# Energy recovery from treatment of a municipal-type wastewater in UASB reactors at ambient temperatures

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## Abstract

The research assessed the potential of upflow anaerobic sludge blanket (UASB) reactors operated at very low upflow velocities to provide full-flow anaerobic treatment of low strength wastewater at low temperature 35 °C.

The work was carried out using laboratory-scale UASB reactors fed on a synthetic wastewater which was designed to simulate a typical unsettled municipal wastewater. The reactors were operated under a range of condition to test their performance and stability based on four main indicators: chemical oxygen demand (COD) removal, total suspended solids (TSS) removal, gas production and gas composition. The results from this investigation showed that UASB reactors operated at a temperature of 35°C were highly effective in the treatment of synthetic sewage at influent COD concentrations from 450 to 2250 mg $l^{-1}$ COD at a constant HRT of 1 day, and at HRT from 24 to 8 hours with an influent COD concentration of 450 mg $l^{-1}$. The specific methane yield obtained was around 0.32 l $CH_4$ $g^{-1}$ COD removed. COD removal efficiencies were high at $\geq 93$ % and total suspended solid removal was around 95 %.

The results confirmed that full flow treatment under ambient conditions, without heating of the UASB reactor, was feasible at wastewater temperatures of 20 °C or above. The warm temperate areas that are suited to this application, e.g. the Mediterranean region, also often have relatively low water use and/or high rates of re-use due to water scarcity.

## Introduction

The Mediterranean region is considered as one of the world's most water-stressed regions. Wastewater production is the only potential water source which will increase as a result of the increase in population and the need for fresh water (Loutfy 2011). Municipal wastewaters consist of a mixture of domestic sewage from households and a proportion of industrial and commercial effluents (Pescod 1992). The wastewater itself normally consists of ~99% water; and is usually further characterised with respect to its rate of flow or volume, chemical constituents, physical condition and in some cases microbiological quality (Pescod 1992, Metcalf & Eddy. 2003). Contaminants are removed from wastewater through the process known as sewage treatment, which may involve a combination of biological, chemical and physical processes designed to remove biological, chemical and physical contaminants. All these processes are directed towards the production of an environmentally safe effluent (GonCalves, Charlier et al. 1994). The principal objective of wastewater treatment is generally to allow human and industrial effluents to be disposed of without peril to human health or unacceptable damage to the natural environment.

In conventional sewage treatment the biological processes employed are generally aerobic, with activated sludge and biological filtration systems being the most common examples of suspended growth and fixed film processes, respectively. Anaerobic biological treatment is an alternative approach that offers several advantages: in addition to removing the energy-intensive requirement for the supply of oxygen, anaerobic systems usually have low sludge yields and produce methane that can be captured for use as a renewable energy source. Anaerobic systems are already in widespread use in the water and wastewater industry for treatment of primary, secondary and co-settled sludges (municipal wastewater biosolids) and other high-strength effluents (Chernicharo 2007). Anaerobic digestion of wastewater biosolids, however, typically operates at mesophilic temperatures (~35-37 $^{o}$C), and in dilute wastewaters there is insufficient energy potential per unit of volume to raise the temperature to this range.

The upflow anaerobic sludge blanket (UASB) reactor is now a common type of high-rate reactor for treatment of industrial and domestic wastewaters. It has a simple design, can be easily built and maintained, is relatively low cost, and can cope with a range of pH, temperature, and influent substrate concentrations (Lettinga and Hushoff 1991, Cronin and Lo 1998, Alvarez, Ruiz et al. 2006, Tiwari, Guha et al. 2006). A number of laboratory-scale studies have investigated the potential of this design and of modified versions of it for the treatment of various wastewater types (Rebac, Ruskova et al. 1995, Lettinga, Rebac et al. 1999, Collins, Woods et al. 2003, McHugh, Carton et al. 2004, Collins, Foy et al. 2005).

## Methodology

An experimental investigation was carried out using eight 4-litres continuously fed UASB reactors o, maintained at 35 ±1 $^{0}$C. The synthetic sewage feed was prepared daily from frozen pre-prepared concentrate by dilution with tap water to obtain the desired OLR. Four of the reactors were operated at a constant HRT of 24 hours. The OLR in these reactors was increased by increasing the influent concentration during the experimental period, starting at 450 mg COD $l^{-1}$ on day 0 then rising to 900, 1350, 1800 and 2250 mg COD $l^{-1}$. The other four reactors were operated at a constant influent concentration of 450 mg COD $l^{-1}$, and OLR was increased by increasing the daily feed and reducing the HRT from 24 to 12 and then 8 hours. These upper and lower limits were selected as the aim was to simulate the treatment of domestic wastewater: in practice the strength of this is unlikely to exceed 2 g COD $l^{-1}$ while full-scale plants rarely operate at HRT much below 8 hours. Operating conditions are summarised in Table 1.

**Table 1 Reactor operating conditions for baseline studies at 35 °C**

| Reactor | Date | | Day | | Days | Target temp | Target Inf COD | Target OLR | Target HRT |
|---|---|---|---|---|---|---|---|---|---|
| | From | To | From | To | No. | °C | mg $l^{-1}$ | g COD $l^{-1}$ $day^{-1}$ | Hours |
| *Constant HRT* | | | | | | | | | |
| R1-2 | 17/12/09 | 29/01/10 | 0 | 43 | 44 | 35 | 450 | 0.45 | 24 |
| | 09/02/10 | 30/03/10 | 54 | 103 | 50 | 35 | 900 | 0.90 | 24 |
| | 31/03/10 | 11/05/10 | 104 | 145 | 42 | 35 | 1350 | 1.35 | 24 |
| | 12/05/10 | 28/05/10 | 146 | 162 | 17 | 35 | 1800 | 1.80 | 24 |
| | 29/05/10 | 31/10/10 | 163 | 318 | 156 | 35 | 2250 | 2.25 | 24 |
| R3-4 | 17/12/09 | 29/01/10 | 0 | 43 | 44 | 35 | 450 | 0.45 | 24 |
| | 09/02/10 | 12/04/10 | 54 | 116 | 63 | 35 | 900 | 0.90 | 24 |
| | 13/04/10 | 11/05/10 | 117 | 145 | 29 | 35 | 1350 | 1.35 | 24 |
| | 12/05/10 | 31/10/10 | 146 | 318 | 173 | 35 | 2250 | 2.25 | 24 |
| *Constant influent COD concentration* | | | | | | | | | |
| R5-8 | 11/09/10 | 11/11/10 | 0 | 61 | 62 | 35 | 450 | 0.45 | 24 |
| | 12/11/10 | 11/12/10 | 62 | 91 | 30 | 35 | 450 | 0.90 | 12 |
| | 12/12/10 | 27/03/11 | 92 | 197 | 106 | 35 | 450 | 1.35 | 8 |

### ***Feedstock***

It was decided that synthetic sewage rather than real wastewater would be used to feed the digesters in this research. This decision was made based on the fact that that the strength and composition of real wastewater vary depending on a number of factors, including water availability, climatic conditions, economic status and social customs(Gloyna 1971). It is difficult to give a chemical definition of the composition of sewage, and even in a single collection system, there are significant variations in strength on hourly, daily and seasonal time scales. This makes it difficult to carry out controlled simulation experiments for the purpose of understanding and development of treatment processes. In this study, the use of a synthetic wastewater allowed production of a material with repeatable and reproducible characteristics. Additionally, synthetic sewage is easy to prepare, to handle, safe to store, cheap, and the risk of exposure to pathogens present in real sewage is avoided (Whalley et al. 2008; Zhao et al. 2014). The composition of the synthetic wastewater used is given in Table 2 (Based on Whalley, 2008).

Table 2 Composition of synthetic wastewater concentrates. (Diluted to give a working solution) (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 $(NH_4)\ 2HPO_4$ | g | 3.4 |
| Tap water | | Make up volume to 1 l |

The synthetic wastewater was based on one used by Whalley (2008) which was designed to resemble municipal wastewater in a range of relevant properties, as shown in Table 3.

**Table 3 Characteristics of synthetic wastewater as used by used by Whalley (2008) at 1:100 dilution**

| Parameter | unit | average | range (in 5 samples) |
|---|---|---|---|
| TS | mg $l^{-1}$ | 772 | 746-813 |
| VS | mg $l^{-1}$ | 498 | 449-541 |
| TSS | mg $l^{-1}$ | 170 | 140-202 |
| VSS | mg $l^{-1}$ | 118 | 83-138 |
| Fixed SS | mg $l^{-1}$ | 52 | |
| TDS | mg $l^{-1}$ | 556 | 522-587 |
| VDS | mg $l^{-1}$ | 329 | 310-349 |
| Fixed DS | mg $l^{-1}$ | 227 | |
| Settleable solids (ml/l) | ml | 1hr = 0.1 | 0.1-0.1 |
| | ml | 2hr = 0.2 | 0.2-0.2 |
| | ml | 3hr = 0.3 | 0.2-0.3 |
| | ml | 4hr = 0.4 | 0.3-0.3 |
| | ml | 6hr = 0.4 | 0.4-0.4 |
| | ml | 24hr = 0.5 | 0.5-0.5 |
| | ml | 5d = 1.4 | 1.3-1.5 |
| TC | mg $l^{-1}$ | 221 | 213-238 |
| TOC | mg $l^{-1}$ | 195 | 175-221 |
| COD | mg $l^{-1}$ | 460 | 450-474 |
| BOD | mg $l^{-1}$ | 220 | 187-247 |
| COD:BOD | ratio | 2.1 | |
| Settled COD | mg $l^{-1}$ | 345 | |
| Settled BOD | mg $l^{-1}$ | 195 | |
| TN | mg $l^{-1}$ | 33 | 29-36 |
| TKN | mg $l^{-1}$ | 24 | 21.8-26 |
| Nitrate | mg $l^{-1}$ | 0.38 | 0.21-0.56 |
| Ammonia | mg $l^{-1}$ | 9.8 | 9.1-10.6 |
| Orthophosphate | mg $l^{-1}$ | 5.2 | 4.8-5.5 |
| Total Phosphorus | mg $l^{-1}$ | 7.0 | 6.9-7.2 |
| Alkalinity | mg $CaCO_3$ $l^{-1}$ | 147 | 127-164 |
| pH | | 7.34 | 7.32-7.36 |
| Chloride | mg $l^{-1}$ | 49 | 44-54 |
| Sulphate | mg $l^{-1}$ | 43 | 37-47 |
| Copper | mg $l^{-1}$ | 0.161 | 0.158-0.162 |
| Zinc | mg $l^{-1}$ | 0.066 | 0.06-0.07 |
| Lead | mg $l^{-1}$ | 0.043 | 0.038-0.047 |
| Iron | mg $l^{-1}$ | 0.285 | 0.278-0.296 |
| Fats & oils | mg $l^{-1}$ | 44.0 | 41.5-47.5 |
| Anionic detergents | mg $l^{-1}$ | 0.21 | 0.21-0.21 |

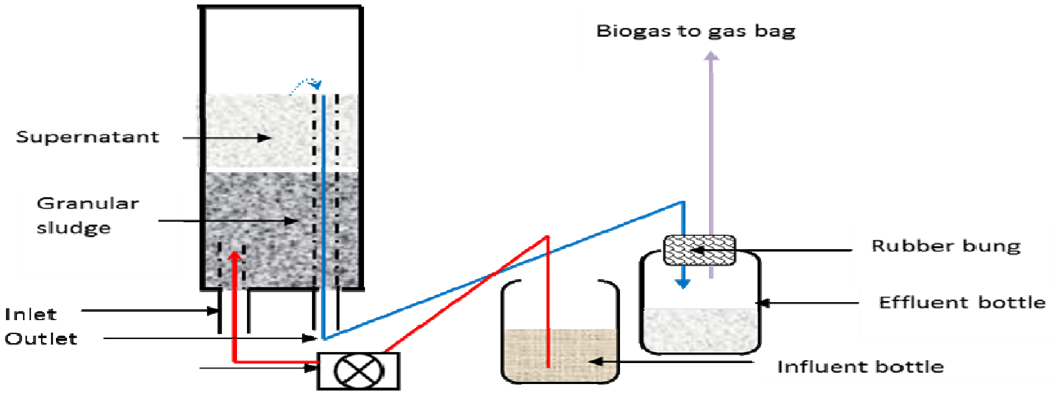


Figure 1 Schematic showing the original layout based on (Idrus 2013)

## Results and discussion

### *Reactor performance at constant HRT with increasing OLR*

Figure 2 and Figure 5 show the monitoring parameters for R1-4 during the experimental period, while Figure 3 & 4 shows the volumetric biogas and methane yield and the biogas methane content for each digester, and the specific biogas and methane production and actual/theoretical methane. The main performance parameters for each set of operating conditions are summarised in Table 4 UASB performance at different OLR and constant HRT.

*Treatment performance*

Effluent COD concentrations rose approximately in step with influent COD (as shown in Figure 2). COD removal efficiency was over 90 % in all reactors from day 2 onwards and remained consistently high at all OLR tested, with an average value of 95% for R1-4. Effluent TSS concentrations were generally below 20 mg $l^{-1}$ apart from occasional disturbances. TSS removal efficiency was also high stabilising at around 93 % at the maximum OLR of 2.3 g COD $l^{-1}$ $day^{-1}$.

## Table 4 UASB performance at different OLR and constant HRT

| **Reactor** | **Average OLR** | **COD removal** | **VMP[a] added** | **Methane** | **SMP added [b]** | **SMP removed [c]** | **Actual/Th $CH_4$ [d]** |
|---|---|---|---|---|---|---|---|
| | g COD $l^{-1}$ $day^{-1}$ | % | 1 l-1 day-1 | % | l $CH_4$ $g^{-1}$ COD added | l $CH_4$ $g^{-1}$ COD removed | |
| Nominal OLR 0.5 (last 30 days of start-up) | | | | | | | |
| 1 | 0.44 | 0.90 | 0.113 | 0.78 | 0.256 | 0.284 | 0.82 |
| 2 | 0.46 | 0.94 | 0.123 | 0.78 | 0.259 | 0.276 | 0.79 |
| 3 | 0.44 | 0.94 | 0.120 | 0.78 | 0.261 | 0.278 | 0.77 |
| 4 | 0.44 | 0.90 | 0.093 | 0.78 | 0.202 | 0.224 | 0.60 |
| Average | 0.45 | 0.92 | 0.112 | 0.78 | 0.245 | 0.266 | 0.75 |
| Nominal OLR 1 (last 30 days) | | | | | | | |
| 1 | 0.90 | 0.96 | 0.296 | 0.78 | 0.328 | 0.343 | 0.98 |
| 2 | 0.96 | 0.96 | 0.307 | 0.79 | 0.307 | 0.320 | 0.91 |
| 3 | 0.93 | 0.95 | 0.312 | 0.79 | 0.320 | 0.336 | 0.96 |
| 4 | 0.93 | 0.95 | 0.299 | 0.79 | 0.307 | 0.323 | 0.92 |
| Average | 0.93 | 0.95 | 0.304 | 0.79 | 0.315 | 0.330 | 0.94 |
| Nominal OLR 1.3 (last 20 days) | | | | | | | |
| 1 | 1.34 | 0.98 | 0.436 | 0.78 | 0.326 | 0.334 | 0.95 |
| 2 | 1.39 | 0.97 | 0.446 | 0.78 | 0.308 | 0.318 | 0.91 |
| 3 | 1.38 | 0.96 | 0.448 | 0.79 | 0.310 | 0.322 | 0.92 |
| 4 | 1.34 | 0.97 | 0.434 | 0.79 | 0.311 | 0.321 | 0.92 |
| Average | 1.36 | 0.97 | 0.441 | 0.78 | 0.314 | 0.324 | 0.93 |
| Nominal OLR 1.8 (last 10 days) | | | | | | | |
| 1 | 1.81 | 0.97 | 0.574 | 0.76 | 0.318 | 0.326 | 0.93 |
| 2 | 1.84 | 0.97 | 0.559 | 0.76 | 0.289 | 0.297 | 0.85 |
| Average | 1.82 | 0.97 | 0.567 | 0.76 | 0.303 | 0.311 | 0.89 |
| Nominal OLR 2.3 (last 50 days) | | | | | | | |
| 1 | 2.28 | 0.96 | 0.708 | 0.76 | 0.310 | 0.324 | 0.93 |
| 2 | 2.30 | 0.96 | 0.753 | 0.77 | 0.314 | 0.327 | 0.93 |
| 3 | 2.30 | 0.96 | 0.754 | 0.78 | 0.314 | 0.328 | 0.94 |
| 4 | 2.24 | 0.96 | 0.736 | 0.75 | 0.316 | 0.329 | 0.94 |
| Average | 2.28 | 0.96 | 0.738 | 0.76 | 0.313 | 0.327 | 0.93 |

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 $g^{-1}$ COD

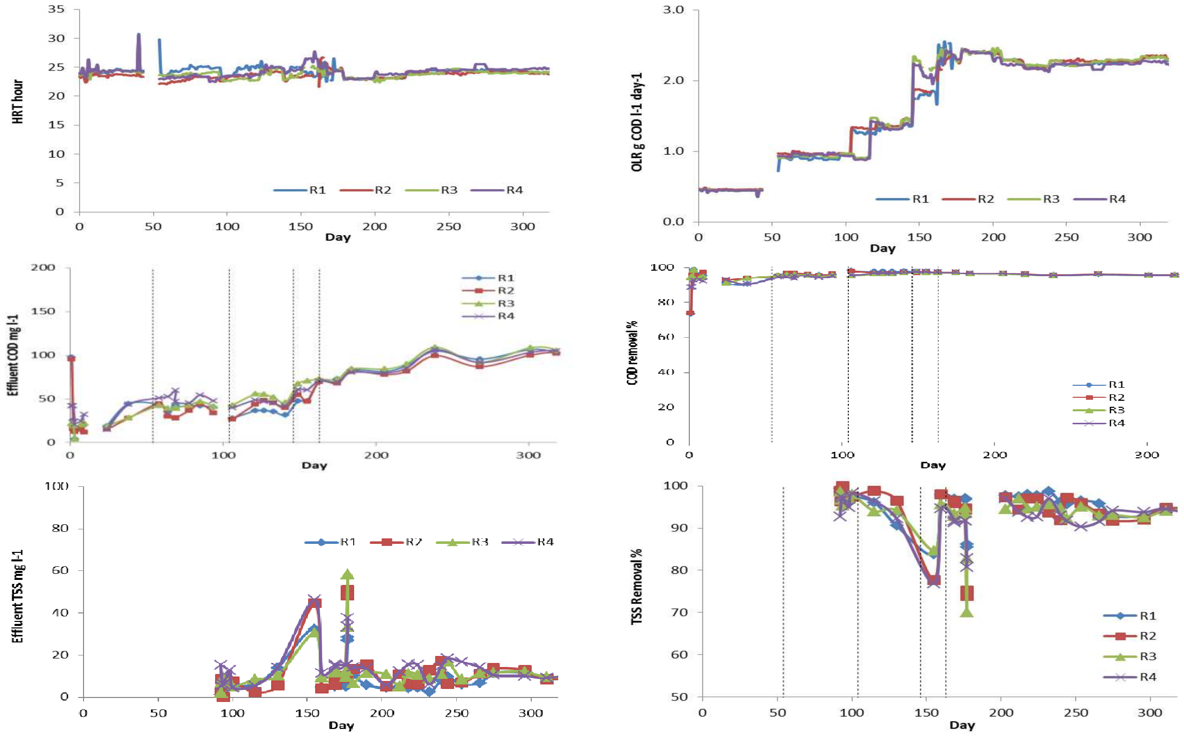


Figure 2 HRT, OLR, effluent COD and TSS and COD and TSS removal for R1-4 during operation at 35 °C. The vertical dotted lines indicate a change in OLR as shown in Table 4 UASB performance at different OLR and constant HRT

## *Biogas production*

Volumetric gas production in all reactors responded quickly to increases in OLR (as shown in Figure 3), reaching around 0.74 l $CH_4$ $l^{-1}$ day at the maximum OLR applied. Specific biogas and methane production showed some fluctuation up to day ~75 (as shown in Figure 4), indicating that the reactors were still acclimating to the substrate and the OLR. These values then stabilised at around 0.40 l biogas $g^{-1}$ COD added, 0.311 l $CH_4$ $g^{-1}$ COD added and 0.32 l $CH_4$ $g^{-1}$ COD removed. The average biogas methane content in all reactors was around 77%.
The theoretical methane equivalence of COD is 0.350 litres $CH_4$ $g^{-1}$ COD at STP 0 $^0$C and 101.325 kPa (Angenent and Sung 2001), and the actual specific methane production per g of COD removed therefore represents around 92 % of this theoretical value.

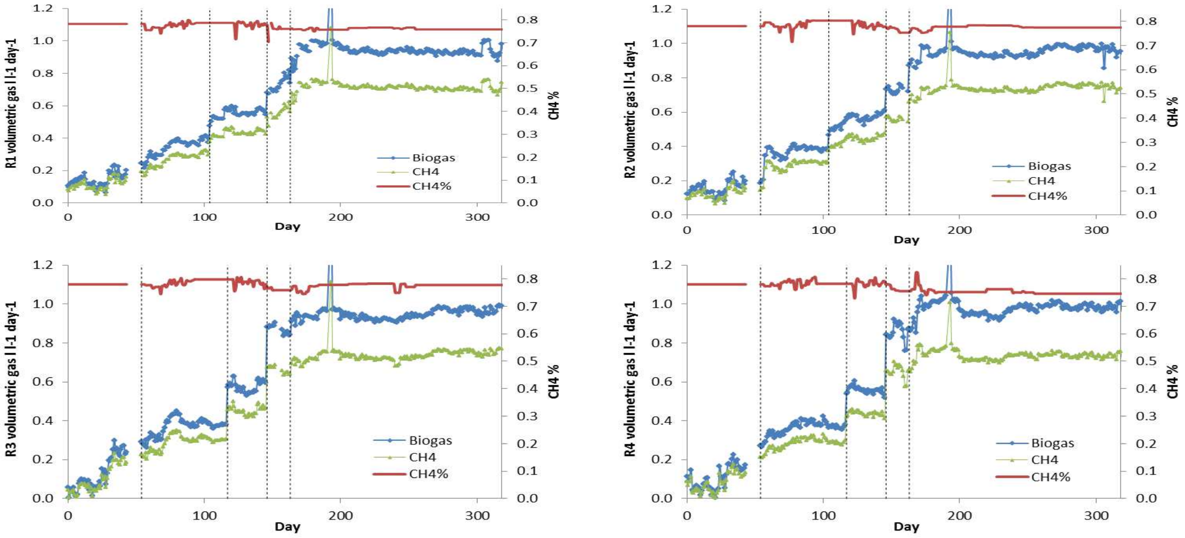


Figure 3 Volumetric biogas and methane production and biogas methane content for R1-4 during operation at 35 $^{o}$C. The vertical dotted lines indicate a change in OLR as shown in Table 4 UASB performance at different OLR and constant HRT, $CH_4$ content shown as fractions (i.e. %/100).

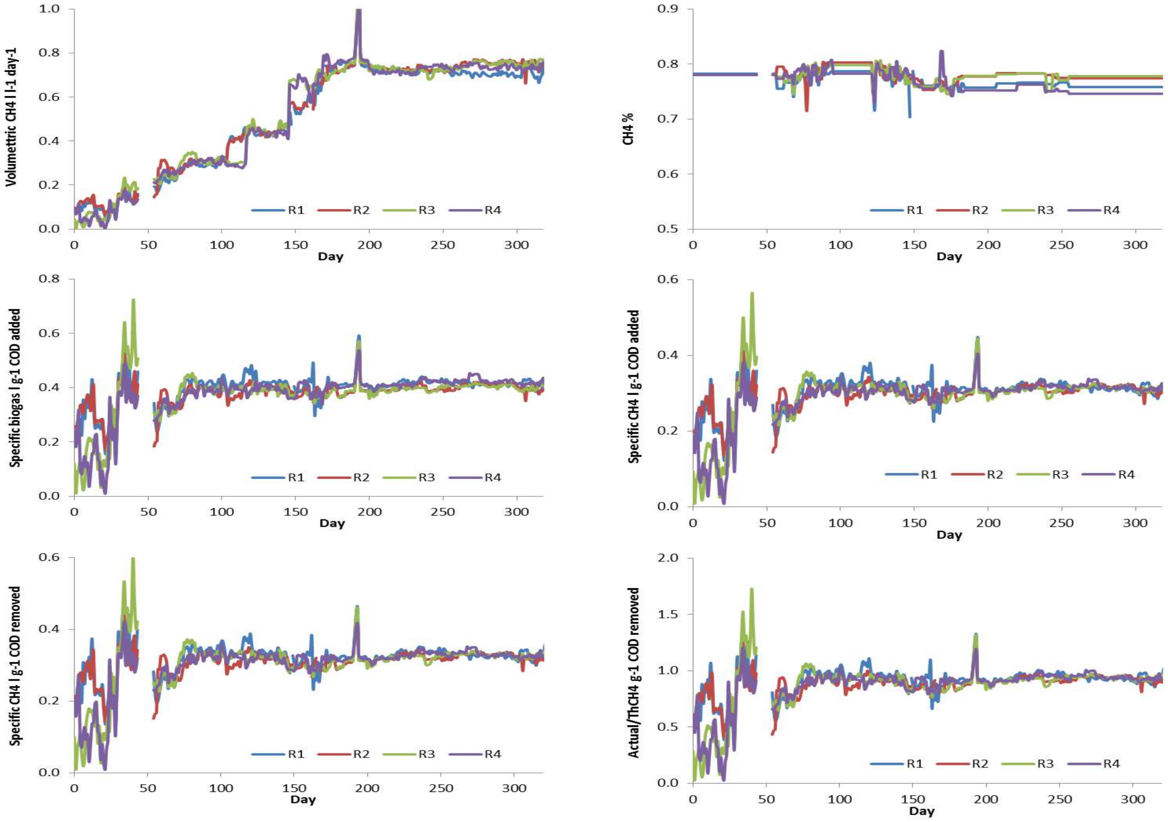


Figure 4 Volumetric methane production, biogas methane content, specific biogas and methane production and actual/theoretical methane for R1-4 during operation at 35 $^{o}$C.

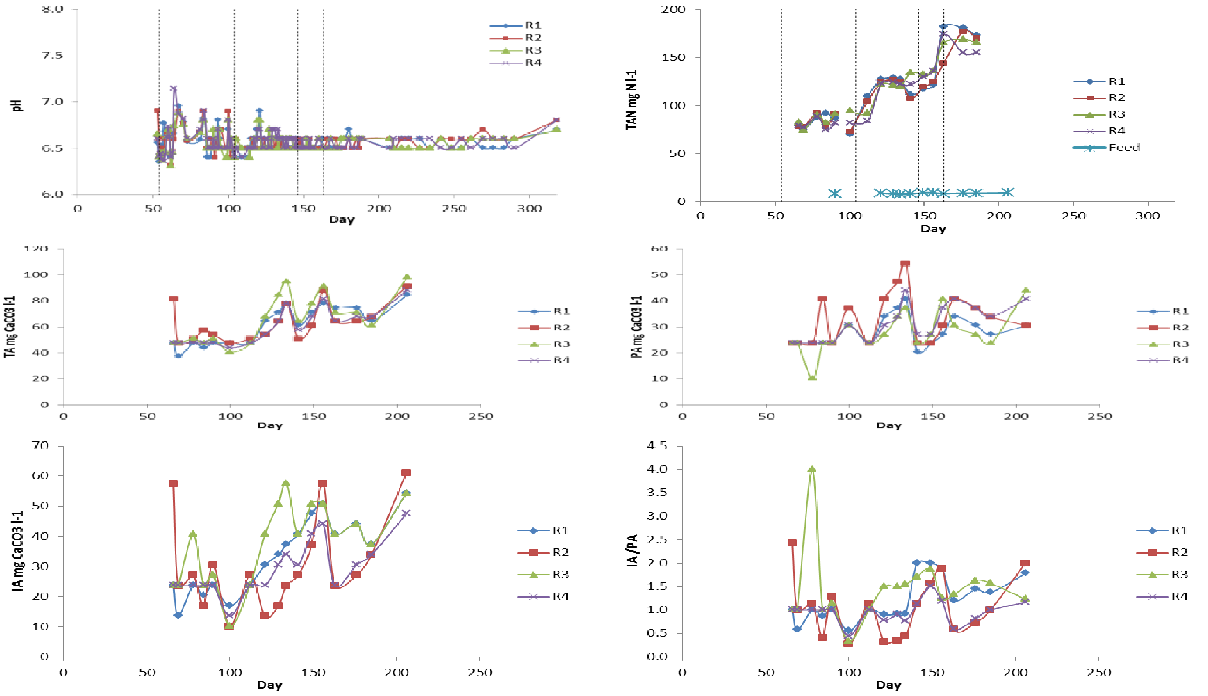
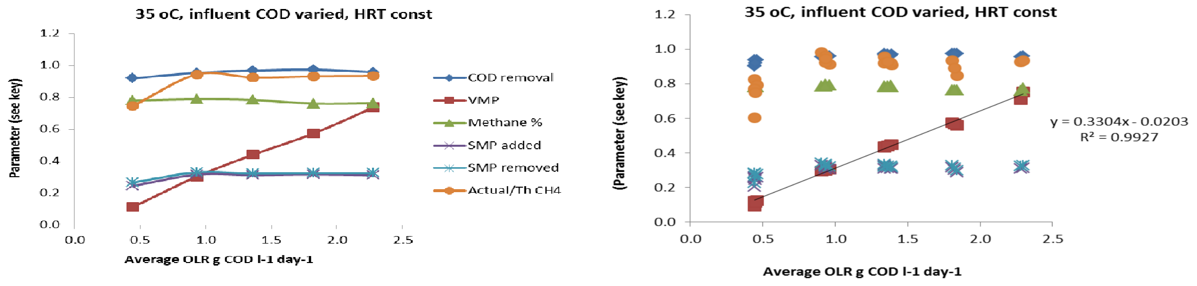


Figure 5 Effluent pH, TAN and alkalinity for R1-4 during operation at 35 $^{o}$C.

## *Overall performance*

Table 5 overall performance parameters with increasing OLR and shown in Figure 6, summarise the results at each OLR. It can be seen that, apart from at the lowest OLR, COD removal and SMP are unchanged tested while the volumetric methane production (VMP) increases linearly with OLR, at a rate of 0.33 l $CH_4$ $g^{-1}$ COD added. This is as expected, as the range of OLR tested is well within the reported capacity of mesophilic UASB. The values in Table 5 are closely similar to those found by Idrus (2013) using the same synthetic sewage substrate. At 0.45 g VS $l^{-1}$ day-$^{1}$ the values for all parameters were slightly lower, probably indicating that the system was still acclimating to the operating temperature and feedstock in this start-up period (Idrus 2013).



(a) Average values (b) All data

Figure 6 Kinetics of key parameters with increasing OLR and increasing influent COD at 35 $^{o}$C

**Table 5 Overall performance parameters with increasing OLR**

| **Average OLR** | **COD removal** | **VMP** | **Methane** | **SMP added** | **SMP removed** | **Actual/Th $CH_4$** |
|---|---|---|---|---|---|---|
| g COD $l^{-1}$ $day^{-1}$ | % | l $l^{-1}$ $day^{-1}$ | % | l $CH_4$ $g^{-1}$ COD added | l $CH_4$ $g^{-1}$ COD removed | |
| 0.45 | 0.92 | 0.11 | 0.78 | 0.245 | 0.266 | 0.75 |
| 0.93 | 0.95 | 0.30 | 0.79 | 0.315 | 0.330 | 0.94 |
| 1.36 | 0.97 | 0.44 | 0.78 | 0.314 | 0.324 | 0.93 |
| 1.82 | 0.97 | 0.57 | 0.76 | 0.318 | 0.326 | 0.93 |
| 2.28 | 0.96 | 0.74 | 0.76 | 0.313 | 0.327 | 0.93 |

### *Reactor performance at constant influent COD with increasing OLR*

In this part of the experiment, the second set of reactors (R5-8) was started up and used to investigate the performance of the system with a constant influent COD concentration and with increases in OLR achieved by reducing the HRT.

The main performance parameters for each set of operating conditions are summarised in Table 6 for Figures 7-8. Figure 9 show the monitoring parameters for R5-8 during the experimental period.

### *Treatment performance*

Effluent COD concentrations rose slightly with the decrease in HRT from 24 to 12 hours, but remained ≤ 60 mg $l^{-1}$ (as shown in Figure 7). Average COD removal efficiency remained over 90%. Effluent TSS concentrations were consistently below 20 mg $l^{-1}$ and TSS removal efficiency was high, averaging around 95% throughout the experimental period.

*Biogas production*. Volumetric gas production responded very quickly to increases in OLR in all reactors apart from R5, where there was a lag until day ~35: this was probably due to floating on day 4 followed by setting up again.

Specific biogas and methane production stabilised at around 0.40 l biogas $g^{-1}$ COD added, 0.311 l $CH_4$ $g^{-1}$ COD added and 0.33 l $CH_4$ $g^{-1}$ COD removed (average for last 100 days). The average biogas methane content in all reactors was around 77% (as shown in Figure 8 and Table 7). The actual specific methane production per g of COD removed was around 96% of the theoretical value.

**Table 6 UASB performance at different OLR and constant influent COD**

| Reactor | Average OLR | Average HRT | COD removal | VMP | Methane | SMP added | SMP removed | Actual/ Th $CH_4$ |
|---|---|---|---|---|---|---|---|---|
| | g COD $l^{-1}$ day-1 | Hours | % | $l\ l^{-1}$ day$^{-1}$ | % | l $CH_4$ $g^{-1}$ COD added | l $CH_4$ $g^{-1}$ COD removed | |
| Nominal HRT 24 hours (last 30 days) | | | | | | | | |
| 5 | 0.48 | 23.3 | 0.93 | 0.148 | 0.75 | 0.310 | 0.332 | 0.95 |
| 6 | 0.48 | 23.3 | 0.94 | 0.153 | 0.76 | 0.320 | 0.341 | 0.98 |
| 7 | 0.47 | 23.7 | 0.94 | 0.150 | 0.75 | 0.319 | 0.340 | 0.97 |
| 8 | 0.46 | 24.0 | 0.93 | 0.150 | 0.75 | 0.322 | 0.345 | 0.99 |
| Average | 0.47 | 23.6 | 0.94 | 0.150 | 0.75 | 0.318 | 0.340 | 0.97 |
| Nominal HRT 12 hours | | | | | | | | |
| 5 | 0.97 | 11.4 | 0.90 | 0.300 | 0.76 | 0.309 | 0.345 | 0.99 |
| 6 | 0.97 | 11.4 | 0.90 | 0.293 | 0.77 | 0.301 | 0.334 | 0.95 |
| 7 | 0.97 | 11.4 | 0.91 | 0.282 | 0.77 | 0.290 | 0.319 | 0.91 |
| 8 | 0.97 | 11.4 | 0.91 | 0.285 | 0.75 | 0.294 | 0.322 | 0.92 |
| Average | 0.97 | 11.4 | 0.90 | 0.290 | 0.76 | 0.298 | 0.330 | 0.94 |
| Nominal HRT 8 hours | | | | | | | | |
| 5 | 1.41 | 7.9 | 0.89 | 0.429 | 0.78 | 0.305 | 0.342 | 0.98 |
| 6 | 1.42 | 7.9 | 0.89 | 0.433 | 0.78 | 0.306 | 0.343 | 0.98 |
| 7 | 1.42 | 7.8 | 0.91 | 0.425 | 0.78 | 0.299 | 0.328 | 0.94 |
| 8 | 1.42 | 7.9 | 0.91 | 0.450 | 0.77 | 0.317 | 0.348 | 0.99 |
| Average | 1.42 | 7.9 | 0.90 | 0.435 | 0.78 | 0.307 | 0.340 | 0.97 |

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 $g^{-1}$ COD

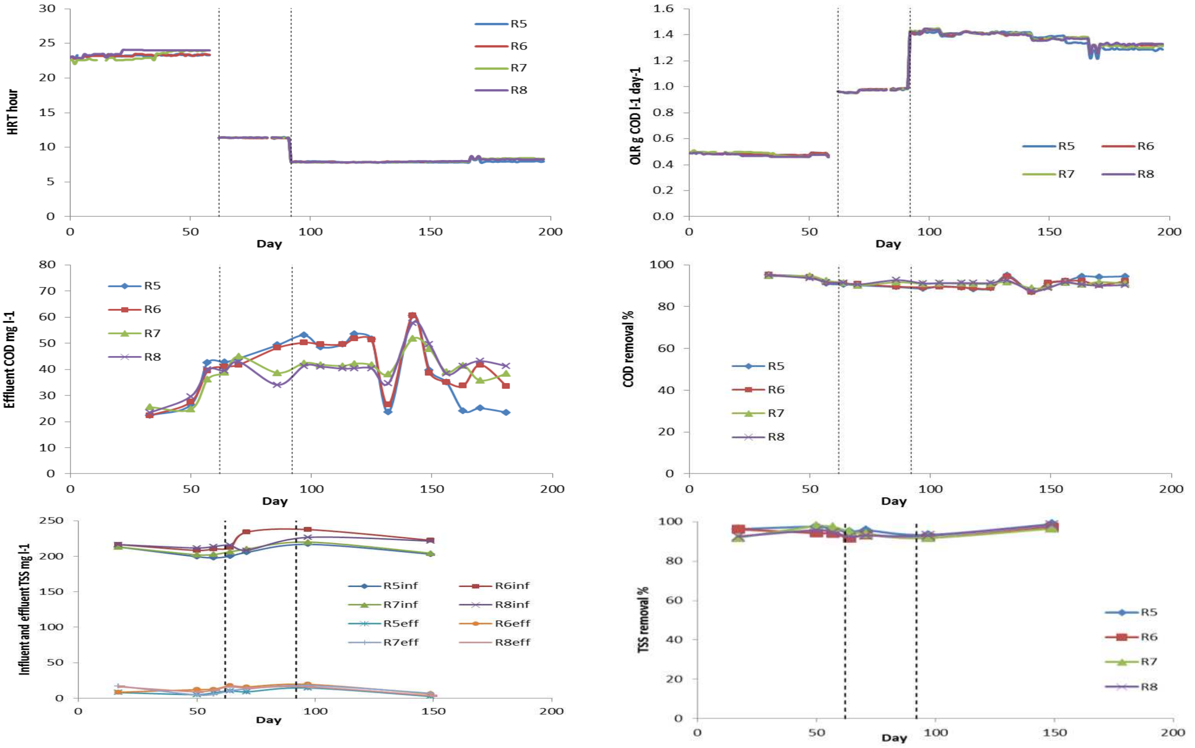


Figure 7 HRT, OLR, effluent COD and TSS and COD and TSS removal for R5-8 during operation at 35 $^{o}$C. The vertical dotted lines indicate a change in OLR..8.

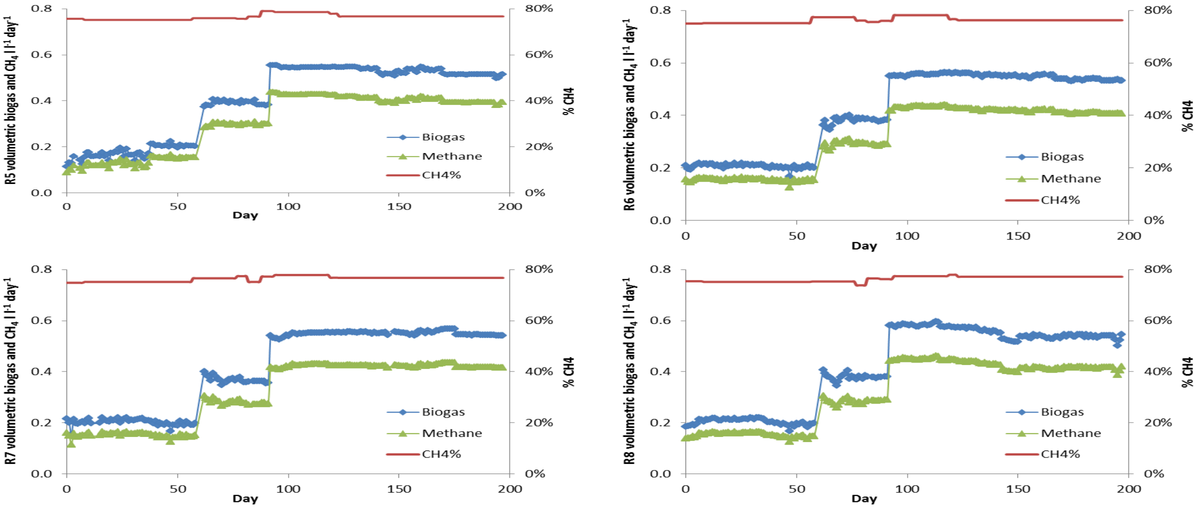


Figure 8 Volumetric biogas and methane production and biogas methane content for R5-8 during operation at 35 $^{0}$C.The vertical dotted lines indicate a change in OLR as shown in Table 7. $CH_4$ content shown as fractions (i.e. %/100).

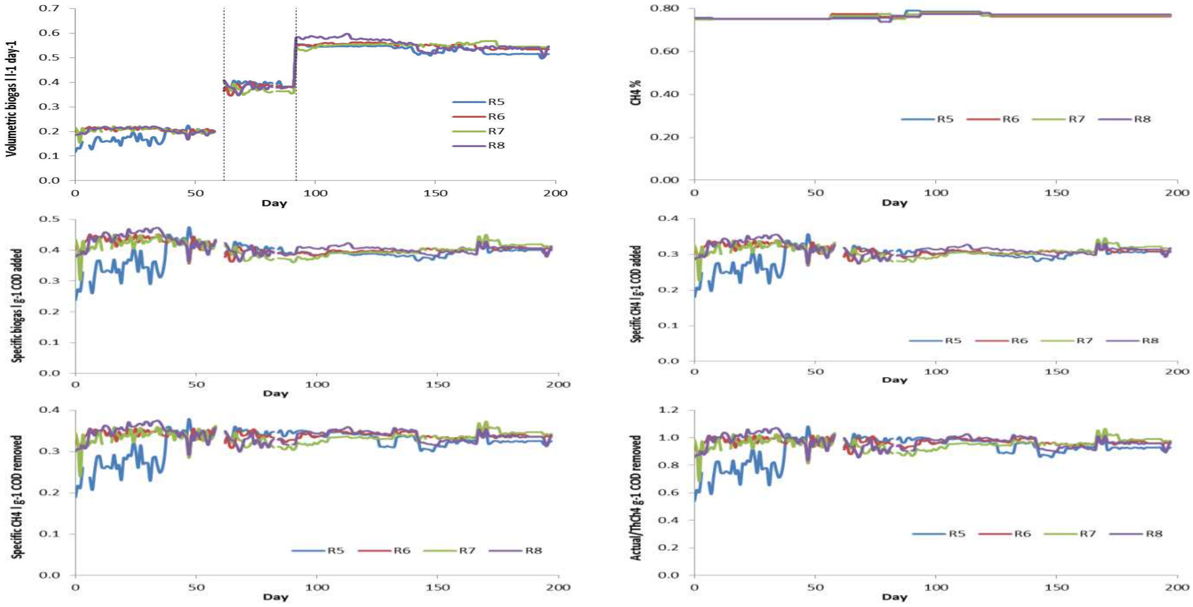
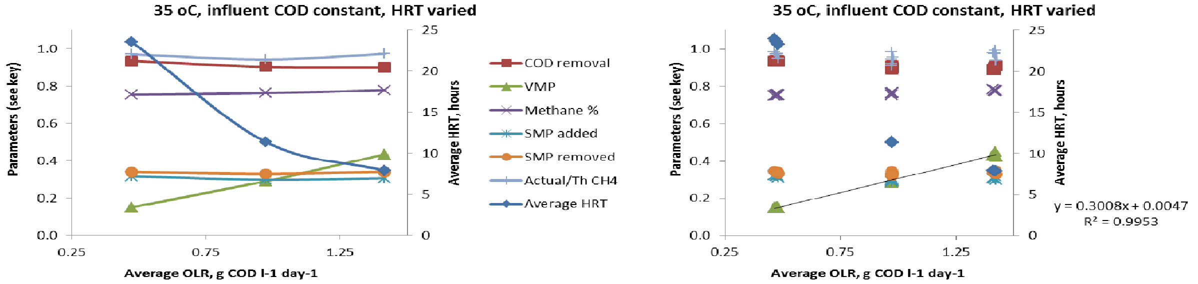


Figure 9 Volumetric methane production, biogas methane content, specific biogas and methane production and actual/theoretical methane for R5-8 during operation at 35 $^{o}$C.

*Overall performance*

The results for each OLR tested are summarised in Table 7 and Figure 10. As with the previous trial of constant HRT, VBP has a linear relationship with OLR and there are no significant changes in other key parameters, apart from a possible slight reduction in COD removal. The slope of the line of VMP/OLR is slightly lower at 0.30 l $CH_4$ $g^{-1}$ COD added, however, indicating that the reduction in HRT may be having some effect.



(a) Average values (b) All values

Figure 10 Kinetics of key parameters with increasing OLR and constant influent COD at 35 $^{o}$C.

**Table 7 Average performance parameters at each OLR during operation at 35 °C**

| Average OLR | Average HRT | COD removal | VMP | $CH_4$ | SMP added | SMP removed | Actual/ Th$CH_4$ |
|---|---|---|---|---|---|---|---|
| g COD l$^{-1}$ day$^{-1}$ | Hours | % | l l$^{-1}$ day$^{-1}$ | % | l $CH_4$ g$^{-1}$ COD added | l $CH_4$ g$^{-1}$ COD removed | |
| 0.47 | 23.6 | 0.94 | 0.15 | 0.75 | 0.318 | 0.340 | 0.97 |
| 0.97 | 11.4 | 0.90 | 0.29 | 0.76 | 0.298 | 0.330 | 0.94 |
| 1.42 | 7.9 | 0.90 | 0.43 | 0.78 | 0.307 | 0.340 | 0.97 |

It is clear that the UASB reactors are capable of providing highly effective treatment in terms of COD and TSS removal in the conditions tested, and of recovering a high proportion of the energy available in the substrate in the form of methane.

*Energy balance*

The energy density of methane is 50.1 MJ kg$^{-1}$ lower heating value (LHV) and 55.5 MJ kg$^{-1}$ higher heating value (HHV)(Hamelers 2008).

**Table 8 Energy balance of methane production**

| | Influent COD | Actual/ Th$CH_4$ | Energy in $CH_4$ from effluent |
|---|---|---|---|
| | mg l$^{-1}$ | | kJ l$^{-1}$ |
| Constant HRT | 450 | 0.75 | 4.7 |
| | 900 | 0.94 | 11.8 |
| | 1350 | 0.93 | 17.4 |
| | 1800 | 0.93 | 23.4 |
| | 2250 | 0.93 | 29.3 |
| Constant Influent COD | 450 | 0.98 | 6.1 |
| | 450 | 0.94 | 5.9 |
| | 450 | 0.97 | 6.1 |

## Conclusions

The results showed that UASB reactors operated at a temperature of 35$^0$C were highly effective in the treatment of synthetic sewage at influent COD concentrations from 450 to 2250 mg l$^{-1}$ COD at a constant HRT of 1 day, and at HRT from 24 to 8 hours with an influent COD concentration of 450 mg l$^{-1}$. The specific methane yield obtained was around 0.32 l $CH_4$ g-$^{1}$ COD removed. COD removal efficiencies were high at ≥ 93 % and total suspended solid removal was around 95 %.

Anaerobic wastewater treatment is a low cost process, and is finally ready to be considered simple and reliable. The main advantages over the conventional aerobic processes are reduced required area, lower energy consumption, lower nutrients requirements, and the possibility of energetic application of the biogas.

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## ملخص

تعد إدارة مخلفات السائلة إحدى المشكلات البيئية الهامة التي تواجه البلدان المطلة على حوض البحر الأبيض المتوسط وإن التخلص الامن من هذه المخلفات يعتبر حاجة ماسة في وقتنا الراهن و يعد الغاز الحيوي الناتج عن الهضم اللاهوائي للمواد العضوية , مصدراً للطاقة المتجددة. إن إنتاج الميثان خلال الهضم اللاهوائي سوف يعود بالفائدة على المجتمع كونه أحد مصادر الطاقة النظيفة التي تساهم في الحد من مشكلة ارتفاع حرارة الكون والمطر الحامضي وايضا منع التلوث الناتج من عدم معالجة هذه المخلفات. في هذا البحث تم استخدام 8 مفاعلات لاهوائية لمعالجة مياه الصرف الصحي داخل المعمل عند درجة حرارة 35 درجة مئوية واختبار ادائها تحت مجموعة من الظروف مثل التغير في تركيز المواد العضوية ومدة بقاءه على كفاءة المعالجة وانتاج الغاز واظهرت النتائج المتحصل عليها ان هذه المفاعلات تمتاز بكفاءة عالية في المعالجة وازالة الملوثات وايضا في انتاج غاز الميثان حيث وصلت كمية المواد العالقة المزالة الى 95% وكمية الطلب الكيميائي للأكسجين المزال الى 93% مما يؤكد مدى صلاحية هذه التقنيات للاستخدام في المناطق التي تمتاز بارتفاع متوسط درجات الحرارة