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Media configuration and recirculation of upflow anaerobic floating filter for piggery wastewater treatment

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Abstract−An upflow anaerobic floating filter media (UAFF) reactor was applied to the treatment of synthetic and real piggery wastewater. The effect of media configuration and internal recirculation on the system performance was studied. In the first experiment, three-UAFF reactors filled with different media, i.e., polypropylene beads, sponge cubes and coconut fiber were continuously fed with synthetic wastewater at upflow velocity of 0.04 m h^{-1}. The COD removal efficiency in the reactor filled with sponge cubes was highest at 90%, whereas the others filled with polypropylene beads and coconut fibers with lower specific surface area were about 80%. In the second experiment, three-UAFF reactors with sponge were applied to treat real piggery wastewater. COD removal efficiencies were found to be about 80% and methane production rate of 0.26 $l\ l_r^{-1} d^{-1}$. The system performance could be slightly improved by 10% when applying internal recirculation. A sludge blanket (60-70% of total biomass) plays an important role in the system when applied to the treatment of piggery wastewater containing high suspended solid concentration.

Key words: Anaerobic Filter, Floating Media, Media Configuration, Upflow Anaerobic Floating Filter Media Reactor

INTRODUCTION

Advancement in anaerobic treatment technology has led to the development of various kinds of processes, for example, upflow and downflow anaerobic fixed bed reactors, fluidized or expanded bed reactors and upflow anaerobic sludge blanket (UASB) reactors. These processes have the ability to retain active biomass in the reactors and solid retention time (SRT) is generally much longer than hydraulic detention time (HRT). The anaerobic fixed bed reactor has been used in numerous applications for both high and low strength wastewaters [1,2]. Many studies have been devoted to upgrading the anaerobic fixed bed reactor process, mainly to overcome the clogging problem of filter bed and to improve their treatment performance. UASB has also been extensively applied in the past few decades due to its process advantages which include less clogging, especially when applied to high solid containing wastewater, but the formation of a good granular sludge bed is difficult for some specific wastewater. An upflow anaerobic floating filter media (UAFF) reactor process, a modification of UASB that combines the process between a fixed bed filter and UASB process system in the use of packing media at the top of the reactor in order to provide better solids capture in the system and prevent the loss of large amounts of solids due to process upsets or change in the sludge blanket characteristics and density [3,4].

The aim of this study was to identify the appropriate type of floating filter media for the UAFF system and to find the effect of internal recirculation to the system performance. The experimental studies were divided into two parts; in the first experiment an UAFF reactor process was applied for the treatment of synthetic wastewater in order to identify the appropriate media configuration in the system. Subsequent experiment was conducted using real piggery wastewater to investigate the effect of media and internal recirculation on the system performance. The biomass grown in the system was studied by using microscopic observation and dry weight measurement.

MATERIALS AND METHODS

Three laboratory scale UAFF reactors made of acrylic pipe with an inner diameter of 0.125 m and 1.0 m height with working capacity of 11.04 *l* were used in the first experiment to determine the performance of the system with different media configurations. Three different floating media, polypropylene beads, sponge cubes and coconut fibers, were selected based on their physical properties (shape, specific surface area, specific gravity, surface roughness), availability as local material and cost. Each material of 0.40 m depth was installed at the upper part of the reactor No. 1, No. 2 and No. 3, respectively. The physical properties of THE floating filter media are presented in Table 1. The most effective floating filter media obtained from the first experiment was then used as supporting media in the second experiment treating real piggery wastewater. Influent was continuously fed with upflow velocity of 0.04 m/h by peristaltic pumps to control HRT at 24 hours under ambient temperature operation (22-28 °C). In the second experiment, four UAFF reactors were set up to determine the effect of media and internal recirculation on

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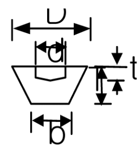
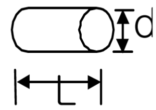
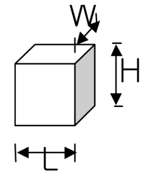
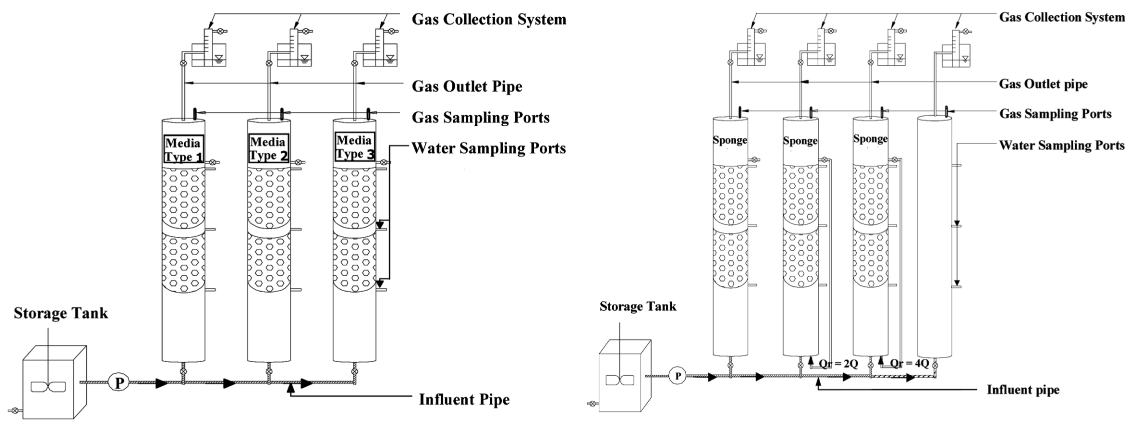
Table 1. Physical characteristics of floating media

Media type	Polypropylene bead	Coconut fiber	Sponge cube
Shape			
Diameter, D/d/b (cm)	0.40/0.234/0.252	0.035	-
Thickness, T/t (cm)	0.311/0.11	-	-
Width, W (cm)	-	-	1.5
Length, L/Height. H (cm)	-	2.5	1.5
Specific surface area (m^2 m^{-3})	897	977	2417
Packing density (kg m^{-3})	1141	67	104
Porosity (%)	79.4	89.3	96.2
Packing weight (g)	1298	39.5	21.8



(a) (b)

Fig. 1. Schematic diagram of the first experimental set-up (a) and the second experimental set-up (b).

the system performance. The first reactor without media was used as the control experiment. The second reactor with sponge cubes was operated without internal recirculation, whereas the third and fourth reactors with sponge cubes were operated at internal recirculation rate of 2 : 1 and 4 : 1, respectively. The reactors were initially operated at HRT of 24 hours and the HRT was subsequently reduced to 12 hours. A schematic diagram of the system is shown in Fig. 1.

In order to demonstrate actual treatment activities of biomass attached on the floating filter media in UAFF reactors, synthetic wastewater containing soluble and easily biodegradable organic substances, i.e., glucose as main carbon sources, were used (Table 2). Other major components were acetic acid, albumin (egg) and nutrients. The stock solution was mixed with tap water to meet desirable COD concentration at about 1,000 mg l^{-1} and COD : N : P ratio of 100 : 1.1 : 0.2. In the second experiment, screened piggery wastewater containing COD concentration of about 5,000 mg l^{-1} equivalent to an organic loading rate of about 5.3 kg of COD m_r^{-3} d^{-1} was used. The chemical characteristics of synthetic wastewater and screened piggery wastewater are shown in Table 3. Pig manure collected from a farm in Thailand was used as seed for all reactors. It was diluted with tap water at a ratio of 1 : 1 (by weight) and passed through 1.0 mm screen. The reactors were filled at 30% of their volume before the start-up of operation as suggested in previous research [5].

Table 2. Composition of stock solution of synthetic wastewater

Chemicals	Concentration
Glucose ($C_6H_{12}O_6$)	935 g l^{-1}
NH_4Cl	15 g l^{-1}
KH_2PO_4	3 g l^{-1}
K_2HPO_4	3 g l^{-1}
Acetic acid (CH_3COOH)	1.725 g l^{-1}
Albumin (egg)	125 g l^{-1}
$NaHCO_3$	1,220 g l^{-1}

The system performance was studied by determination of influent and effluent characteristics in terms of pH, BOD_5, COD, TDS, TSS, NH_3-N, TKN, TP, alkalinity, and VFA. Biomass was determined as total dry weight and microscopic observation of methanogenic bacteria at the end of the experiment. The chemical analysis was carried out according to Standard Methods for Examination of

Table 3. Chemical characteristics of synthetic wastewater and screened piggery wastewater

Parameters	Synthetic wastewater		Screened piggery wastewater	
	Range	Average	Range	Average
pH	6.48-7.70	7.03	6.52-7.31	6.94
COD (mg l^{-1})	905-1,160	1,088	787-7,923	4,043.2
SCOD (mg l^{-1})	468-660	555	280-1,358	894.4
BOD_5 (mg l^{-1})	345-690	501	475-1,245	870
Total VFA (mg l^{-1})	318.2-929.8	602.4	0-2,083	446.5
Alkalinity (mg l^{-1})	900-1,100	967	1,100-3,500	1,689
TSS (mg l^{-1})	125-250	217	978-17,780	3,384
TDS (mg l^{-1})	2,320-3,300	2,746	978-6,047	6,047
TKN (mg l^{-1})	6.3-11.2	9	344-3,438	826
NH_3-N (mg l^{-1})	4.2-6.3	5	210-2,520	572
TP (mg l^{-1})	10.2-14.75	12	972-3,245	1,541

Water and Wastewater [6]. Gas production was daily recorded and the composition was occasionally determined by gas chromatography (Shimadzu GC-14A). At the end of the experiment, a mass balance on the system was determined on a COD basis. The biomass produced in the reactor was taken out at the end of the experiment and analyzed for dried weight. It was also subjected to microscopic observation by using gram stain method. The slide samples were photographed by a microscope (OLYMPUS BH2-RCFA).

RESULTS AND DISCUSSION

1. Performance of UAFF with Different Media Treating Synthetic Wastewater

In the first experiment, lab-scale UAFF reactors were operated for 86 days. Fig. 2 shows the performance of UAFF reactors in terms of COD and SCOD removal. Influent COD concentration was maintained at approximately 1,000 mg l^{-1}, equivalent to an organic loading rate (OLR) of 1.087 kg COD m_r^{-3} d^{-1}. The effluent COD from all three reactors fluctuated between 300 to 700 mg l^{-1} in the first two weeks and maintained around 600 mg l^{-1} for another 40 days in which COD removal was found to be about 40%. Slowly improved performance during initial period corresponded to a latency phase where the attachment of biomass took place followed by the recovery of biological activities. Poor adhesion of biomass and low biomass content may limit the removal of organic matters in this period. It was stated that the establishment of the first bacterial layer was important and surface of the support material, i.e., pores and crevices where bacteria can first adhere played an important role in this process [7,8]. Thus, sponge cube media with high amount of pores and specific surface area needed a shorter start-up period as compared to polypropylene beads and coconut fibers less surface

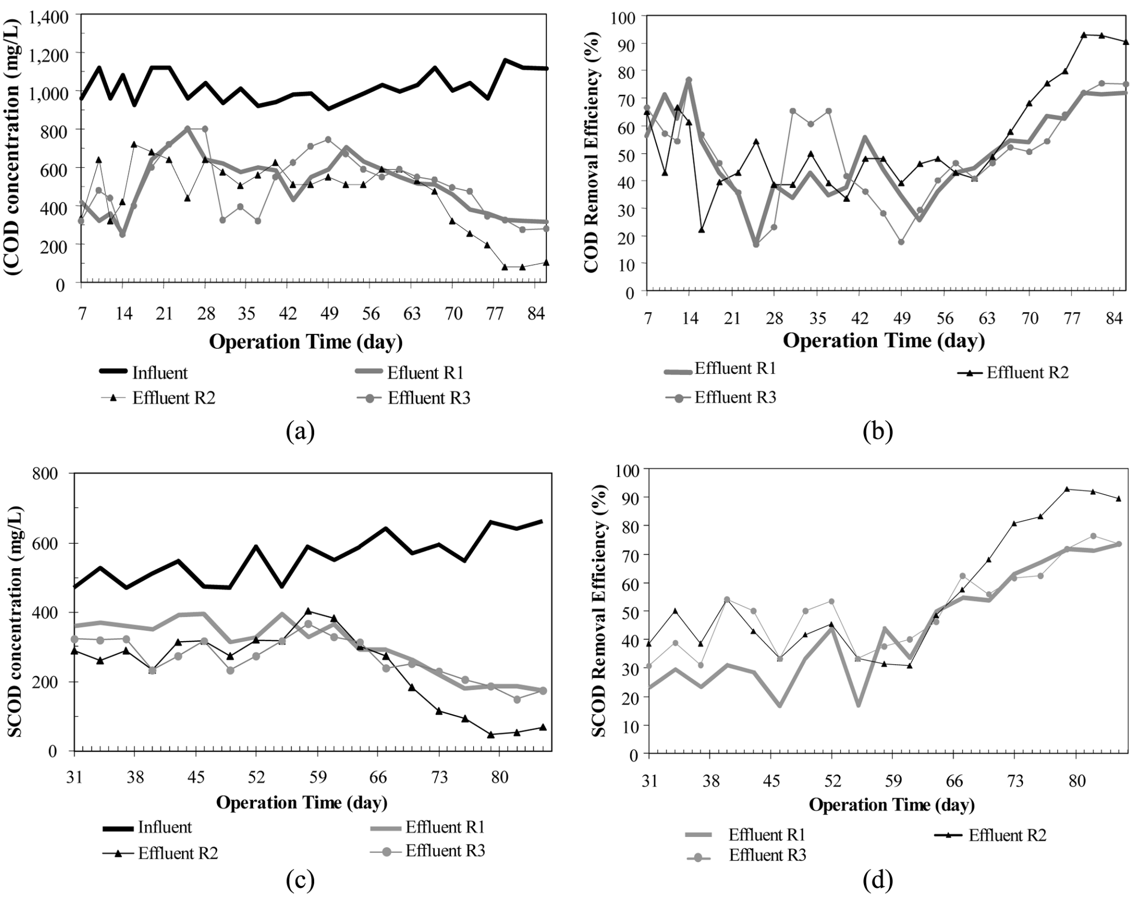


Fig. 2. Performance of UAFF reactors with different media (R1, R2, R3) in terms of (a) Influent and effluent COD concentration (b) COD removal efficiencies (c) Influent and effluent SCOD concentration (d) SCOD removal efficiencies.

area. The surface roughness of media also benefits biomass attachment. During the initial period (day 0-15), the COD removal efficiencies of the reactors decreased from 70% to 20% when albumin started being added as a mixture of synthetic wastewater at day 15. Afterwards, it could be recovered to about 40% within a two week period.

After about 60 days of operation, COD removal efficiencies in the reactors gradually improved to 70-90%. As a result, effluent COD concentrations of 100-300 mg l^{-1} were obtained. It was mentioned that the majority of effluent COD from anaerobic treatment system originated from soluble microbial products (SMP) by the system itself and required further post-treatment [9-12]. Comparatively, a reactor filled with polypropylene beads (R1) and sponge cubes (R2) had better performance in terms of COD removal than that with coconut fiber (R3) during the initial period (day 0-30). The SCOD removal efficiencies of R1 and R2 were approximately 40% compared with 20% in R3. As the operation terminated on day 86, SCOD removal efficiency of R2 improved to 90%, considerably higher than 70-80% of R1 and R3.

BOD_5 concentration was analyzed after 30 days of operation as shown in Fig. 3(a). It was found that influent BOD_5 varied mostly between 400-600 mg l^{-1}. BOD_5 in the effluent of R1 and R3 initially increased from 200 to almost 400 mg l^{-1} during day 36-50 due to an increasing of organic loading from feed wastewater but gradually declined to about 200 mg l^{-1} at the end of the experiment. As a result, the BOD_5 removal efficiencies were about 40% in average and increased to 70% as detailed in Fig. 3(b). In case of R2, BOD removal efficiencies were found better as they were about 50% during days 36-50 and improved to 80% at the end of the experiment (day 86). Biogas production rate during the initial operation from day 0-28 was found to be less than 0.050 l d^{-1} in all three reactors. After 28 days, gas production rate as well as COD conversion efficiencies increased significantly. As shown in Fig. 4(a) and (b), R2 containing sponge cubes as floating filter media had highest gas production rate starting from 0.09 to 0.32 l l_r^{-1} d^{-1} after the biofilm was fully developed within the system. In R1 and R3, biogas production gradually increased from day 28 to 0.3 l l_r^{-1} d^{-1} at the end of the experiment as the biofilm slowly accumulated at the surface of floating filter media.

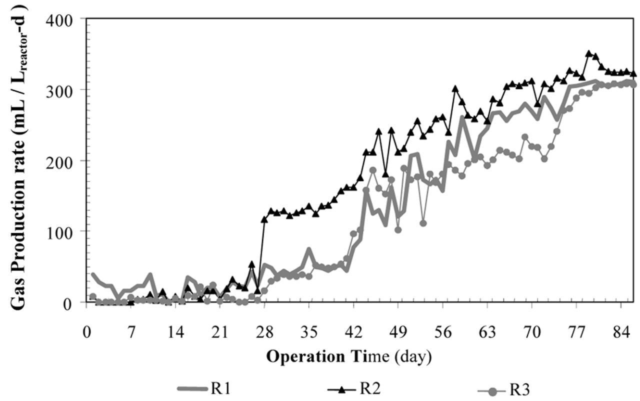


Fig. 4. Biogas production rates in UAFF reactors.

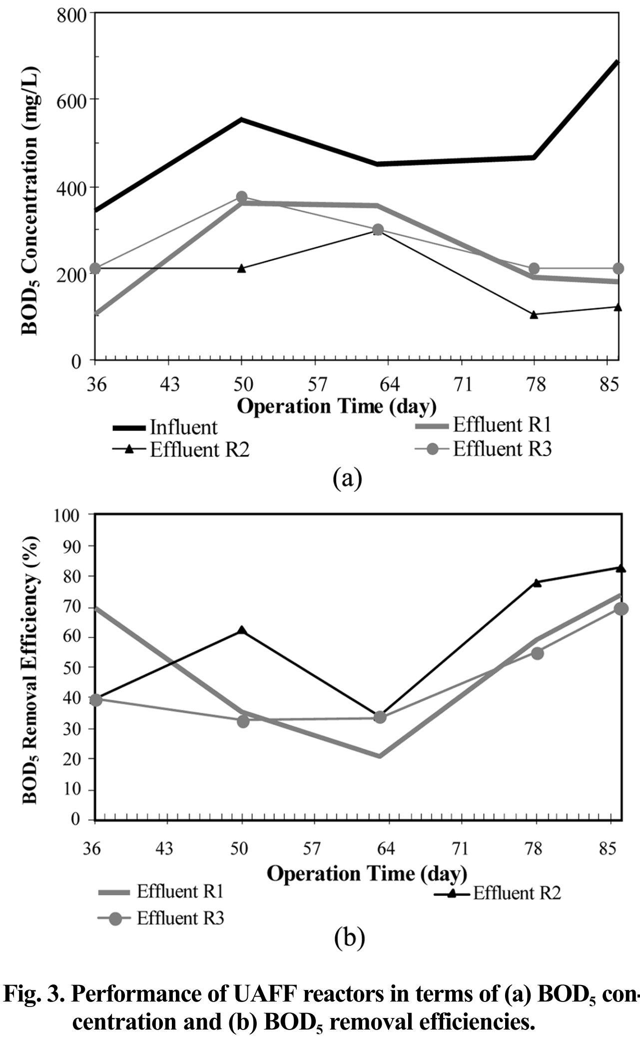


Fig. 3. Performance of UAFF reactors in terms of (a) BOD_5 concentration and (b) BOD_5 removal efficiencies.

Biogas composition was occasionally analyzed during the experimental period. Major composition was found to be methane at a content of about 60%. As shown in Fig. 4(b), methane production rate in R2 was higher than other floating media and increased from 0.05 to about 0.2 l l_r^{-1} d^{-1} at the end of the experiment. Based on the results of COD removal efficiencies and biogas production rate, it was clear that sponge cube was the best floating media for the UAFF system. This could be the beneficial effect of media roughness that provided better biomass attachment and larger surface area available for microbial growth. Based on biogas production and COD removal efficiency, it was noted that the system could be acclimatized in 30 days of operation. According to the reports, the reactors seeded with granulated sludge could give high treatment performance within a few start-up days [13-15]. The required start-up period using pig manure was 40-60 days at 20-25 °C [16].

2. Performance of UAFF Treating Real Piggery Wastewater

The effects of media, internal recirculation and HRT were examined in the UAFF system treating real piggery wastewater. UAFF reactors containing sponge cubes at the upper part of reactor were used. Reactor 2 (R2) was operated without internal recirculation rate, while Reactors 3 and 4 (R3 and R4) were subjected to internal recirculation rate (Q_r : Q) of 2 : 1 and 4 : 1, respectively. Their performance was compared with the control reactor (R1) without media. The reactors were fed with piggery wastewater contained influent COD of about 5,000 mg l^{-1} at 24 h HRT. As shown in Fig. 5, similar

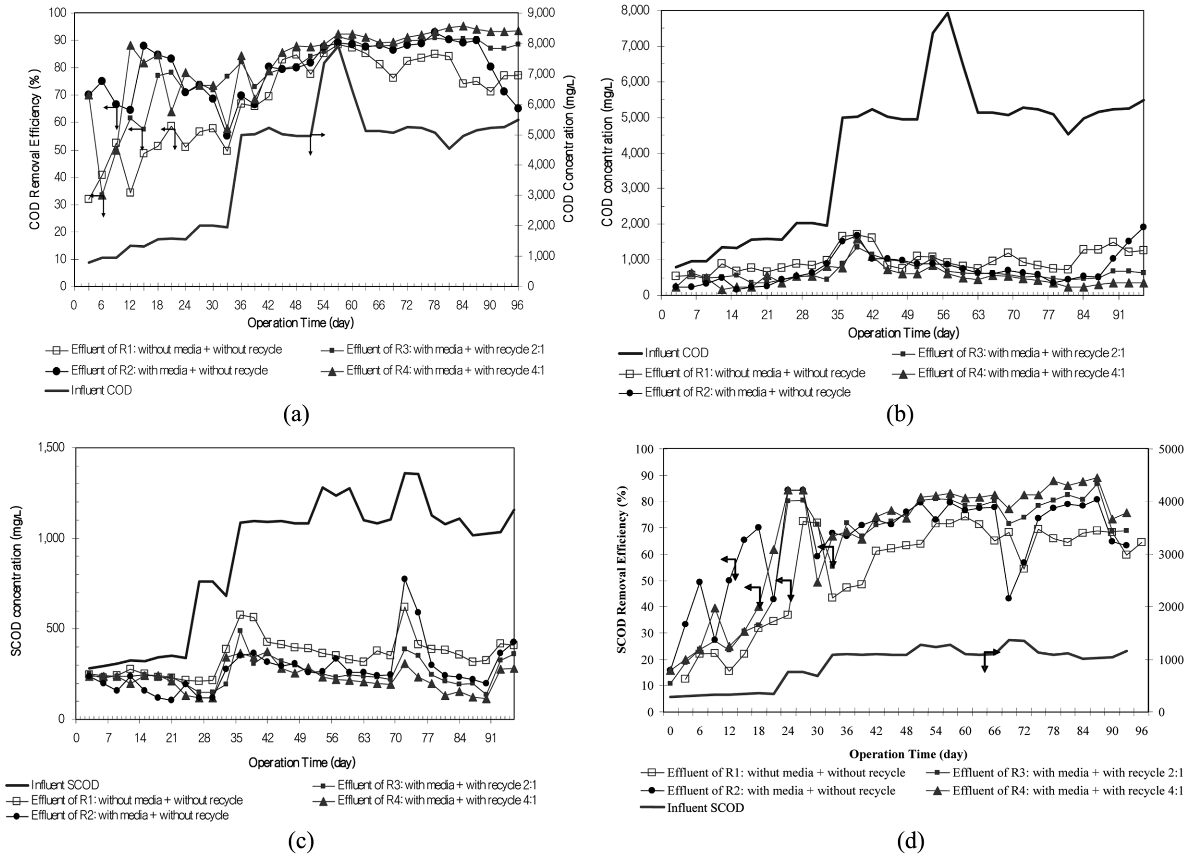


Fig. 5. Performance of UAFF reactors treating piggery wastewater in terms of (a) COD concentration, (b) COD removal efficiencies, (c) SCOD concentration and (d) SCOD removal efficiencies.

trends of COD and SCOD reductions were observed in the reactors with media (R2, R3 and R4) during the first 30 days of operation. Effluent COD and SCOD concentration remained at 500 and 150-200 mg l^{-1}, respectively. Afterwards, the reactors started showing improvement in COD removal efficiencies. The application of internal recirculation (day 42) did not significantly affect the system as they could be recovered within a few days.

Beyond 30 days of operation, R1 without media had some of its biomass lost to the effluent. Nevertheless, SCOD removal rate of R2 was higher than R1 by only about 10%. This could be explained by the fact that not only biomass attached on the floating media but also sludge blanket formed at the bottom of the reactor played an important role in organic removal in the system. However, it was found that sponge cubes installed at the upper part of the reactor could prevent biomass loss from the system and improve the stability of organic removal efficiencies in the system. Comparing COD removal efficiencies and biogas production rate between R2 (without internal recirculation), R3 (with internal recirculation rate at 2 : 1) and R4 (with internal recirculation rate at 2 : 1), it was found that internal recirculation only slightly improved treatment the system performance at HRT of 24 h. COD and SCOD removal efficiencies of both R2 and R3 improved by only about 10 and 20%, respectively, after internal recirculation was being applied. Nevertheless, it was noticed that the system employing internal recirculation could maintain the biomass within the system much better than that without recirculation.

When the HRT was decreased to 12 h on day 72, there was a temporary drop in COD removal in the system, and effluent COD concentrations were found to be fluctuating between 200 and 1,000 mg/L. However, the system can be recovered within about 1 week. Again, R2 with media installed at the upper part of the reactor showed superior performance in terms of COD, SCOD, BOD_5, removal efficiencies as compared to R1 in this period due to the prevention of biomass loss from the system. The application of internal recirculation helped in maintaining COD removal efficiencies under this increased loading condition. Organic removal efficiencies in terms of COD SCOD and BOD_5 of R4 were better than R2 by about 10-20%. The enhancement of organic removal efficiencies in the reactor with internal recirculation could be due to the effect of improved hydraulic condition as substrate flux transfer into biofilm could be provided by increasing hydraulic turbulence within the system. Simultaneously, higher biomass retention was also observed in the reactor with internal recirculation. It was reported that biofilm density was found to correlate very closely with the self-immobilization strength of fixed bacteria, which was determined by the shear force imposed on the biofilm [17]. Therefore, it appeared that a certain shear force in the biofilm system was necessary in order to produce a compact and stable biofilm structure, i.e., higher shear force favored the formulation of a more smooth and dense biofilm. In addition, it was also suggested that the formulation granules could be enhanced through a purely physical aggregation resulting from the hydrodynamic stress applied to the anaerobic flocculant sludge

Table 4. Water qualities of influent and effluent from the UAFF reactors

Parameters	Influent		R1: w/o media+ recirculation		R2: w/ media+ w/o recirculation		R3: w/ media+ recirculation 2 : 1		R4: w/ media+ recirculation 4 : 1	
	Range	Average	Range	Average	Range	Average	Range	Average	Range	Average
pH	6.52-7.31	6.94	6.65-8.08	7.25	6.65-8.08	7.34	6.87-7.73	7.21	6.70-7.80	7.31
COD (mg l^{-1})	787-7,923	4,043.2	445-1,710	1,017.4	455-1,710	732.5	236-1,357	634.5	160-1,576	522.4
SCOD (mg l^{-1})	280-1,358	894.4	210-619	358.9	210-619	274.0	138-488	257.7	113-376	228.3
BOD_5 (mg l^{-1})	475-1,245	870	275-968	574.9	275-968	532.8	145-856	469.7	125-975	453.9
Total VFA (mg l^{-1})	0-2,083	446.5	0-103.3	116.5	0-337	75.18	0-1,077	383.66	0-472	127.24
Alkalinity (mg l^{-1})	1,100-3,500	1,689	900-2,100	1,435.5	900-2,300	1,573	980-3,400	1,718	1,020-2,750	1,666
TSS (mg l^{-1})	978-17,780	3,384	420-2,300	856.0	30-1,600	554	120-1,240	496	180-760	442
TDS (mg l^{-1})	978-6,047	6,047	450-10,340	3,320.5	250-6,320	2648	120-5,960	2921	180-8,720	3,003
TKN (mg l^{-1})	344-3,438	826	258-569	387.5	306-611	425	302-504	395	252-458	358
NH_3-N (mg l^{-1})	210-2,520	572	118-407	408.0	106-449	286	190-409	295	190-433	297
TP (mg l^{-1})	972-3,245	1,541	920-1,663	1,316.0	171-1,361	789	190-1,248	769	217-1,389	809

by increasing the liquid upflow velocity [18]. It was also shown that a high shear force promoted the formulation of high-density biofilm and granules [14].

Volumetric biogas production rate was in accordance with the COD removal efficiencies. During the initial period (day 1-30), volumetric biogas production rate of all reactors fluctuated between 0.02 to 0.15 $l\ l_r^{-1}\ d^{-1}$, corresponding to acclimatization and transition periods when COD loading was stepwise increased. The biogas production rates in R2 and R4 were higher than that in R1; meanwhile, the volumetric biogas production of R3 was found fluctuating. The biogas production in R3 and R4 was disturbed on day 42 when internal recirculation was applied; however, it could be recovered within few days. Volumetric biogas production R4 was significantly improved from 0.27 to 0.52 $l\ l_r^{-1}\ d^{-1}$ as the accumulation of biomass had taken place. R2 also showed high biogas production at about 0.51 $l\ l_r^{-1}\ d^{-1}$ as a result of organic loading increase, whereas volumetric biogas production of R3 was found to be about 0.20 $l\ l_r^{-1}\ d^{-1}$. To explain lower biogas production rate observed in R4, it was be found that gas collection chamber of R3 was leaking so some of the produced biogas had been released to the atmosphere. When the HRT was lowered to 12 h, volumetric biogas production rates increased in response to organic loading. Afterwards, the biogas production rate of R2 gradually decreased due to the loss of biomass into the effluent, whereas R3 and R4 could maintain constant biogas and methane production rate due to the beneficial effect provided by the media installed at the upper part of reactor which could maintain the biomass within the system.

Table 4 shows overall water qualities of influent and effluent from the UAFF system. It was found that total VFA concentrations varied in a similar pattern as SCOD. High organic acid concentration, as well as low specific biogas production rate associated with low methane content of 40-50%, was found during the initial period (days 1-15), which indicated that acidification took place in the reactor. The major VFA compounds found in the system were acetic acid, valeric acids and propionic acids, whereas isobutyric acids and butyric acids were subordinate components in this experiment. Average VFA concentrations in R2, R3 and R4 along this experiment were found to be 75.18, 383.66 and 127.24 mg l^{-1}, respectively. From these results, it can be concluded that internal recirculation employed in R2 and R3 could benefit the system by providing system stability against the inhibitors, i.e., VFA, NH_3-N concentration.

3. Mass Balance of COD in UAFF System

A mass balance of COD in the UAFF system is shown in Table 5. In the case of synthetic wastewater treatment, it was found that R2 filled with sponge cubes had the highest removal efficiency at about 54% of removal substrates (520.3 g COD), where the fraction converted to biomass accumulation in the system was 63 g COD (equivalent to 7.6% of g $COD_{removed}$); whereas R1 and R3 could remove about 50% of incoming substrates. A higher amount of biomass accumulation in the system was observed in R2 as compared to R1

Table 5. Mass balance of COD in UAFF system

Parameters	Synthetic wastewater			Real piggery wastewater			
	R1: w/ media	R2: w/ media	R3: w/ media	R1: w/o media+ recycle	R2: w/ media+ w/o recycle	R3: w/ media+ 2 : 1 recycle	R4: w/ media+ 4 : 1 recycle
Influent COD (g COD)	958.0	958.0	958.0	5,267.2	5,267.2	5,267.2	5,267.2
Effluent COD (g COD)	481.4	437.7	480.4	1,290.3	973.5	808.1	644.7
COD removed (g COD)	476.6	520.3	477.6	3,967.3	4,094.0	4,287.9	4,350.2
-Biomass at day 0 (g COD)	18.5	18.5	18.5	92.0	140.1	141.1	142.1
-Biomass at day 86 (g COD):	20.7	81.5	79.3	92.9	305.5	295.3	372.7
Accumulated biomass (gCOD)	2.2	63	60.8	0.9	165.4	154.2	230.6

Table 6. Biomass in UAFF system treating synthetic wastewater

Reactor	Biomass form	TS (g)	TVS (g)	Biomass/area (gTS/m^2)	Biomass/volume (gTS/m^3)
Reactor 1	- Attached Solids	16.84	9.98	8.25	7.40
	- Suspended Solids	14.89	6.62		
	- Sludge Blanket	2.97	0.87		
Reactor 2	- Attached Solids	78.57	60.03	77.42*	187.07
	- Suspended Solids	16.67	5.91		
	- Sludge Blanket	3.64	2.54		
Reactor 3	- Attached Solids	20.52	15.80	17.80	17.39
	- Suspended Solids	18.57	8.87		
	- Sludge Blanket	17.50	12.83		

Remark: * External surface area of sponge cube was used for the calculation.

and R3. In R2, sponge cube media could allow microorganisms to be entrapped and prevented the detachment of those which adhered to the surface [19-21]. R1 containing polypropylene beads became unstable and had low performance due to the combination of clogging and intense gas bubbles entrapped in the bed and clusters of growth-together beads leading to the accumulation of substrate at the bottom of bed reactor; whereas R3 had high biomass retention in media zone but the attachment of biomass on the media surface was poor and uneven. This suggested that the most appropriate floating filter media was sponge cube in this study.

In case of real piggery wastewater treatment, COD converted to biomass represented only a small fraction of COD removal. In R2, R3 and R4, sponge cube media provide better COD removal as compared to R1. The accumulation of biomass also took place in the reactor with media installation. From this COD balance, it can be clearly seen that the majority of removed COD was accounted for by organic matter being degraded through microbial activities in the system. Although substantial COD removal was also achieved in the system without media thanks to a sludge blanket formed at the bottom of the reactor, the difficulties exist in maintaining biomass within the system especially under low HRT condition [22-24]. The effect of internal recirculation on COD removal was also found. The mass balance of COD reveals that the provision of internal recirculation was beneficial to COD removal through microbial degradation as higher COD conversion was achieved in R3 and R4 as compared to R1 and R2, but the difference was only at about 10%.

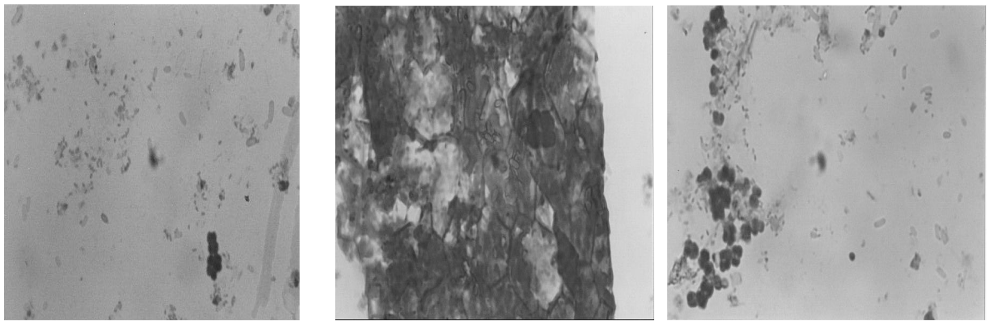
4. Determination of Biomass and its Characteristics in the UAFF System

The biomass contained in the UAFF reactor consisted of three main fractions: a sludge blanket at the bottom of reactor, suspended solids in the reactor, and attached biofilm on the floating media. The amount and activities of biomass, mixed culture between acid and methane forming bacteria, governed the performance of the UAFF system. During the operation period, biomass gradually accumulated from the bottom of floating filter toward the upper part. The amount of biomass accumulated in the system treating synthetic wastewater is shown in Table 6. The attached biomass per unit volume of filter media was determined as 7.40 g, 187.07 g and 17.39 g TS m^{-3} for R1, R2 and R3, respectively. It was found that the major fraction of biomass (36-79% TS) was attached to the floating filter as compared to suspended biomass or sludge blanket forms. Volatile solid content of attached biomass was 59-76%. The results suggested that sponge cube floating media could better promote the attachment and biomass growth in the system. This could be attributed to higher specific surface area and surface roughness of sponge cubes as compared to polypropylene beads and coconut fiber used in R1 and R3, respectively.

Table 7 shows the amount of accumulated biomass in the system treating real piggery wastewater. It was found that the accumulation of biomass in the sludge blanket was the largest fraction as compared to the attached and suspended biomass forms in all cases. In the UAFF reactor, the results indicated that the main fraction of biomass of about 65% of total biomass remained in sludge blanket, whereas 25.4% TS attached at the floating filter media. Volatile solid content of attached biomass was 63.27%. Even though, biological treatment activities took place in the sludge blanket; the installation of media helped in improving the system efficiencies. Bio-

Table 7. Biomass (expressed as gTVS) in UAFF system treating real piggery wastewater

Parameters	R1: w/o media+ recirculation		R2: w/ media+ w/o recirculation		R3: w/ media+ recirculation 2 : 1		R4: w/ media+ recirculation 4 : 1	
	HRT		HRT		HRT		HRT	
	24 h	12 h	24 h	12 h	24 h	12 h	24 h	12 h
Initial biomass at day 0	92.03	92.03	140.11	140.11	140.11	140.11	140.11	140.11
Biomass at day 86	173.14	173.14	207.17	207.17	148.53	148.53	218.54	218.54
- Attached biomass	-	-	42.30	42.30	31.46	31.46	50.94	50.94
- Suspended solid biomass	4.66	4.66	21.20	21.20	16.68	16.68	28.07	28.07
- Sludge blanket biomass	168.48	168.48	143.67	143.67	100.39	100.39	139.53	139.53



(a) (b)

Fig. 6. Microscope observation (×1,250) of microorganism of biomass in UAFF system treating synthetic (a) and real piggery (b) wastewater.

mass yield in the UAFF reactor with media installation was found in the range between 0.080-0.0144 and 0.151-0.197 g TVS $gCOD_{removed}^{-1}$ at HRT of 24 and 12 h, considerably lower than that in a reactor without media (0.221 and 0.315 $gCOD_{removed}^{-1}$). There was no clear relationship between total biomass and internal recirculation in the system.

A microscopic study of microorganisms in UAFF system was conducted at the end of the experiment. The morphologies of microorganisms observed from the microscopic observation of attached biomass on floating filter are shown in Fig. 6. The granules taken from sludge blanket had very small sizes, less than 1 mm, and they appeared mostly unshaped. The biomass taken from the suspended solid biomass, attached biomass and sludge blanket was identified by optical microscope; it was found that various types of bacterial agglomeration were observed. Filamentous cells were found covered by colonies of cocci and rod shaped microorganisms. Methanogenic bacteria in anaerobic systems were normally found to be curved rod and cocci shapes [25-27]. From these observations, it was suggested that the majority of them were bacteria of gram-negative type, red dyed which are likely to be classified as methanogenic bacteria. However, further investigation should be done for specifying actual species of these bacteria.

CONCLUSION

An upflow anaerobic floating filter media (UAFF) reactor was successfully applied to the treatment of synthetic and real piggery wastewater. The effect of media configuration and internal recirculation on the system performance was found. COD removal efficiency in the system was 90% when using sponge cubes as the floating media in the system. Highest gas production of about 0.32 $l\ l_r^{-1}\ d^{-1}$ was achieved. When the system was applied to the treatment of real piggery wastewater, COD removal efficiency of 80% was obtained at HRT of 24 h. At higher organic loading and shortened HRT of 12 h, COD removal efficiencies temporary dropped but recovered within few weeks. The application of internal recirculation improved the system performance by only 10%. However, higher biomass could be maintained in the system as compared to a reactor operated without internal recirculation. The results also demonstrated that the installation of media at the upper part of UAFF reactor was particularly helpful in maintaining attached and suspended biomass within the system. The majority of biomass in the system was attached biomass on the media (59-76%) when it was applied to the treatment of soluble synthetic wastewater. Nevertheless, the sludge blanket (60-70% of total biomass) played an important role in the system treating real piggery wastewater. From the microscopic observation, the majority of microorganisms in the system were gram-negative, methanogenic-like bacteria with rods and coccus shapes.

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REFERENCES

1. M. Henze and P. Harremoes, *Wat. Sci. Tech*., **15**, 1 (1983).
2. L. Shu, S. H. Lee and V. Jegatheesan, *Environ. Eng. Res*., **17**(2), 75 (2002).
3. S. H. Lee, J. C. Park and D. Brissonneau, *Environ. Eng. Res*., **8**(3), 107 (2003).
4. M. G. Lee and T. Hano, *Korean J. Chem. Eng*., **18**, 178 (2001).
5. M. S. Salkinoja-Salonen, E. J. Nyns, P. M. Sutton, L. van den Berg and E. D. Wheatley, *Wat. Sci. Tech*., **15**, 305 (1983).
6. APHA, *Standard methods for the examination of water and wastewater*, 20th Ed. American Public Health Association, Washington D.C. (1998).
7. P. Schiener, S. Nachaiyasit and D. C. Stuckey, *Environ. Technol*., **19**, 391 (1998).
8. J. H. Park and J. K. Park, *Korean J. Chem. Eng*., **20**, 83 (2003).
9. S. F. Aquino and D. C. Stuckey, *Wat. Sci. Tech*., **45**, 127 (2002).
10. D. J. Barker, G. A. Mannucchi, S. M. Salvi and D. C. Stuckey, *Wat. Res*., **33**, 2499 (1999).
11. W. C. Kuo, M. A. Sneve and G. F. Parkin, *Wat. Environ. Res*., **68**, 279 (1996).
12. D. R. Noguera, N. Araki and B. E. Rittmann, *Wat. Sci. Tech*., **30**, 339 (1994).
13. J. A. S. Goodwin, D. A. J. Wase and C. F. Forster, *Bioresource Technology*, **41**, 71 (1992).
14. M. C. M. van Loosdrecht, D. Eikelbloom, A. Gjaltema, A. Mulder,

L. Tijhuis and J. J. Heijnen, *Wat. Sci Tech*., **32**, 35 (1995).
15. J. A. Park, J. M. Hur, B. S. Son and J. H. Lee, *Korean J. Chem. Eng*., **18**, 486 (2001).
16. G. Zeeman, K. Sutter, T. Vens, M. Koster and A. Wellinger, *Biological Wastes*, **26**, 15 (1988).
17. M. J. Chen, Z. Zhang and T. R. Bott, *Biotech. Tech*., **12**, 875 (1998).
18. A. Noyola and G. Merino, *Biotechnol. Bioeng*., **44**, 1040 (1994).
19. J. Poels, P. Assche, P. Van and W. Verstraete, *Biotechnology Lett*., **6**, 747 (1984).
20. J. H. Tay, S. Jeyaseelan and K. Y. Show, *Wat. Sci. Tech*., **34**, 453 (1996).
21. J. W. Hudson, F. G. Pohland and D. Pendergrass., Proceeding of the 33rd Industrial Waste Conference, May 9, 10 and 11, 1978, Purdue University, West Lafayette, Indiana. Ann Arbor Science, Ann Arbor, Mich., 560-574 (1978).
22. K. V. Lo, P. H., Liao and Y. C. Gao, *Bioresources Technology*, **47**, 153 (1994).
23. T. A. Elmitwalli, M. H. Zandvoort, G. Zeeman, H. Bruning and G. Lettinga, *Wat. Sci. Tech*., **39**, 177 (1999).
24. V. Jegatheesan, S. H. Lee, C. Visvanathan, L. Shu and M. Marzella, *Environ. Eng. Res*., **4**(4), 283 (1999).
25. M. R. Domingues, J. C. Araujo, M. B. A. Varesche and R. F. Vazoller, *Wat. Sci. Tech*., **45**, 27 (2002).
26. D. R. Ranade and R. V. Garade, Microbiological Aspects of Anaerobic Digestion: Laboratory Manual, Maharashtra Association for the Cultivation of Science, Research Institute, India (1988).
27. W. K. Ng, V. R. Jegatheesan and S. H. Lee, *Korean J. Chem. Eng*., **23**, 333 (2006).