The effect of temperature reduction on the performance and stability of UASB reactors treating synthetic sewage

Masood Abdusalam Ghanem Ali
Department of Geology and Environment, Faculty of Sciences, Baniwaled University, Libya

KEYWORDS
- Methane (CH$_4$)
- Chemical Oxygen Demand (COD)
- Total Suspended Solid (TSS)
- Organic loading Rate (OLR)
- Hydraulic Retention Time (HRT)
- Specific Methane Production (SMP)

ABSTRACT

The objective of this investigation is to determine the effect of temperature reduction on the performance and stability of laboratory-scale up-flow anaerobic sludge blanket (UASB) treating synthetic sewage. The work was carried out using four 4-litre continuously fed UASB reactors. The operation started at a constant hydraulic retention time of ~24 hours (up flow velocity ~0.02 m/hour) and an influent COD concentration of ~2250 mg/L, with an organic loading rate of ~2.25 g COD/L/day. During the experiment, the operating temperature was reduced in a single step from 35 to 30 °C, then stepped down to 25 °C. COD removal efficiency fell slightly from ~96% in all reactors to ~93%. Effluent TSS concentrations remained below 20 mg L$^{-1}$ and TSS removal efficiency ranged between 93-98%. Gas production showed a slight disturbance following the initial drop in temperature to 30 °C, but stabilised at around 0.74 L CH$_4$/L, 0.30 L CH$_4$/g COD$_{added}$ and 0.31 L CH$_4$/g COD$_{removed}$. The subsequent drop to 25 °C produced a stronger disturbance, but both volumetric and specific methane production recovered to the previous values by about day 412. The average biogas methane content in all reactors was unchanged or marginally higher at 78-79%.

Introduction

Temperature has a considerable influence on the growth and survival of microorganisms. Below 30 °C, the methanogenic activity in an (up-flow anaerobic sludge blanket) UASB may be affected and the digestion rate will decrease by about 11% for each °C temperature decrease (van Haandel and Lettinga 1994; Gómez 2011). Although anaerobic treatment is possible in all three temperature ranges (psychrophilic, mesophilic and thermophilic), low temperature usually leads to a decline in the maximum growth rate and methanogenic activity (Bodik et al., 2000). However, long-term acclimation to lower temperatures is possible.

According to Seghezzo et al. (1998), the UASB process has been successfully applied for low strength wastewaters such as domestic sewage at 20 °C or above, with chemical oxygen demand (COD) removal efficiencies in the range of 57% to 82% at hydraulic retention time (HRT) from 5 to 15 hours (Seghezzo et al., 1998). Lettinga et al. (1983) reported that when raw domestic sewage was treated in a 120-L reactor at temperatures in the range of 8-20 °C, 65-85% COD reduction was achieved (Lettinga et al., 1983). COD removal with 97% efficiency was achieved at 20 °C and 90% COD reduction was still observed when the temperature dropped to 10 °C. At lower temperatures (5–20 °C), however, the performance of one-stage UASB reactors can be severely limited by the slow hydrolysis of entrapped solids that accumulate in the sludge bed when high loading rates are applied.

Singh and Viraraghavan et al. (1996) used a UASB system to treat municipal wastewater in low-temperature conditions and reported 70% COD removal at 11 °C and 30-50% at 6 °C. Lew et al. (2003) reported a gradual decrease in COD removal efficiency with decreasing temperature, from 82% at 28 °C to 72% at 20 °C, 68% at 14 °C and 38% at 10 °C. Halalsheh (2002) treated a relatively high strength municipal sewage (COD = 1531 mg/L) from Jordan in a pilot UASB reactor operated at temperature (18-25 °C). Total COD removal efficiencies were 62% and 51% in summer and winter, respectively at HRT of 24 hours. Singh and Viraraghavan (1998) used two UASB reactors, with total volume of 8 L, for the treatment of municipal wastewater at 20 °C. Start-up was at a HRT of 48
hours, and was reduced to 10 hours by the 280th day of operation. The total COD of the municipal wastewater varied in the range of 350 to 500 mg/L with soluble COD of 150-300 mg L−1. The reactors achieved a treatment efficiency in terms of COD removal of the order of 60-75% (Singh and Viraraghavan, 1998).

Takahashi et al. (2011) investigated treatment of raw sewage using a 1.15 m³ pilot-scale UASB reactor operated at a HRT of 8 hours at wastewater temperatures ranging from 10.6 to 27.7 °C for more than 1100 days. The stable removal efficiencies for total COD and SS were 63± 13% and 66 ± 20 %, respectively. After two years of operation, the average concentration of the retained sludge was 24.5 g SS/L. The solid retention time was evaluated as 293 ± 114 days, which was sufficient for mineralisation of solid organic matter, as indicted by a growth yield of 0.132 g VSS/g COD. In summer, the water temperature increased above 20 °C leading to enhanced biodegradation. The above results indicate considerable potential for UASB operating on low-strength municipal-type wastewater at ambient temperatures of 30 °C or below, but also leave some questions unanswered.

The objective of this investigation is to determine the effect of temperature reduction on the performance and stability of laboratory-scale UASB in treating synthetic sewage.

Research Methods
An experimental investigation was carried out using four 4-litre continuously fed UASB reactors (Figure 1). The synthetic sewage feed was used and prepared daily from frozen pre-prepared concentrate by dilution with tap water to obtain the desired organic loading rate (OLR). The composition of the synthetic wastewater used is given in Table 1. The operation started at a constant HRT of ~24 hours (up flow velocity ~0.02 m/hour) and an influent COD concentration of ~2,250 mg/L, with an OLR of ~2.25 g COD/L/day. During the experiment, the operating temperature was reduced in a single step from 35 to 30 °C, then stepped down to 25 °C as indicated in Table 2. Temperature reduction was achieved by adjusting the thermostat on the thermo-circulator.

Figure 1. Schematic of the revised layout (based on Idrus, 2013)

Table 1. Composition of synthetic wastewater concentrates (Based on Whalley, 2008)

| Component                              | Unit  | Quantity |
|----------------------------------------|-------|----------|
| Yeast (block bakers form)              | g     | 23       |
| Urea                                   | g     | 2.14     |
| Full cream milk (UHT sterilised)       | ml    | 144      |
| Sugar (granulated white)               | g     | 11.5     |
| Dried blood                            | g     | 5.75     |
| Ammonium phosphate (NH₄) 2HPO₄         | g     | 3.4      |
| Tap water                              |       | Make up volume to 1 L |
Table 2. Reactor operating conditions for initial temperature reduction study

| Reactor | Days No. | Target temp (°C) | Target Inf COD (mg/L) | Target OLR (mg/L) | Target Hours (HRT) |
|---------|----------|------------------|-----------------------|-------------------|-------------------|
| R1-4    | 65       | 30               | 2250                  | 2.25              | 24                |
|         | 8        | Varied a         | 2250                  | 2.25              | 24                |
|         | 74       | 25               | 2250                  | 2.25              | 24                |

a Temperature reduced by 1 °C every 2 days
Inf = influent

Results and Discussion

Characteristics of synthetic sewage
The average characteristics of the synthetic wastewater are shown in Table 3.

Table 3. Average characteristics of synthetic sewage substrate

| Parameter | Unit   | Value  | No. | SD  |
|-----------|--------|--------|-----|-----|
| COD       | mg/L   | 456    | 60  | 18  |
| TSS       | mg/L   | 211    | 36  | 14  |
| TAN       | mg N/L | 8      | 11  | 0.34|

No. = number of samples analysed, SD = standard deviation, COD = Chemical Oxygen Demand, TSS = Total Suspended Solid, TAN = Total Ammonia Nitrogen

Reactor performance
The main performance parameters are summarised in Table 4 and Figure 2.

Treatment performance
Effluent COD concentrations showed little or no change on reduction to 30 °C, but rose sharply from around 100 mg/L to 150 mg/L as the temperature was further reduced. COD removal efficiency fell slightly from ~96% in all reactors to ~93%. Effluent TSS concentrations remained below 20 mg/L and TSS removal efficiency ranged between 93-98%.

Table 4. UASB performance on temperature reduction to 30 and 25 °C

| Reactor | Average OLR g COD/L/ day | COD removal % | VMP + L/L/day | CH4 content % | SMP added b L CH4/g COD added | SMP removed c L CH4/g COD removed | Actual/ Th CH4 d |
|---------|---------------------------|---------------|---------------|---------------|-------------------------------|-------------------------------------|-------------------|
| Nominal OLR 2.3 (T = 30 °C, last 30 days) | 2.37 | 0.96 | 0.732 | 0.79 | 0.309 | 0.323 | 0.92 |
| 1       | 2.36 | 0.96 | 0.721 | 0.79 | 0.293 | 0.305 | 0.87 |
| 2       | 2.34 | 0.96 | 0.728 | 0.79 | 0.298 | 0.311 | 0.89 |
| 3       | 2.37 | 0.96 | 0.729 | 0.8  | 0.295 | 0.309 | 0.88 |
| 4       | 2.36 | 0.96 | 0.727 | 0.79 | 0.299 | 0.312 | 0.89 |
| Average | 2.36 | 0.96 | 0.727 | 0.79 | 0.299 | 0.312 | 0.89 |
| Nominal OLR 2.3 (T = 25 °C, last 50 days) | 2.12 | 0.93 | 0.669 | 0.79 | 0.317 | 0.341 | 0.97 |
| 1       | 2.13 | 0.93 | 0.658 | 0.78 | 0.289 | 0.311 | 0.89 |
| 2       | 2.12 | 0.93 | 0.656 | 0.77 | 0.289 | 0.311 | 0.89 |
| 3       | 2.13 | 0.93 | 0.654 | 0.78 | 0.286 | 0.307 | 0.88 |
| 4       | 2.12 | 0.93 | 0.659 | 0.78 | 0.295 | 0.317 | 0.91 |

a Volumetric methane production
b Specific methane potential (SMP) per g COD added
c Specific methane potential (SMP) per g COD removed
d ratio of actual SMP per g COD removed to the theoretical value of 0.35 L/g COD
Figure 2. Volumetric methane production, biogas methane content, specific biogas and methane production, COD removal, TSS removal and actual/theoretical methane for R1-4. The vertical dotted lines indicate a change in temperature.

**Biogas production**
Gas production showed a slight disturbance following the initial drop in temperature to 30 °C, but stabilised at around 0.74 L CH₄/L, 0.30 L CH₄/g CODₐdд and 0.31 L CH₄/g CODₘₐₛ. The subsequent drop to 25 °C produced a stronger disturbance, but VMP and SMP recovered to the previous values by about day 412. The average biogas methane content in all reactors was unchanged or marginally higher at 78-79%.

**Overall performance**
Table 5 and Figure 3 show the results at 30 and 25 °C together with the values for 35 °C. A slight fall in VMP can be seen, as well as the increase in biogas methane content. The performance was better than expected as it showed relatively little change despite the large change in operating temperature.
### Table 5. Average performance parameters at 25, 30 and 35 °C

| Temp °C | Average OLR g COD/L/day | COD removal % | VMP a L/L/day | CH₄ % | SMP added b L CH₄/g COD added | SMP removed c L CH₄/g COD removed | Actual Th CH₄ d |
|---------|-------------------------|---------------|---------------|-------|------------------------------|-----------------------------------|----------------|
| 35      | 2.28                    | 0.96          | 0.74          | 0.76  | 0.313                        | 0.327                             | 0.93           |
| 30      | 2.36                    | 0.96          | 0.73          | 0.79  | 0.299                        | 0.312                             | 0.89           |
| 25      | 2.12                    | 0.93          | 0.66          | 0.78  | 0.295                        | 0.317                             | 0.91           |

(a) Average values  
(b) All data

**Figure 3.** Kinetics of key parameters with temperature change from 25 to 35 °C

### Specific experimental findings

Step changes in operating temperature to 30 °C led to some short-term disturbance in performance, seen in fluctuating gas production parameters, which stabilised after a period of ~30 days at values slightly below those at the original operating temperature of 35 °C but stabilised at around 0.74 L CH₄/L, 0.30 L CH₄/g COD added and 0.31 L CH₄/g COD removed. A similar disturbance and further reduction in specific and volumetric gas production was seen on reducing the temperature to 25 °C but VMP and SMP recovered to the previous values after ~20 days.

A marked change in effluent COD concentration from ~100 to ~200 mg/L occurred when the temperature was reduced from 30 to 25 °C. This recovered to ~150 mg/L after ~20 days, but showed no further decline in the experimental period.

Despite the relatively short acclimatisation and operating period, performance in terms of both treatment and energy conversion remained good, indicating that the system had the potential to operate effectively at lower temperatures without extended acclimatisation.

### Conclusions

This experiment showed that the reactors experienced some disturbance after a reduction in temperature, which could be seen in fluctuating gas production parameters for a period of ~30 days, after which stabilisation appeared to occur. There was a marked change in COD removal and effluent COD concentration when the temperature was reduced from 30 to 25 °C. Performance in terms of both treatment and energy conversion remained high.

### Conflict of interest

The authors declare that there is no conflict of interest in this publication.

### References

Azbar, N., Dokgöz, F.T., Keskin, T., Eltem, R., Korkmaz, K.S., Gezgin, Y., Akbal, Z., Öncel, S., Dalay, M.C., Gönen, Ç. and Tutuk, F. (2009) ‘Comparative evaluation of bio-hydrogen production from cheese whey wastewater under thermophilic and mesophilic anaerobic conditions’, *International Journal of Green Energy*, 6(2), pp. 192-200

Bodik, I., Herdova, B. and Kratochvil, K. (2000) ‘The application of anaerobic filter for municipal wastewater treatment’, *Chemical Papers-Slovak Academy of Sciences*, 54(3), pp. 159-164
Gómez, R.R. (2011) ‘Upflow Anaerobic Sludge Blanket Reactor: Modelling’, Licentiate Thesis, Chemical Engineering, School of Chemical Science and Engineering, Department of Chemical Engineering and Technology, Royal Institute of Technology, Stockholm, Sweden

Halalsheh, M.M. (2002) ‘Anaerobic pre-treatment of strong sewage: a proper solution for Jordan’, Thesis, Wageningen University, the Netherland

Idrus, S. (2013) ‘Washing of wheat straw to improve its combustion properties with energy recovery by anaerobic digestion of the washwater’, PhD Thesis, Faculty of Engineering and the Environment University of Southampton, Southampton, the United Kingdom

Lettinga, G., Roersma, R. and Grin, P. (1983) ‘Anaerobic treatment of raw domestic sewage at ambient temperatures using a granular bed UASB reactor’ Biotechnology and Bioengineering, 25(7), pp. 1701-1723

Lew, B., Belavski, M., Admon, S., Tarre, S. and Green, M. (2003) ‘Temperature effect on UASB reactor operation for domestic wastewater treatment in temperate climate regions’, Water Science and Technology, 48(3), pp. 25-30

Seghezzo, L., Zeeman, G., Van Lier, J.B., Hamelers, H.V.M. and Lettinga, G. (1998) ‘A review: the anaerobic treatment of sewage in UASB and EGSB reactors’, Bioresource Technology, 65(3), pp. 175-190

Singh, K.S. and Viraraghavan T. (1996) ‘Low strength wastewater treatment by a UASB reactor’, Bioresource Technology, 55(3), pp.187-194.

Singh, K.S. and Viraraghavan T. (1998) ‘Start-up and operation of UASB reactors at 20°C for municipal wastewater treatment’, Journal of Fermentation and Bioengineering, 85(6), pp. 609-614

Takahashi, M., Ohya, A., Kawakami, S., Yoneyama, Y., Onodera, T., Syutsubo, K., Yamakzaki, S., Araki, N., Ohashi, A., Harada, H. and Yamaguchi, T. (2011) ‘Evaluation of treatment characteristics and sludge properties in a UASB reactor treating municipal sewage at ambient temperature’, International Journal of Environmental Research, 5(4), pp. 821-826

Van Haandel, A.C. and G. Lettinga (1994) Anaerobic sewage treatment: a practical guide for regions with a hot climate, Chichester: John Wiley & Sons.

Whalley, C.P. (2008) ‘Performance of variable climate waste stabilisation ponds during the critical spring warm-up period’, PhD Thesis, University of Southampton, Southampton, the United Kingdom