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The potential anaerobic-aerobic treatment of increased strength wastewater as a result of the use of food waste disposal units (FWDs)

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Abstract

Anaerobic treatment of increased strength wastewater (WW) as a result of the use of food waste disposal units (FWDs) is considered to be an economically viable intervention. This is because of its potential methane (CH_4) generation and the production of reduced amount of sludge at low capital and operational costs. However, the anaerobic treatment performance in cold areas (<20°C) is considered to be inefficient, necessitating an additional aerobic biological step to ensure the remove of residual carbon and nutrients. This paper using the GPS-X Hydromantis simulator assesses the potential integration of anaerobic-aerobic treatment processes for enabling the successful treatment of increased strength WW at low temperatures, using the UASB reactor as a high-rate bioreactor. Findings demonstrate that while low temperature can be a limiting factor to the performance of anaerobic treatment of increased strength WW, its benefits over conventional aerobic treatment processes may support its uptake. Gaining an improved insight into its limitations and how these can be solved, and investigating its social, economic and environmental aspects, is critical in determining the potential opportunities and threats that this intervention can create. Further research developments should focus on exploring the potential of new technologies and interventions developed in this area of research in order to inform the development of a viable and sustainable plan that could retain the full value of food waste and WW generated, either in the same or separated pathways.

Keywords: Food waste disposal units (FWDs), anaerobic treatment, WW treatment, methane production, GPS-X Hydromantis simulator

1. Introduction

Food waste disposal units (FWDs), a food waste management option, grinds food waste with the addition of tap water and subsequently disposes it into the sewer for treatment with wastewater (WW). Conventional aerobic processes used for the treatment of the increased strength WW resulting from the use of FWDs, although effective in meeting the effluent discharge standards, are associated with rising costs due to the increased energy consumption and sludge handling requirements. This can be a major problem to WW treatment operations, especially in Europe, where regulations require energy consumption to be reduced and renewable energy generation to be increased, as a way to tackle climate change (Environment Agency, 2010). As a result, new WW treatment alternatives are increasingly being investigated in an attempt to reduce energy requirements, carbon emissions and costs in addition to increase renewable energy generation.

The implementation of anaerobic technology for the treatment of WW is considered a mechanically and economically viable solution due to its ability to generate methane (CH_4) – a renewable source of energy – and reduce sludge. At the same time, anaerobic treatment offer additional benefits including low construction, operational and maintenance costs, high organic removal efficiency and less land requirements (Lettinga, 1995, 2006; Mahmoud *et al.*, 2004). In addition, it can bring about biodegradation of dangerous organic pollutants such as organotins and endocrine disrupting compounds that may be present in WW (Barnabé *et al.*, 2009; Fent, 1996; Voulvoulis and Lester, 2006).

Anaerobic treatment of WW is extensively used in warmer climates, yet its application in colder areas is considered to be inadequate, especially at temperatures lower than 20°C (Lettinga *et al.*, 1983). This is due to the fact that at low temperatures the hydrolysis rate becomes slow, which results to a decrease in BOD removal efficiency and accumulation of suspended solids (SS) (Bodik *et al.*, 2000; Elmitwalli, 2001; Langenhoff and Stuckey, 2000; Lew *et al.*, 2009; Nachaiyasit and Stuckey, 1995).

This paper, making the presumption that the use of FWDs is a common practice, aims to assess the performance of the anaerobic-aerobic treatment of increased strength WW at low temperatures, over conventional aerobic treatment, using the upflow anaerobic sludge bed (UASB) high rate bioreactor. This reactor was selected based on its capability to retain a high concentration of biologically active aggregated biomass in the form of granules (Lew *et al.*, 2004; Singh and Viraraghavan, 2004). Comparison of the two processes was performed via modelling as presented in the Methodology (**Section 2**). The results presented in **Section 3** are then interpreted and discussed in **Section 4**.

2. Methodology

Using the GPS-X software, developed by Hydromantis Inc., the conventional aerobic treatment and the anaerobic-aerobic treatment processes flowsheets were constructed (**Figure 1a and 1b**). The increase in the WW fraction due to the use of FWDs was estimated at 3.51 l/d, using the methodology presented in Iacovidou *et al* (2012). With a per capita WW generation rate of 130 l/d (Ofwat, 2011), and data on BOD, N and P concentration reported at 8.37g/l, 0.27 g/l and 0.054 g/l of food waste ground (Thomas, 2011), the input data were estimated. Flow rate was estimated at 1335 m3/d, while BOD, TKN and TP concentrations were estimated at 650 mg/l, 46.5 mg/l, and 11.3 mg/l respectively. These were adjusted in the influent WW characterisation of both flowsheets. The carbon, nitrogen, phosphorus data were adopted from library mantis2 provided by Hydromantis (Hydromantis, 2012).

Simulations were run at a steady-state of 30 days, 20^{o}C, which is the lowest temperature at which GPS-X can simulate the anaerobic treatment performance with a relatively low uncertainty, and without changing the process kinetics (as advised by Hydromantis specialists). Changes in the design characteristics of the WW treatment objects were adjusted for calibrating the model. For the UASB reactor, the volume was set up to achieve a HRT of 8 hours, which is the average HRT used for UASB reactors working at a temperature of 20^{o}C (Elmitwalli *et al*., 2002; Singh and Viraraghavan, 2003). The dimensions of the primary sedimentation tank, CMAS reactor, secondary sedimentation tank and anaerobic digester were set up to an HRT of 4h, 3.2h, 3.2h and 4d, respectively. In anaerobic digestion process SRT and HRT were assumed to the same

The UASB reactor examined in this study was operated at 20^{o}C, without heating. This was taken as a prerequisite for the whole assessment, alleviating the need to heat up the reactor to a temperature in the optimal mesophilic range that would make its use less favourable than the conventional aerobic treatment due to high energy consumption (Lettinga *et al*., 2001). CH_4's density was calculated at the operational temperature (T^{o}C) using the following equation,

$$d_{CH_4,\,T^oC} = d_{CH_4,\,0^oC} \times \left(\frac{273.15 + 0^oC}{273.15 + T^oC}\right)$$

where $d_{CH_4,\,0^oC}$ is 0.7167g/l (Tchobanoglous and Burton, 2003). CH_4 has a calorific value of 50.1kJ/g and, using the conversion factor of 1kJ to 0.00278 kWh, the potential

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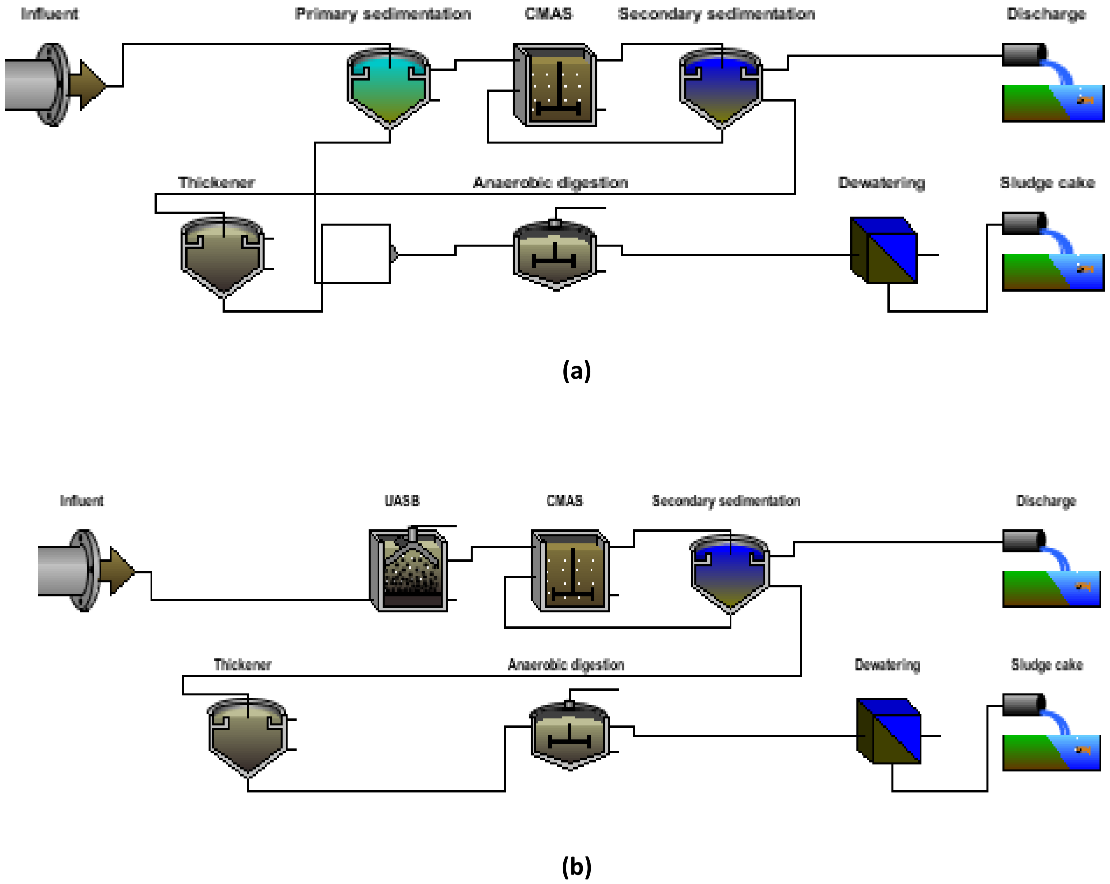

Figure 1 Flow sheets of the (a) conventional aerobic treatment process, (b) anaerobic-aerobic treatment as developed in the GPS-X software

renewable energy generation was calculated (Tchobanoglous and Burton, 2003).

An additional component of this study was to examine the effect of temperature increase on the anaerobic treatment performance. As such, simulations were also run at temperatures between 20 ^{o}C and 35^{o}C.

3. Results

In the conventional aerobic treatment process, primary sedimentation led to the removal of 63.7% and 38.2% of the influent TSS and BOD, respectively. This led 480 kg/d wt. of primary sludge that was diverted for further treatment. Effluent from primary sedimentation went into the CMAS where BOD and TSS were further removed, resulting in the generation of 340.3 kg/d wt. of waste activated sludge (WAS). Thickened WAS was mixed with primary sludge and fed into an anaerobic digester, where up to 333.23 m^3/d of biogas was produced. The composition of biogas was simulated at 61.8% CH_4 and 37.8% CO_2. The stabilised sludge produced was dewatered and disposed of as a sludge cake of 452 kg/d wt. In the anaerobic-aerobic treatment process, WW was treated in a UASB reactor where 69% of BOD and 23% of TSS were removed. Biogas production in the UASB reactor was found to be 262 m^3/d, of which 77% was CH_4 and 18% was CO_2. The remaining 5% was comprised of other gases, such as dinitrogen (N_2) and hydrogen (H_2). Effluent from the UASB reactor flowed into the CMAS and secondary sedimentation for further treatment, where 470 kg/d wt. of WAS was produced. Thickening of WAS by anaerobic digestion led to 32m^3/d of biogas production. This low biogas production can be explained by the low BOD and TSS content of WAS. The digested sludge was dewatered and disposed of as a sludge cake of 358kg/d wt.

In the anaerobic–aerobic treatment process total CH_4 generated was found to be approximately 33% more than in the conventional aerobic treatment process. This is in contrast to sludge which approximately 46% more, would need to be digested in the conventional aerobic treatment flow sheet compared to that of the anaerobic-aerobic treatment flow sheet.

Based on these findings, the incorporation of anaerobic treatment processes in WW treatment operations at 20^{o}C, presents several advantages to the water industry compared to the conventional aerobic treatment. Notwithstanding these advantages, a decrease in temperature could severely upset the microbial consortium, deteriorating the methanogenic activity in anaerobic reactor, and leading to a decrease in biogas production, while incurring additional risks associated with reduced process performance.

This effect is demonstrated herein, where the simulation of anaerobic treatment at temperatures between 35^{o}C and 20^{o}C presented a decrease in the BOD and TSS removal efficiencies and subsequently in biogas production. Additionally, while biogas production decreased with temperature, the CH_4 content of the biogas appeared to increase (**Table 1**).

In previous studies this is explained by the fact that as temperature decreases, acidogenesis rate also decreases lowering the proportion of CO_2 that remains unused, while increasing the proportion of CH_4. The production of acetate from CO_2 and H_2, and its subsequent reduction, was reported as another pathway to an increased proportion of CH_4 in the biogas (Massé *et al*., 2003). In this study, it was not possible to observe dissolved CH_4.

4. Discussion

The results of the anaerobic-aerobic treatment performance agree with those reported in the literature, where UASB reactors used for the treatment of WW demonstrated efficiencies of 50-70 or even 88% BOD removal at temperatures in the range of 12-18^{o}C and 20^{o}C, respectively (Alvarez and Lidén, 2009; Castillo *et al*., 1997; Elmitwalli *et al*., 1999; Seghezzo *et al*., 1998; Singh and Viraraghavan, 2003, 2004). In terms of TSS removal, some studies reported efficiencies higher than the 23% observed in this study. Nevertheless, it is known that UASB reactors may result in limited TSS removal owing to a fraction of solids that flows through the reactor un-reacted. In practice this can be improved by controlling the sludge bed height (Hydromantis, 2012). However, insights into the real performance of anaerobic-aerobic treatment process is limited by the incapability of the modelling software to provide outputs of high degree of certainty, as well as its inadequacy to project the amount of gases dissolved in the WW.

At low temperatures, CO_2 becomes more soluble in water than CH_4 (Singh and Viraraghavan, 2003). However, the potential CH_4 solubility presents the greatest challenge to the implementation of anaerobic-aerobic WW treatment at low temperatures. Methane's solubility even at the lowest proportions can be of major importance when it comes to greenhouse gas (GHG)

Table 1 Temperature effect on the UASB reactor performance (HRT of 8h)

Temperature	**35^{o}C**	**30^{o}C**	**25^{o}C**	**20^{o}C**
BOD removal (%)	71.8	71.2	70.3	69.2
TSS removal (%)	29	28.4	26.9	26.3
Biogas production (m^3/d)	413.7	390.5	364.6	340.1
CH_4 (%)	72.4	73.8	75.7	77.1
CO_2 (%)	23.9	22.3	20	18.2

emissions. Therefore, while the anaerobic-aerobic treatment process could assist the water industry in mitigating conventional energy consumption, it could thereby create problems associated with carbon emissions. This would require additional investments in, e.g. air-stripping or CH_4 capturing systems in order to ensure that implementation of anaerobic-aerobic treatment is an environmentally sound solution.

The exact proportion of CH4 dissolved in aqueous media at low temperatures is yet to be verified (Agrawal *et al.*, 1997; Lettinga *et al.*, 1983; Singh and Viraraghavan, 2003). For example, Uemura and Harada (2000) reported that 40 and 65% of CH4 produced was dissolved in the anaerobically-treated effluent at temperatures ranging from 25 oC to 13oC, whereas Yoda *et al.*, (1985) (as reported in the study of Sanz and Polanco) reported that CH4 collected at low temperatures represented 10-30% of the total CH4 produced, suggesting that 70-90% of the total CH4 produced was in the dissolved form (Sanz and Polanco-Fdz, 1990; Uemura and Harada, 2000).

The extent to which BOD is removed at low temperatures is another determining factor of the efficiency of anaerobic-aerobic treatment of WW. Although, it was reported that increased strength of the influent WW may lead to increased reactor performance and thus higher efficiency, even at low temperatures (Castillo *et al.*, 1999; Lettinga *et al.*, 2001), this remains unknown. Untreated WW at the anaerobic step would require more intensive treatment at the aerobic biological step, increasing the retention time and aeration, while incurring additional costs. Consequently, consideration of adding anaerobic-aerobic treatment of WW as a way of optimising the recovery of the calorific value embedded in food waste is increasingly required. Such optimisation should be based on a holistic analysis and evaluation of the environmental, economic and social aspects associated with the anaerobic–aerobic treatment process in order to best gauge its potential benefits over conventional aerobic treatment for sound decision-making in this area.

Recent advancements in anaerobic technology currently available in the market, such as membrane bioreactors and fixed-film reactors, are reported to achieve higher efficiencies and be less sensitive to environmental variations than high rate bioreactors (Chan *et al.*, 2009). However, the benefits of any technology and/or intervention may only become realised only if the social, economic and environmental aspects are properly assessed and evaluated. Further research developments should focus on looking at the sustainability of WW treatment interventions, in order to unlock benefits and potential opportunities to the water industry operations and society that are both dependent and independent of the prevailing climatic conditions.

5. Conclusions

Prejudice against the performance of anaerobic treatment of WW at low temperatures is an obstacle to its implementation in cold climates like that in the UK. Here we demonstrated that the application of anaerobic-aerobic treatment of increased strength WW as a result of the use of FWDs presents relative benefits over the conventional aerobic treatment. It offers higher renewable energy generation rate, and produces less sludge production, both associated with lower costs while it could generate incentives. Notwithstanding the benefits of this intervention, limitations associated with the organic content removal, and the generation and solubility of biogas could be manifested during its implementation; thus impeding its successful implementation. With these limitations being better investigated, a holistic assessment of the social, economic and environmental perspectives should be then undertaken in order to determine the potential opportunities and threats that this intervention can create. Placing the effort required to exploring the potential of new technologies and interventions developed in this area of research could inform the development of a viable and sustainable plan that could retain the full value of food waste and WW generated, either in the same or separated pathways.

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