[ED07] Initial stage of an upflow anaerobic sludge blanket (UASB) reactor start-up

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Introduction

The upflow anaerobic sludge blanket (UASB) process is the most successful new anaerobic reactor design for various industrial and municipal wastewaters (McCarty, 2001). It has become the most popular and widely used high-rate anaerobic wastewater treatment system worldwide (Schmidt and Ahring, 1996, Hulshoff Pol and Lettinga, 1986). Investigated and developed by Lettinga and his team since 1971 (Lettinga et. al., 1980), it was one of the anaerobic treatment systems that answered the urgent need for alternative treatment systems in view of increased environmental concerns amidst the energy crisis in the 1970s.

Compared to other anaerobic treatment systems, it offers high chemical oxygen demand (COD) removal efficiency at shorter retention times, small land area requirement, low construction cost, simple operation and minimal pumping requirement (van Haandel and Lettinga, 1994). Its ability to retain high biomass concentrations in the reactor is its key advantage (Schmidt and Ahring, 1996).

The UASB reactor

Characteristic of a high rate system, the UASB system hinges on a sludge retention mechanism in order to maintain contact between the wastewater and a high concentration of active bacterial mass. The UASB reactor operates on the principles of an effective separation of the biogas, the liquid and sludge, formation of an easily settleable anaerobic sludge, and even distribution of raw waste over the bottom of the reactor (Hulshoff Pol and Lettinga, 1986).

A schematic diagram of the UASB reactor is shown in Figure 1.

Influent wastewater is introduced from the bottom of the reactor, through evenly distributed nozzles. The sludge bed at the bottom of the reactor is the active bacterial mass that digests the organic pollutants in the wastewater. Production of biogas that resulted from the anaerobic digestion process induces mixing in the sludge blanket. Dispersed sludge particles are separated from the liquid and returned to the digestion compartment at the phase separator, while the liquid leaves the reactor via the effluent line, and the gas through the top of the phase separator.

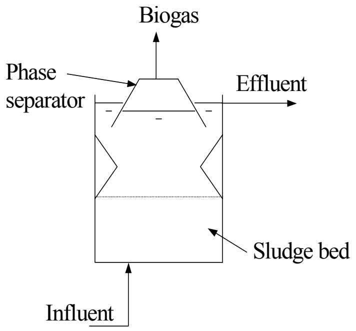

FIGURE 1 The UASB reactor (van Haandel and Lettinga, 1994)

While the other concepts are closely related to the reactor design, formation of highly active biomass with good settling abilities is dependent on the start-up process. Described as Hulshoff Pol and Lettinga (1986) as “a fairly delicate and time-consuming process”, several start-up conditions to be adhered to have been outlined in the literature (Hulshoff Pol and Lettinga, 1986). Careful start-up will ensure proper sludge granulation in the reactor, which is essential for the successful performance of the system in treating wastewater.

The normal start-up procedure generally involves feeding of the reactor continuously at low organic and volumetric loading rates, and increasing these parameters stepwise once the substrates have been reduced considerably. Hulshoff Pol and Lettinga (1986) recommended at least 80% reduction.

In practice, start-up procedures vary in terms of loading applied, and whether seed sludge is used. While it has been proven that seed sludge is not required for the start-up of an UASB reactor treating sewage, its application will shorten the start-up time, which can take three to four months (van Haandel and Lettinga, 1994).

This paper reports the approach taken in starting up an UASB reactor to be developed to treat domestic wastewater. Its performance during the initial stage of start-up will be presented and relevant observations highlighted.

Materials and methods

Experimental setup

The experimental setup used is as shown in Figure 2. The UASB reactor was a modified perspex column of 1.102m high and 0.1905m ID. It has a working volume of 13 l. A funnel designed with an OD of 0.182m and inclination of 45 – 60° was installed as the phase separator. Except for the influent tank, influent pump and gas collection bottles, the whole setup as shown in Figure 2 was housed in a chamber controlled at 37°C. However, due to various factors, the temperature of the reactor body varied from 31 – 39°C throughout the period of the experiment. Wastewater was fed into the reactor using a peristaltic pump (Watson Marlow, 323 E/D, UK). Pinch corks were used to divert the influent and effluent flows during sampling.

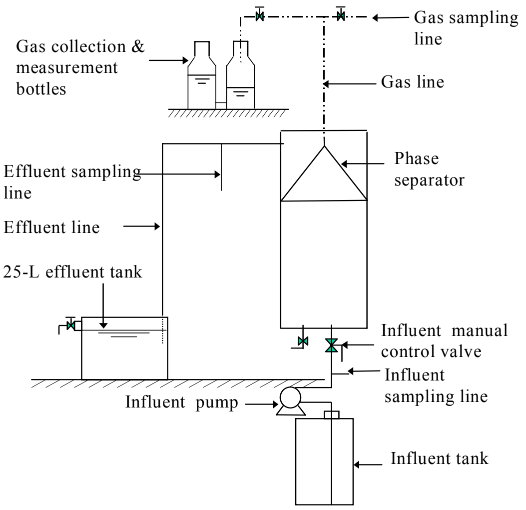

FIGURE 2 Experimental setup

Start-up Procedure

In this research, a more flexible approach was adopted. The start-up strategy employed was to fill up about 20% of the reactor working volume with seed sludge. Synthetic waste of approximately 11 g COD/l was fed into the reactor by batch every three days. This was to avoid wastage of chemicals while the biomass acclimatise itself to the waste and multiply.

The synthetic waste consisted mainly of acetic acid, propionic acid, n-butyric acid and glucose, supplemented with nutrients and trace metals, as described by Praveen (1994). Stock solution with concentration of 220g COD/l was prepared. Dilutions to 11g COD/l were made using tap water and the pH adjusted to 6.5 – 7.5 by addition of concentrated NaOH before the synthetic waste was fed into the reactor.

The first batches of synthetic waste fed immediately after seeding were of the same volume as the seed sludge pumped into the reactor. Subsequent volumes fed ranged from approximately 0.5 – 1.0 l per batch. The feeding of synthetic waste would be switched to continuous mode once the biomass is acclimatised and growing well, characterised by stable biogas production. Initially, continuous pumping of feed would be at the lowest flow rate. Once COD removal reaches 90% or more, the flow rate would be increased stepwise by 10% or 5 rpm, whichever the higher.

During the first start-up exercise of the UASB reactor in this research, the seed sludge used was from the Damansara Regional Sewerage Treatment Works, Taman Tun Dr. Ismail, which employs the activated sludge process. The sludge taken was freshly pumped into the sludge holding tank from the clarifier. Following the procedure outlined above, the reactor start-up initiation was accomplished over a period of three days. After about two months, no obvious biogas production was observed, other than some frothing on the top water level of the wastewater body.

Sixty days after the first start-up, a second start-up was attempted with seed sludge from an operating UASB reactor treating a mixture of brewery wastewater and sewage at Carlsberg Brewery Malaysia Berhad's Waste Water Treatment Plant. After all the previously fed media had been pumped out, leaving only the domestic wastewater sludge in the reactor, the same procedure described above was employed with the second batch of seed sludge.

On the 78th day after the first start-up (18th day after the second), feeding of synthetic waste was changed to continuous mode at a flow rate of 3.7 ml/min. The influent and effluent pH, temperature and COD were determined periodically, and biogas production was monitored. The pumping rate of waste was increased when COD removal increased. The frequency of analysis was increased when gas produced was quantifiable.

It should be noted that throughout the duration of the experiment during the continuous feed mode (78th day onwards), frequent feed interruptions occurred due to various reasons such as power failures, maintenance works on the reactor e.g. unclogging of tubing, troubleshooting and modifications of the experimental setup to improve data collection, and other unavoidable circumstances in the laboratory. The duration of interruptions varied from a few minutes to about 60 hours.

Analytical Methods

Sludge biomass was characterised according to the Standard Methods for total, volatile and fixed suspended solids analyses (APHA, AWWA, WEF, 1998). Glass fiber filter disks (Pall Life Science, Type A/E, 1µm, 47mm, USA) were used to filter the suspended solids. Total suspended solids were determined from drying the filtered solids at 104°C, and volatile and fixed suspended solids after ignition at 550°C.

pH and temperature were measured using a pH/temperature probe (Thermo Orion, 9107BN, USA) with automatic temperature compensation. The method used for pH is simplified from the Standard Method 4500B (APHA, AWWA, WEF, 1998).

For COD analysis, Hach's Method 8000: a combination of Reactor Digestion Method and Colorimetric Method was used (2000). This method is equivalent to Standard Method 5220D: Closed Reflux, Colorimetric Method (APHA, AWWA, WEF, 1998). Samples were digested with a strong oxidising agent, potassium dichromate, to form green chromic ion (Cr^{3+}). The amount of green Cr^{3+} was measured using a calibrated, pre-programmed colorimeter (Hach, DR/890, USA).

Biogas was collected by water displacement and the volume read from a calibrated gas collection bottle. Gas volume readings were recorded not less than four hours after the start of collection to allow the water displacement to normalise.

Results and Discussion

Observations

During the first 60 days of the reactor start-up (with domestic sludge), only frothing was observed on the surface of the wastewater body. This may indicate some respiratory activity within the reactor, but it did not result in noticeable biogas production. Minimal movements of sludge in the reactor could only be perceived over a considerably long period, e.g. a day. These were deduced from shifts in positions of coloured 'particles' suspended in the wastewater body. On the 18th day, a layer of sludge was observed on the top water level of the wastewater below the bubbles. These are presumed to be inactive biomass, which floated to the top. Over time, this sludge layer accumulated. Overall, the start-up process was either exceedingly slow, or not progressing well.

On the 60th day, the second start-up was initiated to expedite the reactor start-up. On the 88th day, gas eruptions that pushed the biomass up and down the length of the reactor were observed. The longest feed interruption (60 hours) occurred just after this observation, i.e. from day 88 to day 90. However, it did not affect the gas production in the reactor, which was still visible on day 90. Over the next few weeks, these eruptions were observed periodically; frequent incidences of wastewater and sludge extending into the phase separator were observed. Frothing could also be seen, indicating almost consistent gas production.

Start-up characteristics

Table 1 shows the characteristics of the reactor start-up. Comparisons with recommended values from the literature show some deviations. However, as can be seen by the COD removal efficiency in Figure 3, these deviations did not affect the growth and activity of the biomass.

pH and temperature

Figure 3 shows the pH and temperature profiles of both the influent and effluent.

The effluent pH, which reflects the pH in the reactor, lies between 6.9 and 7.955. The maximum pH recorded is higher than the optimum pH for anaerobic digestion cited in most references, i.e. 6.5 – 7.5. However, from Figure 3, this did not affect the COD removal efficiency, which remained high at above 90%.

Influent pH ranged from 5.706 to 6.393, although the pH prior to feeding to the influent tank was adjusted to near 7.0. This may be due to degradation of glucose in the tank, but the low influent pH did not affect the COD removal in the reactor, as shown in Figure 3. This agrees with the results obtained with liquid sugar waste by Lettinga et. al. (1980).

Both influent and effluent temperatures were well within the mesophilic temperature range of 20 – 40°C.

Volumetric loading rate

Figure 4 shows the volumetric loading rate in relation to COD removal efficiency. From the 78th day (when continuous feeding was employed) to the 133rd day, the volumetric loading rate was increased from 4.26 kg COD/m^3/d to 9.56 kg COD/m^3/d once COD removal efficiency increased, although it had not reached 90% removal. Despite this, COD removal reached 89.95% removal at the highest volumetric loading rate employed during that period.

Thereafter, due to experimental complications, the flow rate was decreased a step lower to 7 ml/min. However, up to the 133rd day, difficulty in maintaining the flow due to clogging resulted in decreased volumetric loading rate that fluctuated between 7.78 – 9.54 kg COD/m^3/d. During this period, COD removal remained almost constant at 96 – 97 %. On the 134th day, feeding had to be stopped periodically due to an emergency; continuous feeding was resumed at the lowest flow rate and increased stepwise again. Despite this interruption, COD removal efficiency remained well above 95% throughout.

TABLE 1 Characteristics of the UASB reactor start-up in comparison with literature values

Characteristics	1st start-up	2nd start-up	Recommendations from literature
Seed sludge concentration, kg TSS/m^3	8.423	12.74	> 60 (Hulshoff Pol and Lettinga, 1986)
Seed sludge amount, kg sludge VSS/m^3	1.206	[a]2.534	Approx. 6 (Hulshoff Pol and Lettinga, 1986)
Initial specific loading rate, kg COD/kg VSS/d	0.182	[b]< 0.289	0.05 – 0.1 (Praveen, 1994)
Wastewater COD level, mg/l	Approx. 11,000	Approx. 11,000	1000 (Hulshoff Pol and Lettinga, 1986)

[a] This is the cumulative value from the first start-up, not taking into account any biomass that might have grown during the first 60 days.

[b] The maximum value shown was calculated without taking into account any biomass that might have grown during the first 60 days.

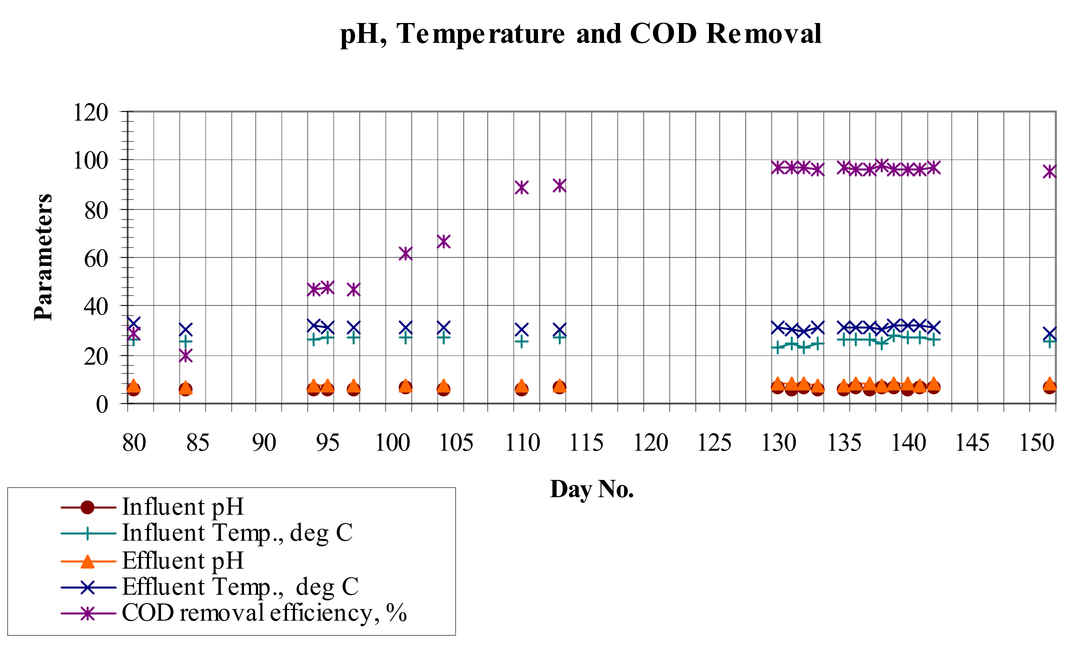

FIGURE 3 Effect of pH and temperature of reactor influent and effluent on COD removal efficiency

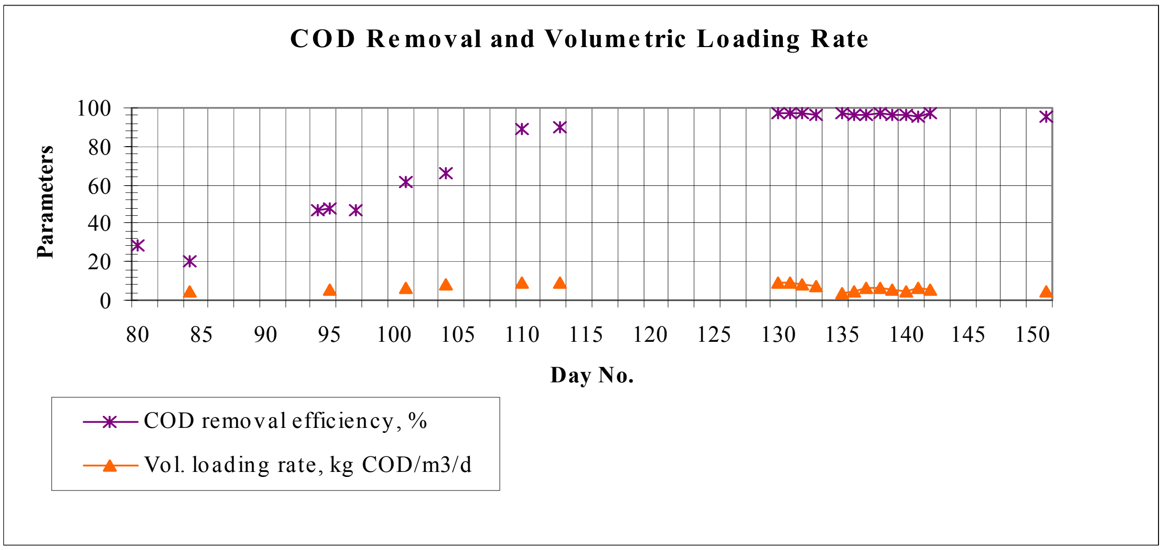

FIGURE 4 Effect of volumetric loading rate on COD removal efficiency

Biogas production

Despite the consistent bubbling observed in the wastewater body and phase separator during the period described earlier, no readings were registered in the gas collection and measurement bottle. This was due to an error in the experimental setup, which was rectified on the 129th day. The first valid gas volumetric reading was recorded on the 132nd day.

From Figure 5, biogas production was not constant and stable, despite the constant and high COD removal. This may be due to loss of gas through dissolution in the effluent and desorption of methane at the water surface. Losses between 20 and 50 per cent of the produced biogas are common (van Haandel and Lettinga, 1994). This could also be an indication that part of the substrate digested was still used to synthesise new cells, as the reactor is still considered to be in its start-up stage.

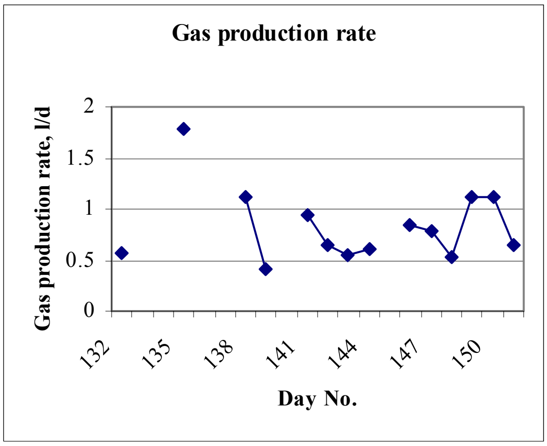

FIGURE 5 Biogas production rate

Conclusion

Based on the COD removal attained so far, the start-up is progressing well at the applied loadings. The deviations from the recommended start-up strategy in the literature did not cause any harm to the performance of the UASB reactor so far. However, the use of anaerobic seed sludge will shorten the start-up period considerably. Overall, the UASB process showed considerable tolerance and flexibility in terms of operation.

Acknowledgements

The authors wish to thank the Ministry of Science, Technology and Innovation (MOSTI), Malaysia for the National Science Fellowship awarded to Tan Yee Ying @ Jennifer, and for the IRPA grant awarded to Mohd. Ali Hashim and Kadathur B. Ramachandran. Due appreciation is also accorded to University of Malaya for the Vote F funds awarded to Tan Yee Ying @ Jennifer. The authors were also grateful to Green & Smart Sdn. Bhd. for lending the reactor column and stand and to Indah Water Konsortium and Carlsberg Brewery Malaysia Berhad for the seed sludge.

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