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Separation of organic matter from domestic sewage in a UASB-ABF system with anoxic bio-flocculation

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ABSTRACT

An anoxic sewage treatment process, an upflow anaerobic sludge blanket (UASB) followed by an aerated bio-filter (ABF), was investigated for the reduction of oxygen demand and the separation efficiency of the organic matter. After recycling the nitrified effluent, complete denitrification occurred in the UASB, with an enhancement in both turbidity characteristics and TCOD removal rates. Low turbidity and COD in the effluent of the UASB reduced the oxygen demand and improved the nitrification efficiency in the subsequent ABF. Both with and without the recycling of the nitrified effluent in the UASB, 95 and 63% of the TCOD values, respectively, were removed. Compared with a conventional activated sludge system, approximately 11.74% of the TCOD was converted to CO_2 in both the UASB and the ABF, generating an approximately 60% reduction in the amount of CO_2. After accumulation in the UASB, 84% of the influent TCOD could be sequestered for use as a marginal energy source in a subsequent anaerobic digester.

Keywords: Anoxic sewage treatment; Bio-flocculation; Separation of organic matter; CO_2 reduction

1. Introduction

The major objectives of sewage treatment have included improvements in public health, reductions in the oxygen demand after a discharge into streams, decreases in the eutrophication of natural bodies of water, and the removal of various synthetic organic chemicals. In the beginning of the twenty-first century, global warming concerns originating from greenhouse gases have become important issues worldwide, and the reduction of carbon dioxide from environmental utilities has emerged as another major objective.

As alternative approaches in the treatment of domestic wastewater, sequential anaerobic–aerobic processes have many advantages compared with conventional aerobic technologies, including reductions in energy consumption, excess sludge production, carbon dioxide generation, and operational complexity [1,2].

With multiple inherent advantages, anaerobic treatment processes can require additional aerobic treatments to comply with effluent standards. Anaerobic processes have been generally adopted for the

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pre-treatment of domestic sewage to reduce the organic load on subsequent aerobic processes. An upflow anaerobic sludge blanket (UASB) has been a popular anaerobic process used in sewage treatment at ambient temperatures. The hydraulic retention time (HRT) of the UASB typically ranges from 3 to 6 h with a wide range of TCOD removal efficiencies (34–94%), as reported by several researchers for various combinations of UASB and aerobic processes [1]. La Motta et al. [3] reported that only 34% of the TCOD was removed in a UASB reactor at ambient temperatures (15–30˚C) using a UASB-ASC (aerated solid contact) system. The low removal efficiencies of the TCOD in the UASB reactor may have resulted from the low HRT (1.5 h based on sludge bed volume), low temperatures, and the relatively low extracellular polymer production by the anaerobic sludge [4]. The production of methane gas with respect to the removed TCOD was reported to be approximately 0.1 L/gr-COD, a value that was far smaller than the theoretical value of 0.35 L/gr-COD at 25˚C. Elmitwalli et al. [5,6] reported that 63% of the TCOD was removed in a combined AF + AH (anaerobic filter (AF) + anaerobic hybrid (AH)) system, and 46% of the influent TCOD was converted into methane gas. The TN and TP removal efficiencies were approximately 43 and 20%, respectively, in the AF + AH + PTF (polyurethane form trickling filter) system.

The additional contributions of the UASB reactor to the TCOD removal amounts in an anaerobic–aerobic system can reduce both the aeration energy and sludge production in subsequent aerobic processes. Pontes et al. [7] demonstrated that a UASB reactor was able to remove TCOD amounts in excess of 93% by recycling the trickling filter sludge with an approximately 1% recycle ratio (compared with the influent flow rate). Jun et al. [8] reported a 95% removal rate in a UASB reactor by recycling the AF effluent using a 100% recycle ratio, suggesting that the recycling of the nitrified effluent of the AF may have enriched the heterotrophic microorganisms (denitrifiers) that improved the bio-flocculation of the particulate COD in the UASB reactor. The TN removal efficiency in this UASB-AF system was approximately 70% of the value determined for a similar system that was characterized with efficiencies that were comparable with other biological nutrient removal processes.

Even with the advantages of the anaerobic–aerobic system, the methane production efficiencies in the anaerobic process (UASB) can be enhanced with multiple improvements, and the nitrogen removal efficiencies should be increased to comply with local effluent standards. Anaerobic processes generally exhibit good performance at increased operating temperatures (above 35˚C), organic loading rates, and HRT values. With the successful separation and concentration of the organic matter in domestic sewage, methane gas was recovered efficiently using the optimized operating conditions in a separated anaerobic process. Using anoxic sludge bed reactors instead of anaerobic units in these anaerobic–aerobic systems could result in improved TCOD removal rates from domestic sewage with additional TN removal rates, as well [9]. The objectives of this research were to investigate the separation of TCOD from domestic sewage prior to contact with oxygen in the aerobic processes. An anoxic UASB (instead of an anaerobic reactor) was tested to determine the recovery efficiency of the influent TCOD using recycling of the nitrified effluent from an aerated bio-filter (ABF). CO_2 emissions from the UASB-ABF domestic sewage treatment process were also evaluated by an analysis of the COD balances throughout the process.

2. Methods

2.1. Experimental apparatus and operating conditions

A schematic diagram of the laboratory-scale experimental setup that consisted of a UASB and an ABF is shown in Fig. 1. The system design (a UASB followed by an ABF) incorporated two elements: (1) an effective contact of the small particles to enhance the gravitational settling in the UASB with effective

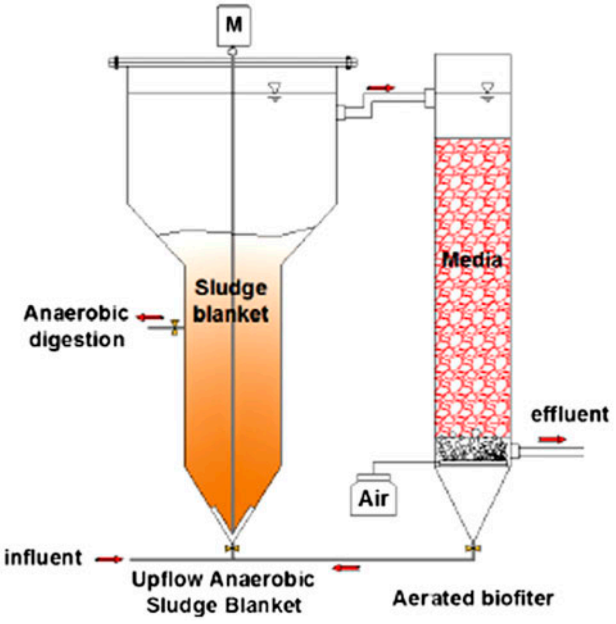

Fig. 1. Schematic diagram of the UASB-ABF system.

denitrification and (2) an efficient aerobic process for the ammonia nitrogen to increase the nitrification efficiency in the ABF. For an effective denitrification process, the influent sewage and the recycled flow from the ABF effluent were fed to the bottom of the UASB, with gentle agitation to prevent both sludge rising and channeling effects. The functions of UASB in this study are not to convert the influent TCOD into methane gas but to separate it as the raw sludge from the influent sewage by enhancing bio-flocculation through efficient contact of the small particles. To enhance the suspended solids removal, the cross-sectional area of the upper UASB was designed to be fivefold wider than the dimensions of the lower UASB to prevent the small particles from carrying over and to concentrate the sludge bed in the lower part of the UASB. The thickened sludge was withdrawn periodically from the middle of the UASB to maintain the level of the sludge bed, and the total mass (the dry base weight and the TCOD) of the wasted sludge was measured for the COD balance analysis. The ABF was packed with porous media (stainless steel ring, specific surface area of 114 m^2/m^3, and porosity of 94%) to ensure the effective inoculation at high concentrations of the nitrifying microorganisms. The effluent of the UASB was fed to the top of the ABF, flowing downward through this unit. A portion of the treated final effluent was recycled to the UASB with settled sludge that was detached from the media. The remaining portion was held in a reservoir for further analysis.

The detailed specifications and operating conditions of both the UASB and the ABF are shown in Table 1. The hydraulic residence times of both the UASB and the ABF were 3 h, based upon the influent flow rate. Three recycle ratios (0, 120, and 180%) were considered in this study, and the percentage of each recycle ratio was determined based on the amount of recycled effluent from ABF compared to the amount of the influent (Fig. 1). Three recycle ratios (0, 120, and 180%) were used to determine the effectiveness of the recycle process on the removal of the organic matter and the TN in the UASB. The DO levels were held at values of approximately 8.0–9.0 mg/L in the ABF by a diffused aeration process, and the operating temperature was maintained at approximately 20 ± 3℃.

Table 1
Specifications and operating conditions of the UASB and the ABF

Parameters	UASB	Aerated bio-FILTER (ABF)
Flow rate (mL/min)	25	25
Volume (L)	4.5	4.5
HRT (h)	3	3
Recycle ratio (%)	0, 120, 180	
DO (mg/L)	0–0.2	8.0–9.0
Temperature (℃)	20 ± 3	

2.2. Characteristics of the influent sewage

The characteristics of the influent sewage sampled from the local domestic sewage treatment plant are shown in Table 2. COD and NO_3^- were analyzed as described by Standard methods 5220 D and 4500-NO_3^-B, respectively [10]. The total COD(Cr) ranged between 320 and 450 mg/L (average 380 mg/L). The total nitrogen and the ammonia nitrogen were 35 and 23 mg/L, respectively, with the resultant TCOD/TN ratio of approximately 11. The pH and alkalinity values were 7.3 and 140 mg/L (as $CaCO_3$), respectively.

2.3. Fractionation of the influent COD

In sewage treatment, organic matter can generally be divided into 3 categories: readily biodegradable COD (rbCOD); slowly biodegradable COD (sbCOD); and hardly non-biodegradable COD (nbCOD). As the size of the organic particles is significantly related to the biodegradability of the materials in sewage, a serial filtration method with various size membrane filters were used to analyze the particle size distributions, as one of the physical methods of COD fractionation [11]. The particle size distribution was done by a particle counter (PAMAS, Germany). Biological methods such as oxygen uptake rate (OUR) and nitrogen uptake rate (NUR) were known to be time-consuming as well as tedious and with relative simplicity and short analytical times; the serial filtration method generally offers several advantages over biological methods [12].

Table 2
Characteristics of the influent sewage

Parameters	Range	Average
pH	6.8–7.8	7.3
$TCOD_{Cr}$ (mg/L)	320–450	380
TS (mg/L)	320–480	380
T-N (mg/L)	25–44	35
NH_4^+-N (mg/L)	20–28	23
NO_3^--N (mg/L)	0–0.2	0.1
NO_2^--N (mg/L)	0	0
Turbidity (NTU)	100–520	250
Alk. (as $CaCO_3$)	80–180	140

In this study, two membrane filters (0.01 and 0.45 μm) were used for the fractionation of the influent COD (Table 3). The COD of the filtrate through the 0.01-μm membrane was classified as the soluble COD (SCOD). The COD between the 0.45-μm and 0.01-μm membrane filtrates was classified as the colloids COD (CCOD). The COD remaining on the 0.45-μm membrane was classified as the particulate COD (PCOD). The PCOD was assumed to be the sbCOD, and the SCOD was considered to be the rbCOD. The PCOD contained both the settleable COD (stCOD) and the non-settleable (suspended) COD. The stCOD was the settled PCOD occurring within 30 min in an imhoff cone. CCOD was also included in the PCOD.

3. Results and discussion

3.1. COD fractions in the raw sewage

The compositions of the COD in the raw sewage are shown in Table 4. The average TCOD, SCOD, and PCOD were approximately 380, 87, and 293 mg/L, respectively. Approximately 77% of the influent sewage was PCOD, with a SCOD value of 23%. Nominal particle sizes were defined to be less than 0.45 μm (SCOD + CCOD in Table 3), instead of the 0.01 μm value generally reported in the wastewater treatment field, with representative SCOD values at approximately 30% of the TCOD. Difficult to remove using physical methods, the SCOD (including the CCOD that was represented by rbCOD) was readily assimilated by the microorganisms in the activated sludge processes. The fraction of settleable COD (stCOD) was approximately 21%, as measured by the removal by simple settling within 30 min. The COD removal efficiency has been reported to be approximately 30%, using a typical primary sedimentation basin [11]. A part of the suspended COD (SSCOD) may have been removed with the stCOD in a primary sedimentation basin, possibly by flocculation and sedimentation with the extended hydraulic residence time.

Table 3
Serial filtration method and the fractionation of the COD

COD		Descriptions	Comments
TCOD		SCOD + PCOD	
SCOD		Filtrate through 0.01 μm	rbCOD
PCOD	CCOD	0.01 < Filtrate < 0.45 μm	
	SSCOD	0.45 μm < non-settled COD	sbCOD
	stCOD	30 min settled COD	

3.2. COD removal by sedimentation in UASB

Small particle flocculation can be accelerated by gentle agitation and the addition of polyelectrolytes. Figs. 2 and 3 show the TCOD and SCOD removal patterns in the UASB at the various recycle ratios of the nitrified effluent from the ABF. Without the recycle process, the TCOD from the UASB reached steady state in 20 d of operation after start-up. The steady state TCOD in the UASB effluent was approximately 140 mg/L, suggesting that the removed TCOD in the UASB was approximately 240 mg/L. As a result, 63% of the influent TCOD was removed in the UASB by simple flocculation and sedimentation. The fraction of PCOD excluding CCOD was approximately 70%, as shown in Table 4. Approximately 85% of this fraction was successfully removed in the UASB by directing the influent to the vessel bottom and by gently agitating the sludge blanket formed on the bottom of the UASB, suggesting that the PCOD removal could be improved with modifications in the flocculation and sedimentation conditions in a primary sedimentation basin. With an almost constant value of approximately 80 mg/L, the SCOD from the UASB exceeded 90% of the influent SCOD, suggesting that the SCOD was difficult to remove by physical flocculation and sedimentation processes, and the 3-h contact time of the SCOD with the sludge was not sufficient to ensure an anaerobic degradation in the UASB. The removal

Table 4
COD fractions in the raw sewage as measured by the serial filtration method

Parameters		Concentration (mg/L)		Percentage (%)	
Total COD (TCOD)		380		100	
Soluble COD (SCOD < 0.01 μm)		87		23	
Particulate COD (PCOD)	Colloids COD (CCOD < 0.45 μm)	293	27	77	7
	Settleable COD (stCOD)		80		21
	Suspended solids COD (SSCOD)		186		49

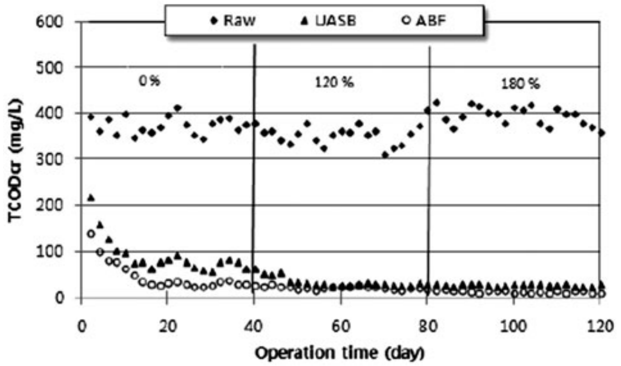

Fig. 2. TCOD removal patterns in the UASB at various recycle ratios.

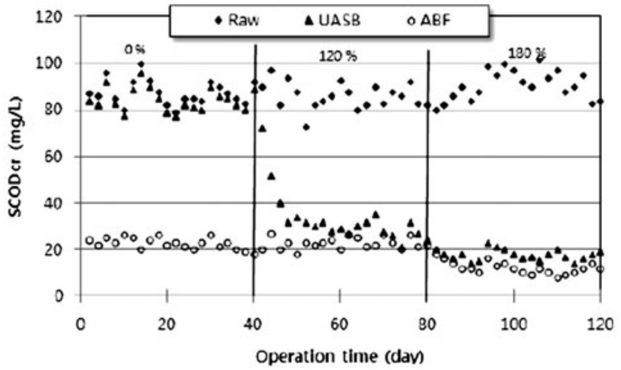

Fig. 3. SCOD removal patterns in the UASB at various recycle ratios.

efficiency of the CCOD was also below 26%, as shown in Table 5.

Park et al. [13] reported that 75% of an influent TCOD could be removed by chemical coagulation at pH 6.2 and at alum doses of 0.44 mM, as determined with Al measurements using the standard jar test methods that are typically used in water treatment plants. This report indicated that part of SCOD with sizes less than 0.45 μm might be removed by chemical coagulation, as the PCOD particles exceeding 0.45 μm were approximately 63% of the total. These results suggested that a significant portion of the PCOD including the CCOD could be removed by chemical coagulation, indicating that 77% of the influent TCOD could be also removed by sedimentation and bio-flocculation in this study.

3.3. COD removal by bio-flocculation in UASB

As the readily biodegradable portion of COD, SCOD may be preferentially processed by microorganisms in both aerobic and anaerobic environments. In this study, the UASB was operated anaerobically without a recycle process of the nitrified effluent during the first 40 d of operation. Subsequently, the reactor became an anoxic environment with the recycling of the nitrified effluent at a nitrate concentration of approximately 7 mg/L and a recycle ratio of 180%. With the growth of heterotrophic bacteria, such as denitrifying microorganisms, bio-flocculation of the influent particles may result from the microbial floc formed with the extracellular polymeric substances (EPS) that are a major component of the bio-aggregates holding the floc together [14].

The TCOD in the UASB effluent decreased rapidly with the recycling of the nitrified effluent from the ABF to the head of the UASB, as shown in Fig. 2. The removal efficiencies of the influent TCOD were determined to be 92 and 95% at recycle ratios of 120 and 180%, respectively. The nitrate recycled from the ABF was completely denitrified in the UASB. Along with the nitrate, the PCOD was also completely removed with the bio-flocculation by the denitrifying microorganisms. Jun et al. [8] demonstrated that the EPS extracted by a formaldehyde–NaOH method resulted in an increase of approximately 52% with a 120% recycle ratio of the nitrified effluent. As discussed in the report, the EPS may have promoted the bio-sorption and flocculation of the colloidal organic particles in

Table 5
COD removal at each recycle ratio in the UASB-ABF system (mg/L)

Parameters		Raw			UASB			ABF		
Recycle ratio (%)		0	120	180	000	120	180	0	120	180
TCOD		380	368	400	140	30.5	20	28	24.5	15.5
SCOD		87	85	92	79	28.5	17	22	22	10
PCOD	CCOD	27	25	28	20	2	3	6	2.5	5.5
	SSCOD	186	187	196	41	10	6	10	5	4
	stCOD	80	71	84	–	–	–	–	–	–

the UASB. At a recycle ratio of 180%, the removal efficiency of the colloid and organic particulates was increased to 99%, and the turbidity of the UASB effluent was less than 1.24 NTU. With the recycling of the nitrified effluent to the UASB, even small particulates were entrapped in the sludge blanket, producing clear effluent. The recycled nitrate changed the anaerobic UASB to anoxic conditions, activating denitrifying microorganisms. The newly grown heterotrophic biomass may facilitate the aggregation of the colloidal matter in the raw sewage, forming the sludge blanket in the UASB. These results suggest that the nitrate in the recycled effluent triggered the production of EPS, generating improved bio-flocculation of the colloidal particles within the sludge blanket.

Fig. 4 shows the particle size distribution in the raw sewage and in the effluent of the UASB at a recycle ratio of 180%. With a 180% recycle ratio of the nitrified effluent, particles exceeding 1 μm were completely removed, with over 95% of the 0.5–1.0 μm particles separated in the UASB. The nitrate recycled to the UASB increased the removal efficiency of both the PCOD and the particles by enhancing the bio-flocculation process and the growth of the denitrifying microorganisms. Bio-flocculation was determined to effectively remove the PCOD, with 90% of the CCOD removed in the UASB.

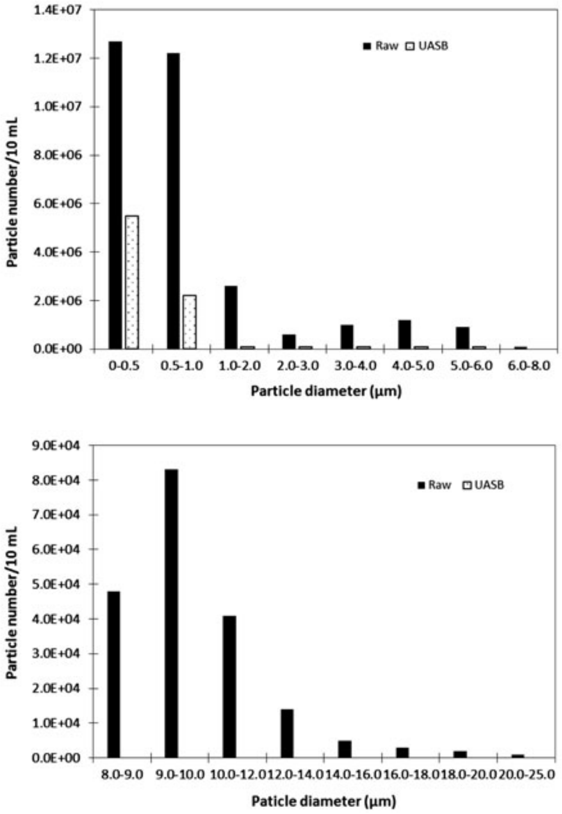

Fig. 4. Particle size distribution in the raw sewage and the UASB effluent at a recycle ratio of 180%.

3.4. COD removal by microbial assimilation in UASB

Denitrifying microorganisms use organic matter (COD) as both carbon and energy sources and reduce nitrate (as an electron acceptor) in denitrification reactions. The amount of COD required for the denitrification reactions can be calculated by the production of nitrate removed and 2.86 (oxygen equivalent of nitrate, g-O_2/g-NO_x^--N). With the nitrate in the ABF effluent at 7.0 mg/L and a recycle ratio of 180%, complete denitrification occurred in the UASB. The total removed nitrate (the same amount as the recycled nitrate) was approximately 0.45 gr/d, as shown in Table 6. The COD used for the denitrification reactions can be calculated with the following equation [11], generating a value of 1.61 gr/d with the assumption of $Y_n = 0.14$. This value was equivalent to 44.72 mg/L for the COD concentration in influent.

$$\mathrm{SCOD_{utilized}} = \frac{2.86 \times \mathrm{NO_S^-} - \mathrm{N}}{1 - 1.42Y_n} \tag{1}$$

At a recycle ratio of 180%, the removed SCOD in the UASB was approximately 1.60 gr/d, as shown in Table 6. From these results, the calculated SCOD used for the denitrification reactions was exactly the same as the value of the removed SCOD, as determined from the COD balance analysis of the UASB at a recycle ratio of 180%. These results suggest that portions of the SCOD may have been removed through denitrification by microbial assimilation as carbon sources in the UASB with the recycling of the nitrified effluent. The microbial growth in the anoxic environment may have also improved the PCOD removal in the UASB, as described previously.

3.5. COD balance for the UASB-ABF system

The removal of the COD occurred by sedimentation, bio-flocculation and heterotrophic assimilation in the UASB. The oxidative conditions of the UASB were controlled by recycling the nitrified effluent from the ABF. Without recycling, the UASB can become strictly anaerobic. Anoxic conditions can be generated in the UASB by recycling the nitrified effluent from the ABF. The results of the COD balance (in terms of gr-COD/d) analysis for recycle ratios of 0 and 180% are

Table 6
COD balance for the UASB at a recycle ratio of 180%, unit: gr/d

Items		TCOD	SCOD	$SCOD_{(removed)}$	$SCOD_{(utilized)}$	NO_x^--N
Input	Raw	14.40	3.31	3.31–1.71 = 1.60	1.61	–
	Recycle	1.00	0.65			0.45[b]
Output		2.02	1.71[a]			0.00
Removal (%)		85.97	48.34	–	–	100

[a] SCOD in output = 17.0 mg/L × (1 + 1.8) × 0.025 L/min × 60 min/h × 24 h/d × 10^{-3} = 1.71 g/d.

[b] Recycled NO_3^--N = 7.0 mg/L × 1.8 × 0.025 L/min × 60 min/h × 24 h/d × 10^{-3} = 0.45 g/d, NO_3^--N in ABF effluent: 7.0 mg/L.

summarized in Table 7. Theoretically methane production should not have been possible due to the operating temperature of these pilot plant systems (20℃); therefore, the amount of methane as well as CO_2 generated should be negligible [15]. Hence, the total biogas generated from UASB was not enough to measure in this test, the amount of CO_2 generation was calculated from the mass balance analysis across the UASB instead. Therefore, the CO_2 emissions were calculated from the results of the COD balance analysis for each reactor.

With strictly anaerobic conditions, the TCOD removal with the UASB was approximately 63.1%, with 60.7% recovered as waste sludge and 2.4% released as gas into the air. At a recycle ratio of 180%, the TCOD removal in the UASB was approximately 86%, with 84% recovered as waste sludge and 8.5% released as gas into the air. With this method, 84% of the influent TCOD could be separated periodically as excess sludge by a withdrawal process from the bottom of the UASB. With a 180% recycle ratio, a 23% improvement in the TCOD removal was possible in the UASB, possibly reducing the CO_2 emissions in the subsequent ABF by aerobic respiration. Therefore, lower CO_2 emission was expected from ABF system with 180% recycle ratio compared to 0% recycle ratio. With a recycle ratio of 180%, the gasified COD (CO_2) value in ABF was calculated to be 0.46 gr-COD/d. Without the recycling process, this value was approximately 1.71 gr-COD/d. Including the biomass, approximately 1.00 gr-COD/d was returned to the UASB with the nitrified effluent, excluding the discharged SS from the ABF. The aeration energy may also be saved for the amount of oxygen demand removed in the UASB before entering the ABF.

At a recycle ratio of 180% in the UASB-ABF system, more than 84% of the influent TCOD can be reserved as sludge that can be possibly converted to biogas in an anaerobic digester, as summarized in Fig. 5 and Table 8. With the recycling of the nitrified effluent, an approximately 21.3% reduction of the CO_2 was possible in the UASB and the ABF, as shown in Table 7. Additional CO_2 reductions could be expected by considering the aeration energy savings in the ABF.

The typical values that were suggested in Tchobanoglous et al. [11] were in the range between 25 and 40% removal of BOD from the primary clarifier (30% of removal was used in this study) and about 95% removal of BOD from activated sludge system. These typical suggested values were used to compare in this study.

The COD balances for both a representative activated sludge process with the assumptions of 30% removal of the influent TCOD [11] at a primary clarifier and the UASB-ABF system at recycle ratios of 0 and 180% are shown in Table 8. The remaining TCOD (approximately 70%) may have been used as carbon

Table 7
COD balances for the UASB and the ABF at recycle ratios of 0% and 180%, unit: gr/d

Parameters	Raw		UASB		ABF	
Recycle ratio (%)	0	180	0	180	0	180
TCOD	13.68	14.40	5.04	2.02	1.05	0.56
SCOD	3.13	3.31	2.84	1.72	0.79	0.36
PCOD	10.55	11.09	2.20	0.30	0.26	0.20
Waste sludge (TCOD)	–	–	8.31	12.15	–	1.00[a]
CO_2 (TCOD)	–	–	0.33	1.23	3.99	0.46

[a] TCOD load returned to the UASB with a 180% recycle ratio of the effluent.

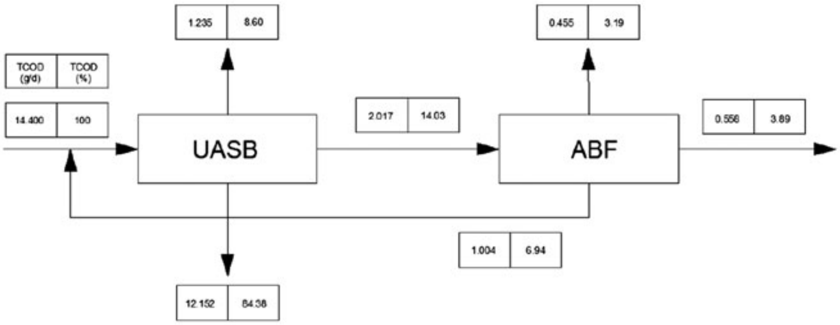

Fig. 5. COD balance for the UASB-ABF system with a 180% recycle ratio.

Table 8
COD balance for a conventional activated sludge system, unit: %, (gr-COD/d)

		Activated sludge			UASB-ABF	
Parameters	Raw	PC	AT	SC	0%	180%
TCOD	100 (14.4)	70 (10.1)	40 (5.8)	5 (0.7)	7.67 (1.05)	3.89 (0.56)
Sludge	–	30 (4.3)		35 (5.1)	60.75 (8.31)	84.38 (12.15)
CO_2	–	–	30 (4.3)		31.58 (4.32)	11.74 (1.69)

Note:AT: aeration tank, PC: primary clarifier, SC: secondary clarifier.

(approximately 40%) and energy (approximately 30%) sources in a subsequent aeration tank. In a further examination of the fate of the influent TCOD, 35% was converted to excess sludge in the secondary clarifier as a result of the aerobic assimilation consuming the dissolved oxygen supplied by the aeration process, and 5% was discharged into the final effluent [11]. The excess sludge was digested anaerobically after being mixed with the raw sludge generated from the primary clarifier. After being collected as sludge from the activated sludge process, 65% of the influent TCOD was subsequently converted into biogas in anaerobic digestion processes. The excess sludge can be difficult to biodegrade, requiring long hydraulic residence times to significantly digest the organic materials. The TCOD can be used as energy sources, with approximately 30% of the influent TCOD stripped to the air in the aeration tank as a result of the biochemical oxidation.

Compared with the amount of CO_2 production observed in conventional activated sludge processes, approximately 50 and 61% reductions were observed both without and with a recycling the nitrified effluent, respectively.

4. Conclusions

An UASB reactor was used to reduce the oxygen demand in a subsequent aerobic process and to separate organic matter directly from the influent raw sewage to produce valuable energy sources for further biogas recovery in an anaerobic digester. Unlike the typical anaerobic reactors, this UASB was designed to operate under anoxic conditions by recycling the nitrified effluent from the ABF to recover the influent TCOD effectively. The CO_2 emissions were also evaluated by an analysis of the COD balance for the UASB-ABF system both with and without the recycling of the nitrified effluent.

With a recycling of the nitrified effluent, complete denitrification occurred in the UASB with improvements in both the turbidity and the TCOD removal rates. The low turbidity and COD in the effluent of the UASB may have improved the nitrification efficiency in the subsequent aerobic filter. Both with and without the 180% recycle of the nitrified effluent, 95 and 63% of the influent TCOD were removed, respectively. Approximately 11.74% of the TCOD was converted to CO_2 in the UASB and the ABF with an approximately 60% reduction in the amount of CO_2 compared with a conventional activated sludge system. Accumulating in the UASB, 84% of influent TCOD could be sequestered as a marginal energy source for use in a subsequent anaerobic digester.

With the 180% recycle of the nitrified effluent, approximately 21% of the CO_2 reduction was observed in the UASB and the ABF with additional CO_2 reductions expected with the aeration energy savings in the subsequent ABF.

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