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*Research Article*

# Efficiency Enhancement of Up-flow Anaerobic Sludge Bed (UASB) by a Modified Three-phase Separation

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**Abstract.** The formation of microbial granules and reduction of microorganism losses at the outflow are important for optimal performances of Upflow Anaerobic Sludge Blanket systems (UASB). In a conventional UASB, continuous selection of sludge particles, generally created by upflow pattern, results in losses of light and dispersed sludge but maintenance of heavy sludge. The objective of this study was to investigate the performance of a 30 liter UASB with a modified three-phase separator giving a spiral flow pattern. A UASB with a conventional three-phase separator was also set-up and operated in parallel for performance comparison. Wastewater, with COD between 2,000-9,000 mg $l^{-1}$ and pH 5-6, was accommodated from a canned fruit factory. The initial seed for microbial granules with volatile suspending solid around 23.37 g $l^{-1}$ was from an anaerobic digester system. The UASB operation was started up under the atmospheric temperature with the hydraulic retention time (HRT) at 85 h, corresponding to an organic loading rate of 2 kg COD $m^{-3}d^{-1}$. The HRT was further reduced in a stepwise fashion, i.e. 85, 65, and 45 hours. After 100 days of operation, both reactors showed good performances in treating wastewaters from a canned fruit production factory. Based on the effluent data, the UASB reactor with the new three-phase separator showed better performances, i.e. 10-25% lower effluent COD, 7-10% higher COD percent removal, 11-15% lower biomass washout, 11-12% higher biogas production and 6-7% higher sludge retention time.

**Keywords:** UASB, Three-phase Separator, Wastewater, Anaerobic Treatment, Sludge Granule.

## Introduction

UASB processes enable the anaerobic degradation of organic matter and subsequent separation to occur in a single reactor. The wastewater was supplied from the bottom of the reactor and the organic matter digested as the wastewater moves up to the top [1]. Methane gas bubbles are produced, and move up to the top together with the upward effluent and light and dispersed sludge. A three-phase separator forms an essential part of a UASB in retaining as much viable sludge as possible. The configuration of a three-phase separator in a conventional UASB usually follows a guideline proposed by the inventors [2], and is commonly a gas cap with a settler situated above it. Below the opening of the gas cap, baffles are used to deflect gas to the gas cap opening [3], while the inclined walls of the settler to facilitate the return of solid particles.

Continuous selection of sludge particles in a UASB results in losses of light and dispersed sludge but maintenance of heavy components. Selection pressure is generally created by upflow pattern [4], and different upflow pattern can be achieved by different designs of the three-phase separator. For example, Bae and Shin (1998) [5] investigated the performance of an inner tube-type three-phase separator in treating synthetic wastewater with glucose as the carbon source, and found that the sludge hold-up efficiency of the separator gradually increased as the superficial gas production rate increased. When the superficial gas velocity increased to 0.67 m $h^{-1}$ at a volumetric loading rate of 11.8 kg COD $m^{-3}$ $d^{-1}$, they found the overall pattern of the UASB reactor was close to a completely stirred tank having no dead space.

In general, special design and construction of a three-phase separation system are performed only for certain cases such as very dilute wastewaters and wastewater containing proteins and fats [6]. Caixeta et al. (2002) [7] proposed a new three-phase separator for treating meat processing industry wastewater with floating fats. The separator was made up of three deflector plates attached to a central axle, alternately positioned to give a spiral movement. The three-phase separator in a 7.2-liter UASB reactor was efficient for the wastewater treatment when operated with organic loads in the range 2.7-10.8 kg COD $m^{-3}$ $d^{-1}$. Average COD removal efficiencies of 85%, 84%, and 80%, and of $BOD_5$ of around 95% were obtained with hydraulic retention time (HRT) of 22, 18 and 14 h, respectively. The sludge retention time of 21, 28 and 40 days for HRTs of 22, 18 and 14 h were achieved respectively.

Foreseeing that the spiral upflow pattern may also increase sludge hold-up efficiency and reactor performance in general, including the case of soluble non-complex wastewaters, we aimed to investigate the performance of a 30-liter UASB with the three-phase separator giving a spiral flow pattern in treating a fruit-processing industry wastewater and to compare its performance with a conventional UASB. The UASB performances were studied through analyses of chemical oxygen demand (COD) removal, washout of biomass, sludge retention time, biogas production rate, and granular size, distribution.

## Materials and Method

### *Wastewater feed*

The wastewater feed was from Malee Sampran factory (Nakonpathom, Thailand), a canned fruit production factory. The main components consisted of sugars and various fruit debris such as rambutan, lychee, pineapple, orange and guava. The wastewater was pretreated with static hydro-screening before being collected for the experiment. Due to the varying fruit supply, the wastewater composition varied with the COD between 2,000-9,000 mg $l^{-1}$ and pH between 5-7. The main characteristics of the wastewater are presented in Table 1.

### *Reactor system configuration*

The reactors with working volume of 30 liter were made of clear acrylic. Each reactor was in a cylindrical shape with 1.1 m in height and 20 cm in diameter. The first reactor had the new three-phase separation system, made up of five deflector plates attached to a central axel, alternately positioned 4 cm one from the other and inclined at $50^{o}$ (Fig.1). This configuration was designed for the flux to make a spiral movement [7], and the reactor was referred as 'unconventional UASB'. The second reactor had a conventional three-phase separator, whose configuration was of a conical-shape. Baffle was installed 2.8 cm under the separator aperture in the second reactor (Fig. 2). The latter UASB was referred as 'conventional UASB'.

**Table 1** Main characteristics of the wastewater from the canned fruit production factory used in this study

| Parameter | Minimum-maximum values |
|---|---|
| Chemical oxygen demand (COD, mg $l^{-1}$) | 2,000 – 9,000 |
| Volatile fatty acid (VFA, mg $l^{-1}$) | 196 - 692 |
| Total nitrogen (N, mg $l^{-1}$) | 15 - 22 |
| Total phosphorus (P, mg $l^{-1}$) | 12 - 25 |
| Suspended solid (SS, g $l^{-1}$) | 0.25-0.45 |
| Volatile suspended solid (VSS, g $l^{-1}$) | 0.2-0.4 |
| Turbidity (NTU) | 96-322 |
| pH | 5 - 7 |

### *Acclimatization, start-up, and operation*

The reactor was inoculated with sludge from an anaerobic reactor of Huaw-Kwang Domestic Waste Water Treatment Plant. The initial volatile solid concentration was 15 kg VSS $m^{-3}$. The acclimatization of the sludge was carried out in each reactor until COD percent removal was approximately 70-80 %, for approximately 2 months. After that, the wastewater was recirculated to the reactor everyday for a week, and the start-up period was followed by gradually flowing wastewater at HRT 85 h. (Organic loading rate, OLR = 2 kg COD $m^{-3}$ $d^{-1}$). After $COD_{removal}$ was constant again at 70-80 %, the HRT was further reduced in a stepwise fashion, i.e., 85, 65, and 45 hours in 100 days. The pH values of the wastewater were adjusted to 7.0 with the addition of NaOH.

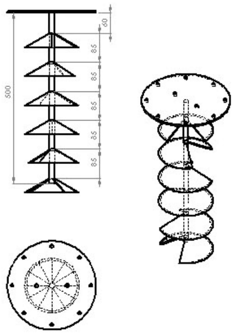
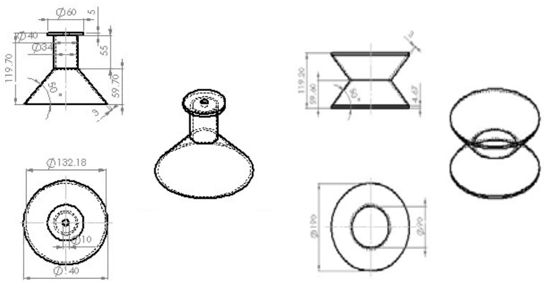


**Fig. 1 Schematic** drawing of the unconventional three-phase separator.



(a) (b)

**Fig. 2** Schematic drawing of the conventional three-phase separator: (a) gas cap and (b) baffle.

***Analytical methods***

Samples from the reactor influent, sampling ports and effluent were collected periodically for analyses of COD, VFA, total alkalinity, SS, VSS, total nitrogen, and pH, by Standard Methods [8]. The height of sludge bed was also recorded, and the sludge particles were taken from each sampling port for estimating the size distribution by a laser particle size analysis system (Mastersizer, Malvern Instruments Ltd., United Kingdom). The amount of generated biogas was recorded using liquid displacement gasometers.

The sludge retention time (SRT) in the reactor was calculated according to the method described by Caixeta et al . [7], but the samples were taken from the five sampling points, Instead of three. The SRT was obtained by dividing the total mass of solids in the reactor by the concentration of solids
removed in the unit of time.

$$M_r = \sum C_i V_i \,, \quad (1)$$
$$SRT = M_r/(Q_e X_e) \,. \quad (2)$$

where $M_r$ is the total mass of volatile solids in the reactor; $C_i$ is the VSS at the sampling points along the reactor height; $V_i$ is the volume of each sampling section; $Q_e$ is the reactor feed rate and $X_e$ is the VSS in the reactor effluent.

**Results and Discussion**

Fig. 3 show the performances of the unconventional and conventional UASB reactors: (a) OLR and HRT; (b) VFA; (c) CODs of the influents and effluents, and HRT; (d) COD percent removal and HRT; (e) pH; (f) total alkalinity; (g) biomass washout; and (h) biogas production, as a function of operation days. Due to the fluctuation of fruit supply and production line, the wastewater COD values varied considerably between 2000-9000 mg $l^{-1}$, but the OLR value s were rather constant, ranging between 1.2-3.5 kg COD $m^{-3}$ $d^{-1}$ during the 100 operation days.

The acclimatization period, which lasted for 2 months, enabled the system to rapidly adjust itself to the wastewater at HRT 85 h. (OLR = 2 kg COD $m^{-3}$ $d^{-1}$). Within 14 days, the COD removals reached 75% and 80% for the unconventional and conventional reactors, respectively. Unfortunately, the reactors experienced a system upset due to a problem with pH control on Day 21. There was an accidental overdose of NaOH, making pH shoot up to 7.86. The decrease in HRT on Day 28 from 85 to 65 hours made the situation worse. The COD percent removal continued dropping and reached the minimum at 40% on Day 42. However, within 14 days, the systems were able to recover themselves, and the COD percent removal bounced back to 80% for both reactors on Day 56.

After the system recovery, the performance of the unconventional UASB had been continuously superior to that of the conventional one. Tables 2 and 3 summarize the general results (mean ± standard deviation) obtained from the unconventional and conventional reactors, respectively. The means and standard deviations were calculated from the data with the same hydraulic retention time. The high standard deviations were basically due to the fluctuating influent COD values. The calculation showed that the new design of three-phase separation system helped lower effluent COD by 10-25%, corresponding to 7-10% higher COD percent removal, lower biomass washout by 11-15%, increase biogas production by 11-12%, and increase the sludge retention time by 6-7%.

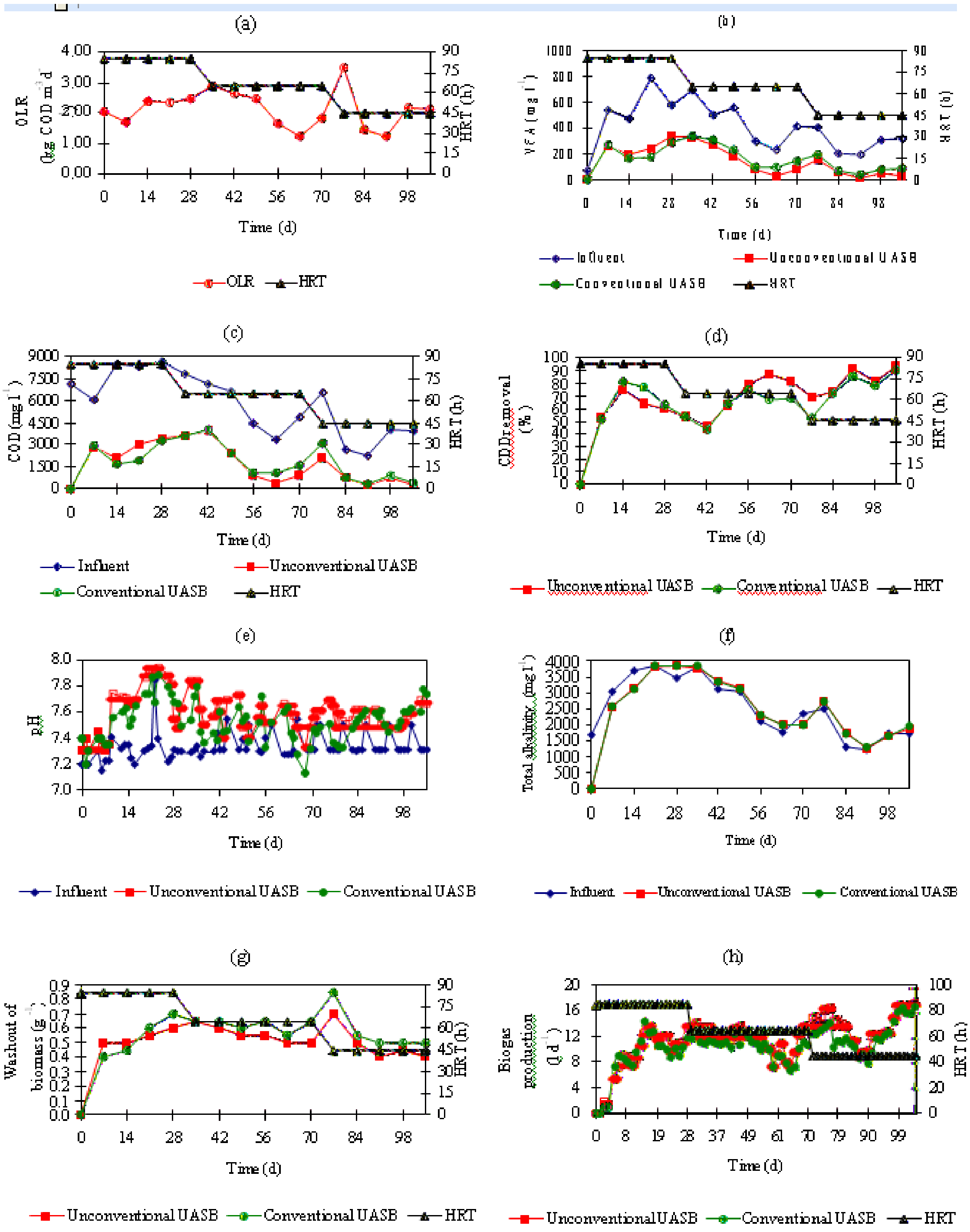



**Fig. 3** The performances of the unconventional and conventional UASB reactors: (a) OLR and HRT; (b) VFA; (c) CODs of the influents and effluents, and HRT; (d) COD percent removal and HRT; (e) pH; (f) total alkalinity; (g) biomass washout; and (h) biogas production, as a function of operation days.

**Table 2** Summary of the general results (mean±standard deviation)* obtained from the unconventional UASB

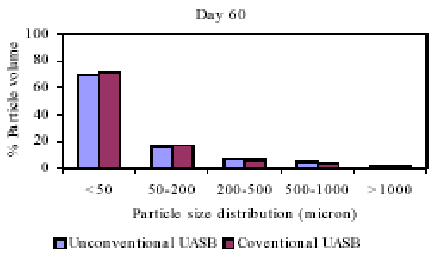
| HRT (h) | Organic load (kg m$^{-3}$ d$^{-1}$) | COD$_{in}$ (mg l$^{-1}$) | COD$_{out}$ (mg l$^{-1}$) | COD$_{removal}$ (%) | Washout of biomass (g l$^{-1}$) | Biogas production (l d$^{-1}$) | 1 liter biogas per gram COD$_{removal}$ | SRT (day) |
|---|---|---|---|---|---|---|---|---|
| 85 | 2.19 ± 0.32 | 7740 ± 1134 | 2879 ± 581 | 62.7 ± 9.28 | 0.54±0.05 | 11.97 ± 3.67 | 2.73±1.05 | 74.55 |
| 65 | 2.11 ± 0.64 | 5724 ± 1738 | 2058 ± 1505 | 68.04±16.78 | 0.56±0.06 | 12.60 ± 2.39 | 3.44±0.51 | 62.58 |
| 45 | 2.09 ± 0.64 | 3926 ± 2166 | 818 ± 1319 | 81.11±14.58 | 0.49±0.08 | 15.64 ± 2.78 | 5.37±1.44 | 47.09 |

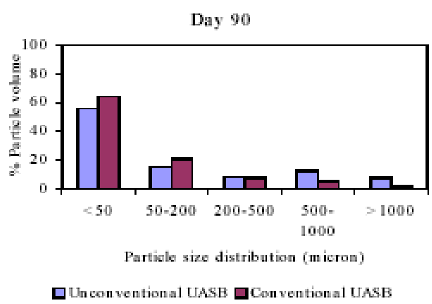
**Table 3** Summary of the general results (mean±standard deviation)* obtained from the conventional UASB

| HRT (h) | Organic load (kg m$^{-3}$ d$^{-1}$) | COD$_{in}$ (mg l$^{-1}$) | COD$_{out}$ (mg l$^{-1}$) | COD$_{removal}$ (%) | Washout of biomass (g l$^{-1}$) | Biogas production (l d$^{-1}$) | 1 liter biogas per gram COD$_{removal}$ | SRT (day) |
|---|---|---|---|---|---|---|---|---|
| 85 | 2.19± 0.32 | 7740 ± 1134 | 2453 ± 766 | 67.65±13.50 | 0.54±0.14 | 11.30±3.35 | 2.49±1.01 | 74.17 |
| 65 | 2.11± 0.64 | 5724 ± 1738 | 2310 ± 1270 | 61.78±11.33 | 0.63±0.04 | 11.37±3.06 | 3.52±0.59 | 58.33 |
| 45 | 2.09± 0.64 | 3926 ± 2166 | 1096 ± 1209 | 75.61±13.49 | 0.58±0.11 | 14.03±2.13 | 5.10±0.59 | 44.23 |

* Average and standard deviation were of the data with the same hydraulic retention time.

After 60 days of operation, small granules became visible at each reactor bottom. They were taken for analysis of granule size distribution. Figs. 4 (a) and (b) present the granule size distribution on Days 60 and 90, respectively. On Day 60, more than 60 % of the sludge samples were in the range of less than 50 μm for both reactors. However, on Day 90, the sludge samples from the unconventional reactor were in the ranges of 500-1000 μm, and > 1000 μm in noticeably higher proportions.




**Figs. 4** The granule size distribution on (a) Day 60 and Day 90.

Based on the average particle size (Fig. 5), the unconventional reactor had higher average particle sizes, and the size difference increased with time. On Day 60, the average particle sizes differed by 30%, while on Day 90, 110%. The higher average particle size of the unconventional reactor was in agreement with its lower biomass washout.

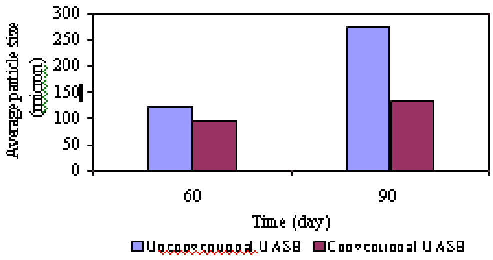



**Fig. 5** The average particle size of sludge samples.

## Conclusions

The results from the first 100 operation days demonstrated that the upflow pattern in a UASB had the influence on biomass retention and granule development. Based on the biomass washout data, the spiral flow pattern created by an unconventional design of a three-phase separator resulted in 11-15% lower biomass washout, and based on the calculation and VSS data, 6-7% higher sludge retention time. The analysis of particle size distribution agreed well with the biomass washout and sludge retention time data. On Day 90, the sludge samples from the unconventional reactor were in the ranges of 500-1000 µm, and > 1000 µm in noticeably higher proportions, and had 2-fold higher average particle sizes. Based on other efficiency parameters, the unconventional reactor had lower effluent COD by 10-25%, corresponding to 7-10% higher COD percent removal, and higher biogas production by 11-12%.

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