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Effects of Upflow Liquid Velocity on Performance of Expanded Granular Sludge Bed (EGSB) System

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***Abstract*—**The effects of upflow liquid velocity (ULV) on performance of expanded granular sludge bed (EGSB) system were investigated. The EGSB reactor, made from galvanized steel pipe 0.10 m diameter and 5 m height, had been used to treat piggery wastewater, after passing through acidification tank. It consisted of 39.3 l working volume in reaction zone and 122 l working volume in sedimentation zone, at the upper part. The reactor was seeded with anaerobically digested sludge and operated at the ULVs of 4, 8, 12 and 16 m/h, consecutively, corresponding to organic loading rates of 9.6 – 13.0 kg COD/ (m^3·d). The average COD concentrations in the influent were 9,601 – 13,050 mg/l. The COD removal was not significantly different, i.e. 93.0% - 94.0%, except at ULV 12 m/h where SS in the influent was exceptionally high so that VSS washout had occurred, leading to low COD removal. The FCOD and VFA concentrations in the effluent of all experiments were not much different, indicating the same range of treatment performance. The biogas production decreased at higher ULV and ULV of 4 m/h is suggested as design criterion for EGSB system.

***Keywords*—**Expanded granular sludge bed system, piggery wastewater, upflow liquid velocity

I. Introduction

ANAEROBIC digestion (AD) of wastewater can concurrently remove organic matter as well as produce biogas which is the renewable energy. The application of AD as pretreatment step for high chemical oxygen demand (COD) wastewater, preferably higher than 2,000 mg/l, is economically suitable while higher COD also results in higher biogas production [1]. In Thailand, piggery wastewater is increasingly treated by AD technology such as upflow anaerobic sludge blanket (UASB) system, anaerobic pond, channel (plug flow) digester and anaerobic covered lagoon. The biogas is generally used for on-farm electricity generation via induction motor. UASB system is the high-rate wastewater treatment process where wastewater is fed at the bottom and flows upward, passing through layers of anaerobic bacteria with upflow liquid velocity (ULV) 0.5 – 1.5 m/h. The bottom layer, referred to as sludge bed, consists of granules with high suspended solids (SS) concentration (~1-5 %) while the upper layer, referred to as sludge blanket, consists of flocculent sludge (SS ~ 0.3-0.5 %). The granule has very high settling velocity as well as treatment efficiency since it consists of layers of bacteria, responsible for various anaerobic digestion steps [2]. The biogas produced is separated by gas-solids separator (GSS) installed at the upper part of reactor while sedimentation zone, above GSS, help SS removal as well as return it back to reactor. The reactions occur under enclosed part and smell is minimal. To improve the efficiency of UASB system, high ULVs (5 -15 m/h) were applied by effluent recycling and resulted in sludge bed expansion throughout the reactor's height. The high total biomass allowed the improved system, called expanded granular sludge bed (EGSB) system, to accommodate higher organic loading rate (OLR) than UASB system [3]. Since EGSB system is recommended for low SS wastewater, the application on piggery wastewater which has high SS should be firstly verified by laboratory experiment. Moreover, high ULV results in high pumping cost which should be minimized. The objective of this study was to determine the effects of ULV on performance of EGSB system as well as to determine the suitable ULV for piggery wastewater treatment.

II. Material And Methods

The laboratory scale EGSB reactor, made from galvanized steel pipe 0.10 m diameter and 5 m height with digestion volume of 39.3 l, was used. The upper part of reactor was sedimentation zone, made from steel plate 0.5 m diameter, 0.6 m height with 0.10 m freeboard and working volume of 122 l (Fig. 1). The biogas was measured by gas meter, i.e. revolving boxes with counter. There were 17 sampling ports along reactor's height at 0.3 m spacing. The major sampling ports were at 0.4, 1.9, 3.4 and 4.6 m – height. The piggery wastewater was biweekly collected from 2 pig farms, firstly Kittiwat Farm and secondly Chomthong Farm. The wastewater was stored in 0 - 4 ^oC storage room prior to using. It was daily prepared in 70-l plastic tank equipped with mechanical mixer (EYELA model MDC-MS). The wastewater was pumped by a peristaltic pump (Watson Marlow model 505s) to the complete-mix acidification tank, operated at 8-h hydraulic retention time (HRT). The acidification tank was made from plastic water tank, 0.25 m diameter, 0.30 m height and working volume of 12.8 l. The complete-mix condition was maintained by a circulating pump, submersible type (8.5 watts). There was no seeding in acidification reactor. The acidification tank effluent was pumped to EGSB reactor at the rate of 1.6 l/h with expected OLR of 10 kg COD/ (m^3·d). The EGSB effluent was stored in a 70-l plastic tank and was recycled by a peristaltic pump (Watson Marlow model 505s) to control ULV at 4, 8, 12 and 16 m/h, consecutively. The EGSB reactor was seeded with anaerobically digested sludge from Chiang Mai University wastewater treatment plant at 25,000 mg VSS/l. During start up period, OLR and ULV were stepwise increased to the target values. The water samples were taken 2 times/week and analyzed according to Standard

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Methods [4]. The experiments had been conducted under ambient temperature, tropical climate at the Department of Environmental Engineering, CMU, Thailand, during May 2003 to May 2004.

a) EGSB system b) Biogas meter

Fig. 1 Experimental set-up

III. Results And Discussion

The piggery wastewater was firstly collected from Kittiwat Farm. During the last period of run 1, this farm which was medium- sized sometimes did not have uniform wastewater flow rate so a bigger farm, Chomthong Farm, was chosen throughout the study. The wastewater characteristics had high fluctuations of COD and SS and the acidification tank helped stabilizing the wastewater concentrations. The performance of acidification tank was rather poor, i.e. COD removal 0 – 5%, VSS removal 2.2 – 27.6%. There was no pH adjustment in acidification tank. The influent pH was in neutral range, 6.8 -8.0, while the effluent pH was slightly decreased, 6.8 -7.8. The effluent VFA from acidification were not significantly increased and sometimes slightly decreased, indicating methanogenesis in reactor. It is expected that bacterial enrichment from pig feces plays an important role in VFA degradation. The effluent of acidification tank was further fed to EGSB reactor, initially at OLR 2 kg COD/ (m^3·d) and ULV 0.5 m/h. The OLRs were stepwise increased to 10 kg COD/ (m^3·d) at ULV 4 m/h. It took about 3 months to start up the EGSB system before the study period. The system was then operated at various durations as follows; run 1 (ULV 4 m/h) 165 d, run 2 (ULV 8 m/h) 76 d, run 3 (ULV 12 m/h) 56 d, run 4 (ULV 16 m/h) 77 d, consecutively. It was found that the influent COD and SS concentrations varied, causing effluent value fluctuations in run 3. During the study, there was no biomass withdrawal from the reactor, except via effluent. The results of COD and SS variations throughout the study are shown in Fig. 2 and 3, respectively.

In run 1, the EGSB influent characteristics had average values as follows; COD 9,601 mg/l, Filtered COD (FCOD) 1,514 mg/l, VFA 1,083 mg/l as acetic acid, SS 1,829 mg/l, VSS 1,530 mg/l. In run 2- 4, the average values are as follows; COD 11,355- 13,050 mg/l, Filtered COD (FCOD) 1,720 -2,300 mg/l, VFA 784 - 1,360 mg/l as acetic acid, SS 2,930 - 6,590 mg/l, VSS 1,390 - 4,310 mg/l. The EGSB influent had low FCOD:COD ratios, i.e. 0.15 – 0.18, and high VSS:SS ratios, i.e. 0.47 – 0.87. These indicated that high proportion of organics was in suspended form which was biologically degradable. In run 3, the influent SS was exceptionally high, causing biomass flushing from EGSB reactor. The peak effluent COD was found to be 8,460 mg/l on the 284th day of study period while FCOD did not increase (Fig. 2). The biomass eventually adapted to high ULV and resumed to normal operating condition during the later period of run 3. The steady-state condition in run 3 therefore could not be concluded. Although the OLR in all runs was expected to be uniform at 10 kg COD/ (m^3·d), the fluctuations in influent COD concentrations resulted in actual OLRs of 9.6-13.0 kg COD/ (m^3·d). The overall performance of EGSB at various ULV is summarized in Table I.

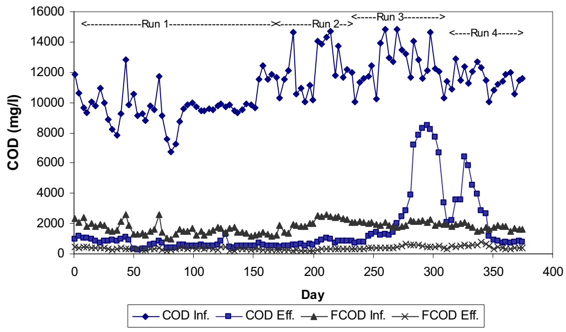

Fig. 2 COD variations

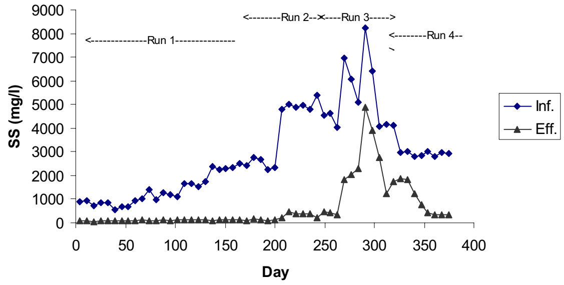

Fig. 3 SS variations

The performance of EGSB system in terms of COD removal was in the same ranges (93.0 – 94.0%), except in run 3 where effluent suspended biomass (VSS) caused poor COD removal (38.1%). The VFA and FCOD in the effluent, i.e. 94-162 mg/l as acetic acid and 330- 512 mg/l, respectively, were not much different, indicating the relatively stable performance. However, heavy biomass flushing in run 3 showed the higher effluent SS concentrations, as presented in Table I, with 45.0% removal. Once the influent SS decreased and the system adjusted to the applied ULV, the EGSB system resumed to normal operating condition. In run 4 where ULV 16 m/h was applied, the SS removal was found to be 88.0%. It is suggested that EGSB system should be operated at influent SS concentration less than 5,000 mg/l, if high COD and SS removal (>80%) is needed. The periodic SS withdrawal from

TABLE 1
AVERAGE PERFORMANCE OF EGSB SYSTEM(1)

Item/Parameter	Run			
	1	2	3(2)	4
ULV, m/h	4	8	12	16
OLR, kg COD/(m^3·d)	9.6	12.5	13.0	11.6
Temp. - Inf., ºC - Eff., ºC	25.0 25.1	22.9 22.3	24.9 26.3	28.4 28.7
pH range -Inf. - Eff.	7.0-7.8 7.5-8.2	6.8-8.2 7.8-8.3	7.1-7.4 8.0-8.3	7.3-7.4 8.0-8.2
COD -Inf., mg/l - Eff., mg/l - Rem., %	9,601 576 94.0	12,470 840 93.3	13,050 8,003 38.1	11,355 794 93.0
FCOD-Inf.,mg/l - Eff.,mg/l	1,514 347	2,300 330	2,170 512	1,720 368
SS -Inf., mg/l - Eff., mg/l - Rem., %	1,829 119 94.8	4,970 348 93.0	6,590 3,690 45.0	2,930 354 88.0
VSS -Inf., mg/l - Eff., mg/l	1,530 77	4,310 283	4,290 2,420	1,390 232
VFA -Inf., mg/l - Eff., mg/l - Rem., %	1,083 153 85.5	1,360 141 88.6	1,270 162 87.2	784 94 87.1
Biogas measured, l/d	13.3	8.5	3.8	2.1
CH_4 in biogas, % by vol.	76.2	78.1	71.4	67.4

Remark : (1) Average values during steady-state conditions
(2) Average values during 284th – 298th day of study period

reactor is also recommended if low SS in the effluent is required. Based on FCOD, there was no significant difference in system performance in terms of organic matter removal at ULV 4 – 16 m/h. The biogas measured had proportionally decreased with increasing ULV. It is expected that biogas volatilization, from excessive dissolving capacity in recycle tank, may be responsible in high effluent recycling condition. The methane (CH_4) composition also slightly decreased at higher ULV along with biogas production. The other major gas compositions were nitrogen (17.5 - 27.2%) and carbon dioxide (3.4 - 3.8%). The carbon dioxide content was relatively low as compared to normal UASB reactors [1, 5]. Based on biogas production and recycling cost of effluent, ULV 4 m/h is suggested as design criterion. There was no pH adjustment in EGSB reactor and the system pH, 7.5-8.3, were slightly higher than optimum range for anaerobic process, i.e. 6.5-7.5 [6]. The influent VFA: alkalinity ratios were 0.37-0.54. The average total phosphorus (TP), NH_4-N and TKN concentrations in the influent of 4 runs were 21.1-65.2, 113 – 181 and 551 – 634 mg/l, respectively. The COD:N:P ratios in the influent of 4 run were 600:29.4:1.2 – 600:33.6:4.2 which were sufficient as compared to the suggested ratio 600:7:1, indicting enough macro nutrients for bacterial cell synthesis [7]. The advantage of EGSB system over UASB system is higher biomass accumulation since higher ULV will expand the sludge bed layer upward through the reactor's height [3]. The vertical solids profile confirmed this assumption, where high concentrations of SS (> 1%) were found along the reactor, as shown in Fig. 4. This solids profile pattern was different from UASB reactor [5], and similar to other EGSB study [8]. However, very high SS concentration (>5%) were found at the bottom layer.

The solids distribution and total biomass throughout the study are summarized in Table II.

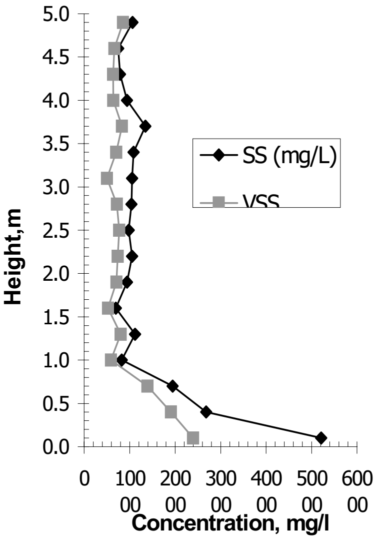

Fig.4 Vertical solids profile of EGSB reactor (run 1, 150th day)

TABLE II
BIOMASS IN EGSB REACTOR

Run	1		2		3		4	
ULV, m/h	4		8		12		16	
Month/year	5/03	10/03	11/03	12/03	1/04	3/04	4/04	5/04
Ave. SS, %	2.0	1.4	1.9	1.5	1.6	2.0	2.0	1.7
Ave. VSS, %	1.3	0.9	1.0	1.0	1.0	1.2	1.2	0.9
Total Biomass, kgVSS	0.79	0.55	0.75	0.59	0.63	0.79	0.79	0.67

Remark :Data at the beginning and the end of each run

According to Table II, the total biomass did not much differ during the study period. The water samples at the reactor's height of 0.4, 1.9, 3.4 and 4.6 m were periodically taken. It was found that COD, FCOD and VFA decreased vertically from the bottom to the top of reactor, according to reactions occurred during upflowing. The granules were measured by microscope. The average granule sizes at 0.4 m from bottom were highest (0.33-0.50 mm) while at 3.4 – 4.6 m were smaller (0.17-0.20 mm). The EGSB granules were much smaller than UASB granules and the flocculent sludge did not present in EGSB reactor as compared to UASB reactor [5]. The high ULV obviously flushed out the floc and low density sludge. The EGSB granule appeared to be round shape and more uniformly distributed than UASB granules [5]. During the study, the scale of struvite ($MgNH_4PO_4.6H_2O$, Magnesium Ammonium Phosphate) was found in recycle tubes. The piggery wastewater is favorable for struvite precipitation due to high magnesium, ammonia and phosphorus, as observed in other study. Periodically cleaning of recycling facility is also required.

IV. Conclusion

Based on the results obtained, the following conclusions can be drawn. The performance in terms of organic matter removal of EGSB system at ULV 4 to 16 m/h is not significantly different. The influent SS concentration should be less than 5,000 mg/l to prevent solids wash out. The high ULV results in lower biogas production and ULV 4 m/h is suggested as suitable design criterion.

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