An innovative low-temperature anaerobic system for high quality biogas production from municipal sewage

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Introduction

Despite being performed for many years, nowadays wastewater treatment has to face new issues due to its energy requirement and production of solid waste (i.e. waste sludge). In past years high strength wastewaters (COD > 4-5 Kg/m^3) were usually treated by means of anaerobic digestion (AD) processes, whereas low strength wastewater were treated by aerobic processes. This approach relied on the amount of energy recoverable from wastewater during AD process in the form of biogas. The latter should ensure process thermoregulation (usually at 35-40°C) and production of extra energy in the form of heat and electricity (Chang et al. 2009). In case of low strength wastewaters, such as municipal sewage, the limited energy content of wastewater suggested the use of aerobic treatment processes. However, these systems has relevant energy requirement (~ 0.6 kWh/m^3; Crone et al. 2016) and produce an undesirable byproduct, namely waste sludge, whose treatment and disposal accounts for about 60% of the treatment plant operating cost (Collivignarelli et al. 2019). Considering the increasing craving for alternative and renewable energy sources, as well as the growing concern about waste sludge management, there is a considerable interest in alternative anaerobic processes suitable for treatment of low strength wastewaters (Gomec et al. 2010). The common denominator of all the studies is the development of an effective and stable anaerobic digestion process operating at low/environmental temperature (i.e. 10-30°C; Crone et al. 2016). This approach would not only ensure energy recovery from diluted wastewaters but, due to the low sludge production characterizing AD processes (~ 0.1 KgTSS/KgCOD$_{rem}$), would also reduce the production of sludge to be disposed of. However, proper operation of AD process in psychrophilic conditions is affected by several issues including poor wastewater mixing (due to the limited generation of biogas bubbles), risk of biomass washout (due to the very low biomass production), low effectiveness in hydrolysis of particulate organic matter and significant loss of methane dissolved into plant effluent. Several reactor configurations have been investigated, but the above-mentioned issues are still not fully overcame (Lettinga et al. 2001; Gomec et al. 2010; Crone et al. 2016).

The current research was aimed to evaluate the effectiveness of an alternative anaerobic reactor operating in fill and draw mode (AnSBIO- Anaerobic Sequencing Biofilter) for treating municipal sewage and operating at environmental temperature. Biomass was confined in a packed section of the reactor in order to ensure a long sludge retention time (SRT) and therefore biomass concentration, whereas wastewater was recycled through the biomass providing its proper mixing.

Methods

A lab scale AnSBIO with a volume of 28 L was used in the present study. It was constituted (see Figure 1) by a packed zone (bed), filled with plastic filling material (14 L) entrapped between two sieves, and two liquid zones, a small one under the bed (1 L) and a bigger one above the bed (11 L). The residual volume (2 L) represented the reactor headspace. The reactor was operated in sequential mode on the basis of a 6 hour cycle with a total of 4 cycles per day. Each cycle included three phases: simultaneous filling/drawing, recirculation and idle phase. During the first phase, the wastewater is pumped into the bottom of the reactor and flows under near-plug flows conditions through the bed allowing the purified effluent at the top of reactor to be discharged from the port located in the upper section of the reactor. During the second phase, wastewater was continuously recycled from the top to the bottom of the reactor in order to ensure wastewater distribution and mixing through the bed. Biogas production was monitored by a MilliGascounter (Ritter), whereas biogas composition was determined by gas-chromatography. Temperature and pH were monitored by selective probes. Wastewater and reactor effluent were characterized in terms of chemical oxygen demand (COD), total and volatile suspended solids (TSS and VSS respectively), total nitrogen (TN), ammonia and phosphorous. Reactor's pH was maintained in the range 7.4-7.6 by adding a proper volume of buffer solution. The influent wastewater was constituted by real municipal sewage from the nearby of Bari (Italy) and sucrose. The latter was added in order to restore the ready biodegradable COD which quickly degraded in the storage tank.

Results

The anaerobic reactor was operated at environmental temperature (23±6 °C) for about three years treating 16 L/d of raw municipal sewage. Table 1 reports the composition of influent and effluent of the plant . Plant performances resulted effective and almost stable in terms of COD removal efficiency showing an average value of 83±7%. Conversely, limited efficiency was obtained for the other parameters. The removal of nitrogen and phosphorous was coherent with the low observed sludge growth yield calculated during the study, namely 0.10±0.07

kgTSS/kgCOD$_{removed}$. Indeed, in AD processes these nutrients are removed almost due to microbial growth. The low effectiveness in TSS removal was in agreement with previous studies on psychrophilic AD reactors reporting that hydrolysis of particulate matter is one of the factors affecting this operating condition (Lettinga et al. 2001; Gomec 2010; Crone et al. 2016).

Biogas production was never inhibited, even when reactor operated at 12°C, and showed a trend related to wastewater temperature. The latter influenced gas solubility, and therefore the amount of gas lost in the effluent (Crone et al. 2016). Indeed, the average amount of methane released in gas and liquid phase (i.e. lost in the effluent) per liter of treated wastewater accounted for 158±39 NmLCH$_4$/L$_{ww}$ (corresponding to 183±45 NmLCH$_4$/gCOD$_{rem}$) and 138±10 NmLCH$_4$/L$_{ww}$, respectively.

Interestingly, biogas was very rich in methane with an average concentration of 82% (Table 2) and even exceeded 90%. This value is much higher than that usually obtained in AD reactors working in mesophilic conditions and is close to the value reported in Leon et al. (2018) in a UASB reactor treating municipal wastewater and operating at 19°C. The production of methane rich biogas has been attributed to the different behavior of acetoclastic and hydrogenotrophic methanogens growing in mesophilic or psychrophilic conditions. The latter are less influenced by low temperature than acetoclastic methanogens and their relative abundance and activity increase in AD reactors operating in psychrophilic conditions (Smith et al. 2014). Therefore, more CO_2 can be converted in CH_4 by this metabolic pathway. However, in the present research, methane concentration in the biogas was only slightly influenced by wastewater temperature and very high methane concentration was observed even when temperature approached 30°C (during summer period). This result would reflect the effect of wastewater recirculation stream promoting gas solubilization, including H_2 and CO_2, which was likely to benefit hydrogenotrophic methanogens. Moreover, the high SRT enabled the maintenance of hydrogenotrophic methanogens in the reactor even during summer, when acetoclastic methanogens might become the dominant population.

Table 1 – Plant influent and effluent composition.

Parameter	**Influent (mg/L) (mean ± st. dev.)**	**Effluent (mg/L) (mean ± st. dev.)**
COD	1052 ± 268	175 ± 66
TSS	91 ± 78	84 ± 51
TN	41 ± 25	33 ± 24
P_{tot}	7 ± 4	6 ± 3

Table 2 – Biogas composition.

Biogas composition (%)					
CH_4	CO_2	N_2	O_2	H_2S	H_2
82 ± 8	5 ± 3	5 ± 3	2 ± 1	< 0.1	n.d.*

*n.d.: never detected

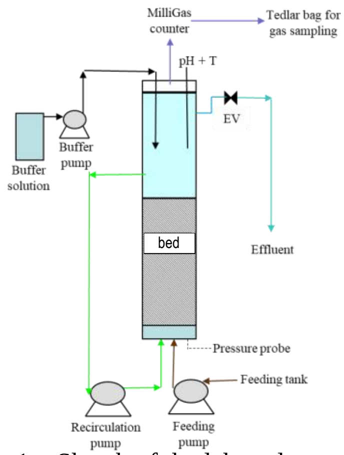

Figure 1 – Sketch of the lab scale anaerobic reactor.

References

Chang Y.J., Chong M.F., Law C.L., Hassell D.G. 2009. A review on anaerobic–aerobic treatment of industrial and municipal wastewater. *Chem. Eng. J.* **155**, 1-18.

Collivignarelli M.C., Abbà A., Miino M.C., Torretta V. 2019. What advanced treatments can be used to minimize the production of sewage sludge in WWTPs? *Appl. Sci*. **9**, 2650

Crone B.C., Garland J.L., Sorial G.A., Vane L.M. 2016. Significance of dissolved methane in effluents of anaerobically treated low strength wastewater and potential for recovery as an energy product: A review. *Water Res.* **104**, 520-531.

Gomec C.Y. 2010 High-rate anaerobic treatment of domestic wastewater at ambient operating temperatures: A review on benefits and drawbacks. *J. Environ. Sci. Health*. **45**, 1169-1184.

Lettinga G., Rebac S., Zeeman G. 2001. Challenge of psychrophilic anaerobic wastewater treatment. *Trends in Biotechnol*. **9**, 363-370.

Leòn E.S., Vargas-Machuca J.A.P., Corona E.L., Aribib Z., Rogalla F., Boizàn M.F. 2018. Anaerobic digestion of municipal sewage under psychrophilic conditions. *J. Clean. Prod.* **198**, 931-939.

Singh K.S., Viraraghavan T. 2004. Municipal wastewater treatment by UASB process: start-up at 20°C and operation at low temperatures. *Environ. Tech*. **25**, 621-634.

Smith A.L., Skerlos S.J., Rskin L. 2014. Anaerobic membrane bioreactor treatment of domestic wastewater at psychrophilic temperatures ranging 15°C to 3°C. *Environ. Sci.: Water Res. Technol.* **1**, 56-64.