kgN.m^{-3} sponge.d^{-1}

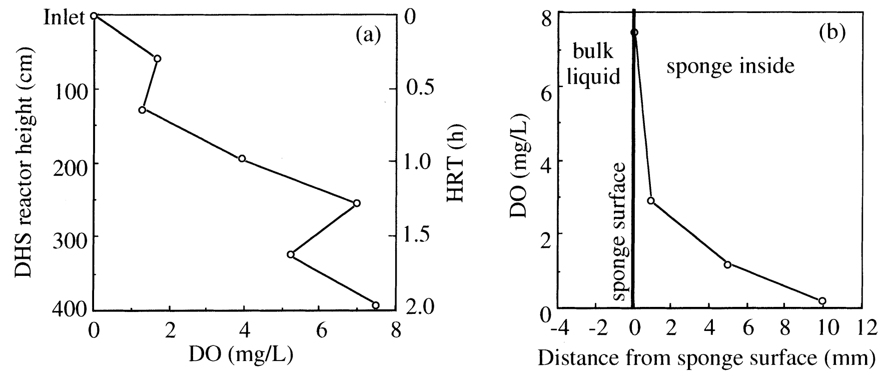

Figure 5 Profiles of disolved oxygen in the curtain-type DHS determined by using a DO microelectrode. (a) along the reactor height; (b) sponge-inward depth

DHS process succeeded in improvement of some drawbacks of the previous cube-type DHS reactor such as area requirement, by maintaining almost the equivalent capability in performing concurrent removal of organic matter and nitrogen.

Figure 5 presents DO profiles along the DHS reactor downward distance (Figure 5-a), and along sponge-inward depth (Figure 5-b). Despite there being no forced aeration input to the DHS unit, DO level of downward-flowing wastewater increased from zero at the inlet up to almost saturated at the exit (Figure 5-a). The sponge-inside DO profile, shown in Figure 5-b, demonstrated a distinctive DO gradient occurring along sponge-inward depth, suggesting coexistence of a nitrification region at the shallow sponge-inside and denitrification region at the deep sponge-inside. Both figures explain eloquently the most important feature of DHS reactor: no requirement of external aeration input.

References

Agrawal L.K., Harada H. and Okui H. (1997). Treatment of dilute wastewater in a UASB reactor at a moderate temperature: Performance Aspects, *Journal of Fermentation and Bioengineering*, **83**(2), 179–184.

Alaerts G.J., Veenstra S, Bentvelsen M. and van Duijl L.A. (1993). Feasibility of anaerobic sewage treatment in sanitation strategies in developing countries. *Wat. Sci. Tech*., **27**(1), 179–186.

Araki N., Ohashi A., Machdar I. and Harada H. (1999). Behaviors of nitrifiers in a novel biofilm reactor employing hanging sponge-cubes as attachment site. *Wat. Sci. Tech*., **39**(7), 23–31.

Machdar I., Harada H., Ohashi A., Sekiguchi Y., Okui H. and Ueki K. (1997). A novel and cost-effective sewage treatment system consisting of UASB pre-treatment and aerobic post-treatment units for developing countries. *Wat. Sci. Tech*., **36**(12), 189–197.

Sekiguchi Y., Harada H. and Ohashi A. (1996). A simple and cost-effective anaerobic sewage treatment system for developing countries. In: *Advanced Technology in the Environment Field,* M.H. Hamza (ed.), Gold Coast, Australia, pp. 99–102.

Downloaded from https://iwaponline.com/wst/article-pdf/42/3-4/83/428415/83.pdf
by guest