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Direct Treatment of Settled Sewage by DHS Reactors with Different Sizes of Sponge Support Media

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ABSTRACT: The down-flow hanging sponge (DHS) reactor, which was developed for post-treatment of effluent from up-flow anaerobic sludge blanket (UASB) process treating sewage, uses polyurethane sponge as media to retain biomass. Wastewater is trickled from the top of the reactor and purified by microorganisms retained both inside and outside of the sponge media as the wastewater flows vertically down through the reactor. Three DHS reactors employing different sizes of sponge media with the same total sponge volume were used for the direct treatment of settled sewage. All the reactors exhibited excellent performance in removal of COD, ammonium nitrogen, and fecal coliform at a fixed hydraulic retention time of 2.0 h based on the sponge volume. It was shown that smaller sponge media produced better removal efficiencies for all the parameters listed above. The most reasonable explanation for this might be that smaller sponge media allows better oxygen uptake in the stream flowing down through the reactors.

Key words: DHS, Settled sewage, Sponge support media, Sponge size, DO

INTRODUCTION

Recently, up-flow anaerobic sludge blanket (UASB) reactor has been favored as the most suitable sewage treatment process in developing countries because of their low energy use, easy maintenance, and cost effectiveness. However, when using UASB reactors to treat solely municipal sewage, it is relatively difficult to produce good quality effluent. Thus installation of an appropriate post treatment process is necessary after UASB treatment (van Haandel and Lettinga, 1994; Uemura and Harada, 2010). The down-flow hanging sponge (DHS) reactor was developed for post-treatment of effluent from UASB systems treating sewage (Machdar *et al*., 2000; Tandukar *et al*., 2006; Tawfik *et al*., 2006). The DHS process uses polyurethane sponge as media to retain biomass. Wastewater is trickled from the top of the reactor and purified by microorganisms retained both inside and outside of the sponge media as the wastewater flows vertically down through the reactor. As the sponge media in DHS reactors are not submerged in wastewater but hang freely in the air, oxygen is dissolved into the wastewater. Therefore there is no need for external aeration or any other energy inputs. Furthermore, in DHS reactors, a large amount of activated sludge grow both inside and outside of the sponge media so that an ecosystem with an extremely long food chain can be established, resulting in minimization of excess sludge production. In combined UASB/DHS systems, the organic substances in the sewage are removed by the first (UASB) step while removal of residual organics, or polishing, is achieved by secondary treatment in the DHS process. As a result of this two-phase treatment, the effluent quality of the combined system is much better than that of effluent treated by UASB treatment alone (Machdar *et al*., 2000; Tandukar *et al*., 2006; Tawfik *et al*., 2006). A feasibility study of the UASB/DHS combined system was conducted by installing a full-scale plant at a sewage treatment site in India in 2001. It has performed superbly in removing COD, BOD, ammonium nitrogen, and fecal coliform (F. coli) from sewage in a long term experiment of more than

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1800 days (Okubo *et al.*, 2008). In most sewage treatment plants installed in developing countries, the UASB process has been sometimes used instead of a primary settling tank (van Haandel and Lettinga, 1994). In Japan and other industrialized countries, on the other hand, raw sewage is usually settled in a primary settler and then treated by an activated sludge process (ASP). Sewage in developing countries is somewhat more concentrated than that in Japan. For example, in India, sewage sometimes exceeds 1000 mg/L of COD (Sato *et al.*, 2006). According to our experience in India, the strength of UASB-treated sewage is more or less comparable to most settled sewage in Japan (Sato *et al.*, 2006). Therefore, if the DHS process can be applied to the direct treatment of settled sewage in Japan, it may be possible for DHS use in industrialized countries to spread by replacing existing ASPs with DHS. In developing countries, securing good quality effluent is important, but the process must be kept as simple as possible. In industrialized countries, effluent is generally chlorinated for disinfection at the last stage of sewage treatment plants. However, in developing countries, simplicity must be the highest priority for sewage treatment technology in order to encourage the spread of sewage treatment plants (Uemura and Harada, 2010). According to our experience, even simple maintenance and operation tasks like the exchange of disinfectant containers are not performed adequately in some developing countries. Therefore, a secondary treatment process that can perform adequate disinfection on its own would be very useful as a sewerage treatment process in such countries.

With these conditions in mind, this study was conducted to test the potential for use of the DHS process not only in developing countries but also in industrialized nations. It had the following objectives:
1) To investigate the possibility of using DHS reactors for the direct treatment of settled sewage, and
2) To investigate the effect of sponge media size on the performance of DHS reactors, especially in terms of F. coli removal.

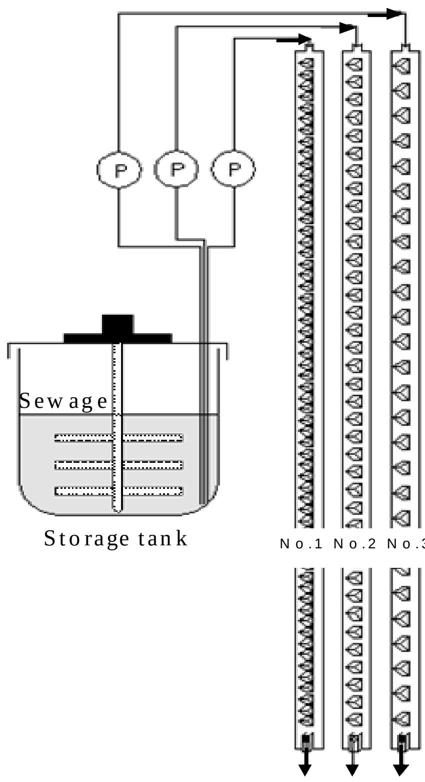
MATERIALS & METHODS

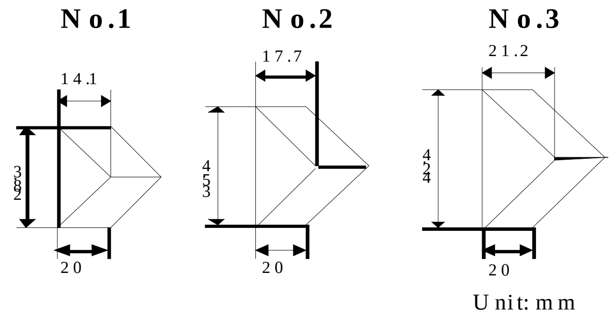
Three identical DHS reactors, 2000 mm in working height and 20 mm in width, were used. The reactors are shown in Fig. 1 along with a sketch of the three different sizes of polyurethane sponge media (Maruei Co. Ltd., MSC-E16, void volume=98.4%) which were adhered onto a polyacrylamide-made plastic plate (2000 mm in height x 70 mm in width). The largest sponge medium is the same size as that used in previous pilot and demonstration studies of curtain type DHS units (Machdar *et al.*, 2000; Okubo *et al.*, 2008; Uemura *et al.*, 2002). The reactors, tiled with the small, medium, and large size sponge media were designated reactors No. 1, No. 2, and No. 3, respectively. Although the sizes of the three sponge media were different, the total sponge volume in each reactor was set at 240 cm^3. The reactors were seeded with activated sludge taken from a municipal sewage treatment site in Kisarazu, Chiba, Japan just before start-up. The activated sludge was concentrated by sedimentation to 3.2 g/L of MLSS. To seed the sludge into the sponge media, the sponges were forcibly soaked with the concentrated activated sludge.

As an influent wastewater, samples of settled sewage were drawn after primary settling at the sewage treatment site in Kisarazu at between 10:00 AM and 11:00 AM to obtain as uniform quality sewage as possible. The sewage in the substrate tank was always slightly agitated by a mixer to prevent sedimentation of suspended solids (SS). The HRT of all three reactors was set at 2 h based on the sponge volume (flow rate = 2.8 L/d). The DHS reactors were placed in a temperature-controlled room set at 25^{o}C, and operated more than 130 days.

Routine monitoring of ammonium nitrogen, nitrate, nitrite, COD and F. coli in the wastewater and the effluent of each reactor was conducted. The number of F. coli was determined by the membrane filter method with mFC medium following the "Standard Methods for the Examination of Water and Wastewater" (APHA, 2005). The COD, ammonium nitrogen, nitrate and nitrite were analyzed using a HACH water quality analyzer (HACH DR-890, USA) as in a previous study (Uemura *et al.*, 2002). To determine the dissolved oxygen (DO) in the stream flowing through the DHS reactors, Clerk-type DO microelectrodes were used as in another previous study (Yamaguchi *et al.*, 2001). All other analytical procedures were carried out according to "Standard Methods for the Examination of Water and Wastewater" (APHA, 2005).

The hydraulic characteristics, in particular the distribution of residence time in the DHS reactors, were determined by an impulse addition of NaCl tracer to the reactors. The mean residence time (actual HRT) of each reactor employing the different sizes of sponge media with and without retained sludge was then calculated from the recorded tracer concentration data. The actual HRTs of the reactors with clean sponge media (without sludge) were measured before the beginning of the continuous experiment. The conductivity was measured in a small sedimentation tank set at the lowest part of the reactor by an electric conductivity meter (TOA-DKK CM-201, Tokyo).





	No.1	No.2	No.3
Total volume (cm ^{3})	240	240	240
No. of sponges	60	38	27
Surface are (cm ^{2})	480	430	384

Fig. 1. Schematic diagram of DHS reactors and sponge size

RESULTS & DISCUSSION

The performance of the reactors is summarized in Table 1 in which F. coli results, with both geometric and arithmetic means were tabulated.The concentration of COD over time in the sewage and effluents from the three reactors is shown in Fig. 2. Excellent COD removal was rapidly established in all the reactors, which is one of the DHS system's merits. This is attributed to the temporary adsorption of organic substances onto the sponge media (Tandukar *et al*., 2006). The average COD concentrations in the sewage and effluents of reactors No. 1, No.2, and No. 3 during the experimental period were as follows; sewage: 106 mg/L, reactor No. 1 effluent: 14.1 mg/L, reactor No. 2 effluent: 16.5 mg/L, and reactor No. 3 effluent: 17.5 mg/L. Thus, the average COD removals in the reactors were as follows: reactor No. 1: 85.2%, reactor No. 2: 83.7%, and reactor No. 3: 82.9%, which correspond well to results of previous studies (Machdar *et al*., 2000; Tandukar *et al*., 2006; Tawfik *et al*., 2006). It should be noted that there was a slight tendency for the smaller sized sponge media to show slightly higher COD removal (Table 1). The COD derived from suspended solids (SS-COD) was estimated by subtracting the soluble COD (COD of the samples filtered through a 0.45μm membrane filter) from the total COD. The superior ability of the DHS process to remove SS has been well verified in previous studies (Machdar *et al*., 2000; Tandukar *et al*., 2006; Tawfik *et al*., 2006). In this study, the SS-COD concentrations in the effluents from the three reactors were always less than 10mg/L in the experimental period (data not shown). Changes of F. coli in the sewage and effluents from the reactors with elapsed time are shown in Fig. 3. Although the F. coli concentration in the influent was relatively stable between 10^6-10^7/100mL, the effluent concentrations from all the reactors fluctuated significantly. The log_{10} reductions of F. coli in each reactor were 2.95 log for reactor No. 1, 2.32 log for reactor No. 2, and 2.19 log for reactor No. 3. Thus, similar to the performance in COD and ammonium nitrogen removals, the No. 1 reactor with the smallest sponge media performed best in F. coli removal, followed by the No. 2 and No. 3 reactors. Changes in water quality along the DHS reactors from the top downward to the lower reactor sections were investigated after the continuous experiment on day 120 and day 130 (profile experiment). COD concentrations were seen to decrease as distance from the reactor inlet increased. There was no clear difference in the pattern of COD decline among the three reactors. As ammonium nitrogen decreased with distance from the reactor inlet, nitrate increased. Nitrite also increased from the top of the reactor to the 1200 mm level, then decreased toward the bottom of the reactor. This change of nitrogen compounds in reactor No. 1 was almost identical to those observed in reactors No. 2 and No. 3 although residual ammonium nitrogen concentrations in the effluents from the reactors with bigger sponge media were slightly higher (data not shown).

Table 1. Summary of continuous experiment

Water quality		Sewage	No.1	No.2	No.3
COD	(mg/L)	106.2 (32.3)	14.1 (8.7)	16.5 (11.7)	17.5 (11.8)
NH_4^+-N	(mg/L)	18.6 (7.8)	1.2 (2.8)	1.8 (3.6)	2.2 (3.7)
NO_2^--N	(mg/L)		1.5 (1.0)	1.5 (1.2)	2.0 (1.9)
NO_3^--N	(mg/L)		12.6 (3.1)	11.0 (3.4)	11.7 (3.0)
F. coli	(CFU/100mL)				
Geometric mean		3.00×10^6	3.22×10^2	5.22×10^2	1.74×10^4
Arithmetical mean		5.61×10^6	6.68×10^3	2.74×10^4	3.66×10^4
Removal					
COD	(%)		85.2 (11.4)	83.7 (12.4)	82.9 (11.6)
NH_4^+-N	(%)		94.7 (9.2)	91.1 (14.8)	90.1 (13.1)
F. coli	(Log_{10})		2.95	2.32	2.19

Figures in parenthesis describe standard deviations

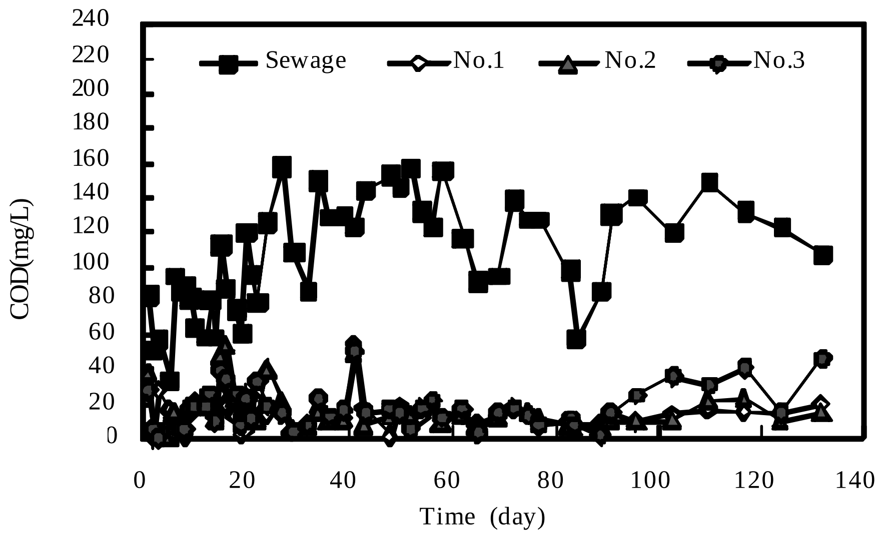


Fig. 2. COD concentration over time in the sewage and reactor effluents

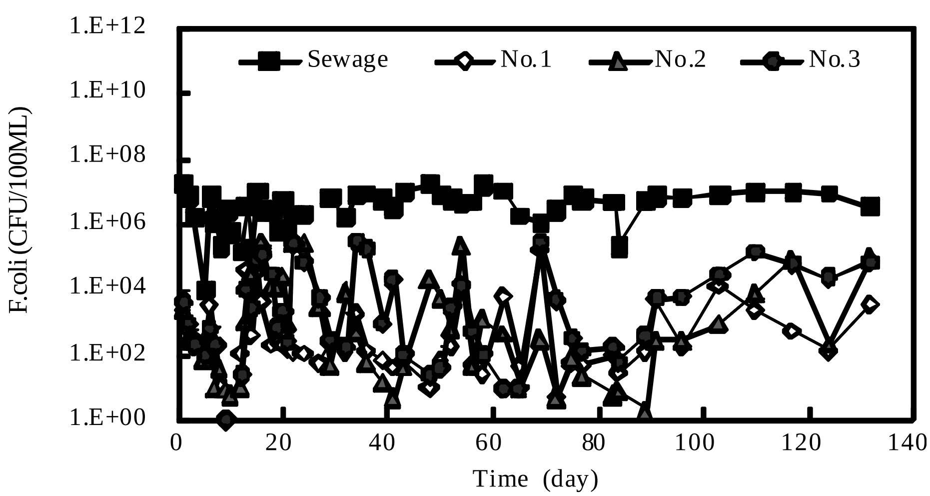


Fig. 3. F. coli concentrations over time in the sewage and reactor effluents

Fig. 4 shows the profile of F. coli concentration along the height of the DHS reactors. Furthermore, Fig. 5 shows the first order decimating constant (k) for each DHS reactor calculated from the data in Fig. 4. Although the F. coli concentrations also tended to decrease with distance from the reactor inlet (Fig. 4), the difference in the F. coli decline patterns among the three reactors was more significant than those of COD and ammonium nitrogen (Table 1). The decline of F. coli in reactor No. 1 was the greatest, followed in order by reactor No. 2 and reactor No. 3. The first order constants calculated were 3.27/h, 2.80/h, and 1.79/h, for reactor No. 1, reactor No. 2, and reactor No. 3, respectively (Fig. 5). Thus, the profile experiment confirms that reactor No. 1, equipped with the smallest sponge media, achieved the best F. coli removal. The DO profile of the reactors is shown in Fig. 6. The DO in each reactor tended to increase as distance from the reactor inlet increased, finally approaching saturation. Although the DO concentrations in all the reactors' influent was approximately 0 mg/L and all effluents DO concentrations were nearly 8 mg/L, the DO concentrations between 250 mm and 1500 mm in height were significantly different. In this region, the DO in reactor No. 1 was the highest, followed in order by reactors No. 2 and No. 3. Of particular note is that at around 870 mm, the DO concentration in reactor No. 1 was 1.7 times that of reactor No. 2 and 4.2 times higher than that of reactor No. 3. The specific area of the sponge media increases as the sponges become smaller (Fig. 1). Therefore, oxygen in the air should dissolve more easily in the water when smaller sponge media are used. This could explain why reactor No. 1, with the smallest sponge media, performed best in removing COD, ammonium nitrogen, and F. coli. Performance of a biological wastewater treatment system depends upon the uniformity of wastewater distribution. With less dead volume, the contact between the substrate and the microbes is enhanced. The uniformity of flow distribution can be evaluated by calculating the difference between the actual and theoretical HRT. To do this, tracer analyses for the three DHS reactors were performed with the same theoretical HRT (120 min based on the sponge volume and flow rate) under two different sponge conditions; clean sponges without any biomass before start-up, and sponges with retained biomass just after the end of continuous experiment (Table 2). The theoretical HRT was calculated from the measured flow rate. Because there was no significant difference between the actual HRTs between reactor No. 1 and reactor No. 3, the actual HRT of reactor No. 2 was not determined. When the theoretical HRT was set at 120 min, the actual HRT with clean sponges was only 82.9 min (68.5%) for reactor No. 1 and 79.1 min (66.5%) for reactor No. 3. However, as the sponges became filled with biomass, the reactors' actual HRTs increased to 100 min (88.2%) for reactor No. 1, 101 min (90.4%) for reactor No. 2, and 93 min (79.7%) for reactor No. 3. The percentage differences between the theoretical HRT and the actual HRT in reactor No. 1 and reactor No. 3 without biomass were similar, 31.5% in reactor No. 1 and 33.5% in reactor No. 3. However, as the sponges became filled with biomass, the differences decreased to 11.8%, 9.6%, and 20.3% for reactor No. 1, reactor No. 2, and reactor No. 3, respectively. This indicated that there was more dead volume in reactor No. 3 than in the other two. Though the difference between the theoretical and actual HRTs was the largest in reactor No. 3, there was no significant difference between reactors No. 1 and No. 2. As the actual HRTs in the reactors with smaller sponges are closer to the theoretical HRTs, the contact between the sludge on the sponges and the wastewater should be more efficient. This could be another reason that the reactor with the biggest sponge media did not perform as well as the others.

All three DHS reactors performed satisfactorily when treating settled sewage. Especially, the DHS reactor with the smallest size sponge media showed the highest removals for all the water quality parameters measured (Table 1). It should be noted that even the DHS with the largest sponge media (reactor No. 3) successfully produced effluent with COD concentrations of less than 20 mg/L and ammonium nitrogen concentrations of less than 5 mg/L. The experiment was conducted under relatively warm climate conditions in a temperature-controlled room set at 25^{o}C. Therefore, there is some potential for replacing existing ASP treatment with DHS processes in tropical or subtropical conditions in both developing and industrialized countries. Further investigation is necessary to determine the applicability of DHS in lower temperature conditions. Removal of pathogenic organisms is one of the principle objectives of sewage treatment for developing countries as these organisms pose a significant risk to public health. The 1989 WHO guidelines for using treated wastewater in agriculture stated that wastewater treatment systems should produce effluents with F. coli concentrations with geometric means of less than 10^3/100mL to permit their use for unrestricted irrigation of crops (WHO, 1989). In our investigation, the effluent of reactor No. 3 still contained more than 10^3/100mL (geometric mean) of F. coli. Reactors No. 1 and No. 2, however, which employed the smaller sizes of sponge media, were able to meet the F. coli standard. This means that even in developing countries where the installation of chlorination is troublesome, DHS effluent quality, F. coli concentrations in particular, can be improved by employing small sponge media.

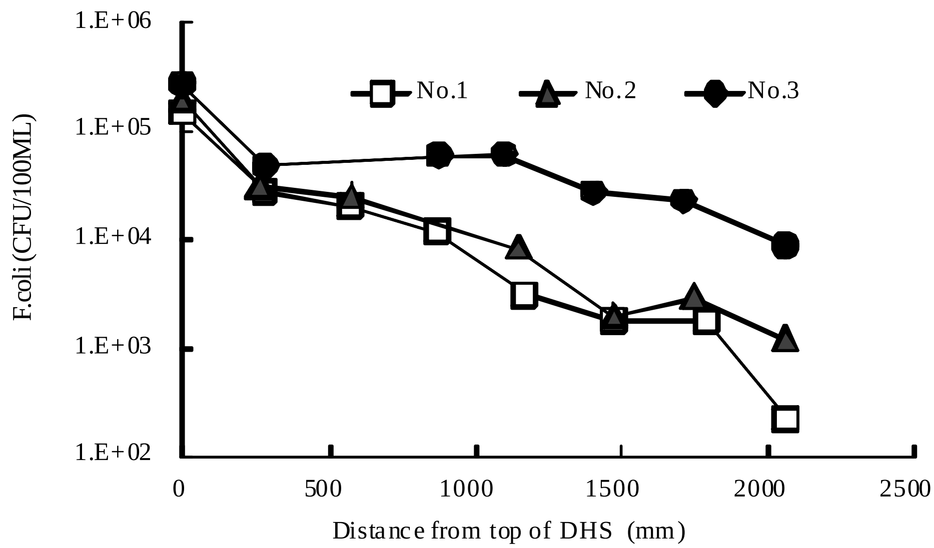
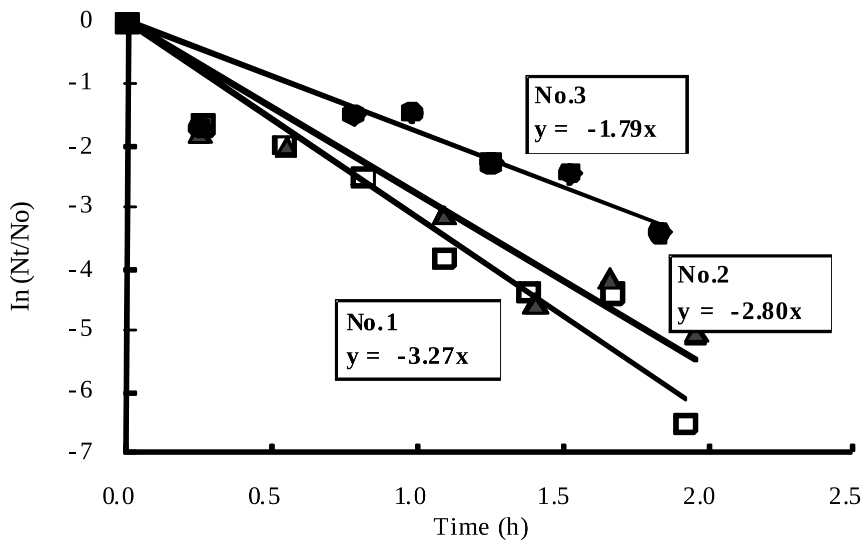


Fig. 4. F. coli profiles in the DHS reactors



No: F. coli concentration at time 0. *Nt*: F. coli concentration at time t.

Fig. 5. First order decimating constants (*k*) for F. coli in the DHS reactors

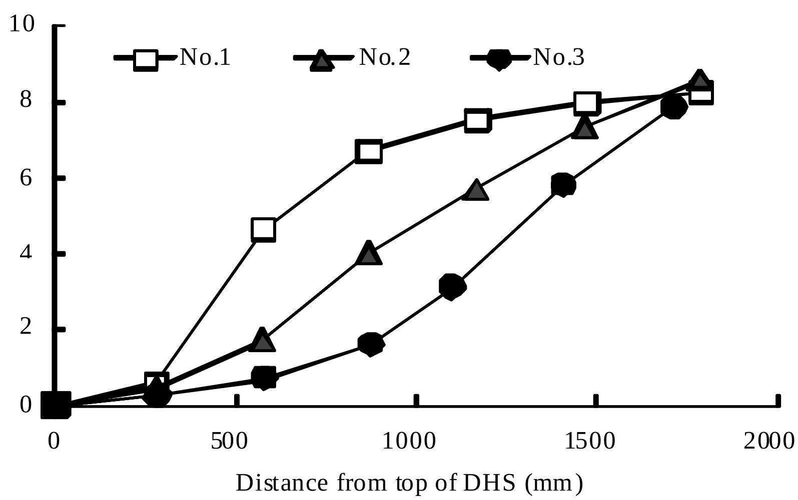


Fig. 6. Profile of DO in each reactor

Table 2. Summary of tracer experiment

Sponge condition	Reactor No.	Theoretical HRT (min)	Actual HRT (min)	Difference (%)
Clean	No.1	121 (100%)	82.9 (68.5%)	31.5
	No.2	-	-	-
	No.3	119 (100%)	79.1 (66.5%)	33.5
With biomass	No.1	113 (100%)	100 (88.2%)	11.8
	No.2	112 (100%)	101 (90.4%)	9.6
	No.3	117 (100%)	93 (79.7%)	20.3

-: not determined

This study showed that the smaller the sponge media sizes of the DHS reactors are, the better the removal efficiencies of COD, ammonium nitrogen, and F. coli. This phenomenon could occur for the following reasons:
1) Smaller sponge media allows better oxygen uptake in the stream flowing down through the reactors.
2) With smaller sponge media, contact between the sludge and the wastewater is better.

Furthermore, the amounts of sludge, measured in terms of volatile suspended solids (VSS), taken from the reactors after the end of the continuous experiment were in the following order: reactor No. 1 (18.7 g-VSS/L) > reactor No. 2 (16.6 g-VSS/L) >reactor No. 3 (16.4 g-VSS/L), indicating that as the size of the DHS sponge media decreases, the amount of retained sludge increases. This might also be due to the reasons given above and contribute the better performance of the DHS reactors with the smaller sponge media.

The difference of actual HRTs between the smallest (reactor No. 1) and the biggest (reactor No. 3) sponge media was only 10% and there was no significant difference between reactor No. 1 and reactor No. 2 (comparison of actual HRT of the sponges with biomass). On the other hand, the DO concentrations in the reactors were highest in reactor No. 1 and lowest in reactor No. 3. The DO concentration in reactor No.1 in the vicinity of 870 mm of height was particularly notable, being 1.7 times as high as that of reactor No. 2 and 4.2 times as high as that of reactor No. 3 (Fig. 6). Therefore, the removal efficiencies might appear to be affected more by DO concentration than the difference of HRTs.

The actual HRT of the sponges with accumulated biomass is closer to the theoretical HRT than that of the new, clean sponges (Machdar *et al*., 2000; Tandukar *et al*., 2006; Tawfik *et al*., 2006). The hydrophobicity of new sponges is high, so they resist water, resulting in actual HRTs for new sponges that are much shorter than the theoretical HRT. It is reasonable to think that biomass gradually spreads and extends uniformly towards inside of the sponge media during the operational period, making the whole sponge media hydrophilic. This could explain why the sponges with biomass had actual HRTs close to the theoretical HRTs. At present, it is difficult to ascribe effects on death rate of F. coli to DO concentration. Tawfik *et al*. (2006) described the mechanism of F. coli reduction by DHS processing in a previous study, in which they posited that adsorption of F. coli onto the retained sludge followed by predation by protozoa played the most important role in F. coli removal. More study is needed on the relationship between protozoan microfauna and DO in the DHS stream.

CONCLUSION

In this study, three identical DHS reactors employing different sizes of sponge media with the same total sponge volume were used for the direct treatment of settled sewage. All three DHS reactors performed satisfactorily in removal of COD, ammonium nitrogen, and F. coli at a fixed hydraulic retention time of 2.0 h based on the sponge volume. This study showed that the smaller the sponge media sizes of the DHS reactors are, the better the removal efficiencies for all the parameters above. The most reasonable explanation for this might be as follows;
1) Smaller sponge media allows better oxygen uptake in the stream flowing down through the reactors.
2) With smaller sponge media, contact between the sludge and the wastewater is better.
It was suggested that the removal efficiencies might appear to be affected more by DO concentration than the difference of HRTs.

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REFERENCES

APHA, (2005). Standard Methods for the Examination of Water and Wastewater. 21th eds., (New York, USA: American Public Health Association).

Machdar, I., Sekiguchi, Y., Sumino, H., Ohashi, A. and Harada, H. (2000). Combination of a UASB reactor and a curtain type DHS (Downflow Hanging Sponge) reactor as a cost effective sewage treatment system for developing countries. Water Science and Technology, **42**, 83-88.

Okubo, T., Harada, H., Onodera, T., Uemura, S., Yamaguchi, T. and Ohashi, A. (2008). Development of a novel sewage treatment technology with minimum energy requirement - performance of organic matters removal by practical-scale DHS reactor-, J. Environmental Systems Engineering G, **64**, 187-195. (in Japanese).

Sato, N. Okubo, T. Onodera, T. Ohashi A. and Harada, H. (2006). Prospects for a self-sustainable sewage treatment system: a case study on full-scale UASB system in India's Yamuna River basin. Journal of Environmental Management, **80**, 98-207.

Tandukar, M., Machdar, I., Uemura, S., Ohashi, A. and Harada, H. (2006). Potential of a combination of UASB and DHS (Downflow Hanging Sponge) reactors as a novel sewage treatment system for developing countries: a long-term evaluation. Journal of Environmental Engineering, ASCE, **132**, 166-172.

Tawfik, A., El-Gohary, F., Ohashi, A. and Harada, H. (2006). The influence of physical-chemical and biological factors on the removal of faecal coliform through down-flow hanging sponge (DHS) system treating UASB reactor effluent. Water Research. **40**, 1877-1883.

Uemura, S. and Harada, H. (2010). Application of UASB technology for sewage treatment with a novel post treatment process, (In Herbert H.P. Fang (Eds.) Environmental Anaerobic Technology, Applications and New Developments (pp.91-112). London, UK: Imperial College Press).

Uemura, S. Takahashi, K. Takaishi, A. Machdar, I. Ohashi A. and Harada, H. (2002). Removal of indigenous coliphages and fecal coliforms by a novel sewage treatment system consisting of UASB and DHS units. Water Science and Technology, **46**, 303-309.

Uemura, S., Suzuki, S., Abe, K., Yamaguchi, T., Ohashi A. and Harada, H. (2010). Removal of organic substances and ammonium oxidation by a down-flow hanging sponge (DHS) reactor under high salinity conditions. Bioresource Technology, **101**, 5180-5185.

Van Haandel, A. C. and Lettinga, G. (1994). Anaerobic Sewage Treatment; a Practical Guide for Regions with Hot Climate. (Chichester, UK: John Willey and Sons).

WHO, (1989). Health guidelines for the use of wastewater in agriculture and aquaculture, Report of a WHO scientific group. (Geneva, Switzerland: WHO press).

Yamaguchi, T., Yamazaki, S., Uemura, S., Tseng, I. C., Ohashi A. and Harada, H. (2001). Microbial-ecological significance of sulfide precipitation within anaerobic granular sludge revealed by micro-electrodes study, Water Research, **35**, 3411-3417.