Performance comparison between mesophilic and thermophilic anaerobic digestion processes carried out on waste activated sludge

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The most consolidated fate of waste activated sludge (WAS) is the production of renewable energy in the form of methane through anaerobic digestion (AD). However, stabilization and reduction of WAS volume during an AD process is hampered by the low degradability that characterizes this particular type of sludge. WAS is made of biological cells that contain a mixture of molecules such as proteins, peptides, lipids and polysaccharides. All these organic substances are surrounded by cell walls or bounded in complex structures (EPS, extracellular polymeric substance) and can only be made available for material and energy recovery after processes in which the bacterial flock structure is disintegrated, the cells are opened and the cell content is released outside. Typical processes capable to deliver intracellular organic substances are pre- or intermediate hydrolysis treatments carried out at high temperature (T > 100°C). The efficacy of these processes have already been demonstrated and implemented at the full scale (Cano et al., 2015; Armstrong et al., 2018).

However, other strategies to improve the lysis phase and, consequently, the overall performance of an AD process of WAS can be implemented. In fact, it is necessary to keep in mind that AD processes can be performed under three temperature conditions named psychrophilic (10-25 °C), mesophilic (30-40 °C) and thermophilic (50-60 °C). Several industrial AD applications designed for WAS management have utilized the mesophilic condition because of its high operational stability. Mesophilic conditions are also preferred to thermophilic conditions for energy and economic aspects, due to the lower demand for thermal energy. However, thermophilic AD presents an advantage over the mesophilic process in terms of disinfection of pathogens and enhanced methane production rate. Thermophilic conditions lead to faster degradation rates with a consequent reduction of digester volumes for a prefixed value of the organic loading rate (OLR) parameter. Values of hydraulic retention time (HRT) for thermophilic conditions are well below the typical values used in mesophilic conditions (i.e. in the order of 15-20 days).

The aim of this work was to prove the sustainability of a thermophilic AD process, in terms of kinetics and methane production, by using reactors at a pilot scale (44 L and 300 L). The WAS employed in the thermophilic tests was collected from one of the gravity pre-thickeners in the sludge line of Castiglione Torinese WWTP (2 M e.i.). WAS samples were characterized by an average TS content of 3% and a VS/TS ratio in the order of 70%. Thermophilic tests (55 °C) were carried out in a semi-continuous mode, in a 44-L pilot scale reactor, in a first phase, and in a 300-L digester, in a second phase. For both tests the HRT was fixed to 20 days. Fed substrate and digestate were analyzed for pH, FOS/TAC, TS, VS daily. Biogas was stored in a gasometer and continuously characterized for CH_4, CO_2, O_2 through a GA3000 Range Gas Analyzer.

The first phase of the test (44-L reactor) lasted approximately two months (57 days) and reached a steady methane production after 40 days from the beginning of the experimentation. No signs of acidification or instability were observed during the test. The test returned a specific methane production (SMP) that was 30% higher than that obtained in a test carried out in mesophilic conditions (38 °C) on the same substrate in the 300-L digester (Campo et al., 2018). The thermophilic test in the 300-L digester is still ongoing.

The methane production data returned from the first phase of the thermophilic test were fitted by using a first order kinetic model, as described by the equation system 1a and 1b, to obtain the B_0 and k parameters characteristic of the process. B_0 and k are the specific methane production and the rate constant of a first-order AD process in which hydrolysis is the limiting step, respectively. In fact, the solubilisation process (made of the disintegration and hydrolysis phases) is generally the rate-limiting step during the AD of particulate/complex substrates (Zhen et al. 2017). If hydrolysis is assumed as the limiting step of AD, the biogas/methane production can be modelled through a first order kinetics. In a semi-continuous reactor, the equations used to predict the methane production and the substrate degradation are (1a) and (1b)

$$\frac{d\,VS(t)}{dt} = \frac{q(t)\times VS_{\text{in}}(t)}{V} - \frac{q(t)\times VS(t)}{V} - k \times VS(t) \qquad (1a)$$

$$B_{CH_4}(t) = VS(t) \times k \times B_o \times V \qquad (1b)$$

where: *q(t)* is the flow rate fed and discharged; *V* is the working volume, VS_{in} is the concentration of volatile solid fed to the digester, *VS(t)* is the concentration of volatile solid inside the digester and $B_{CH_4}(t)$ is the daily methane production.

The model fitted the experimental data adequately, with an error of less than 1%. The values of the two parameters returned by the model were in the order of B_0 = 0.218 Nm^3/kg VS added and k = 0.380 d^{-1}. A fitting process carried out with the same model on the methane production data obtained in mesophilic conditions in the 300-L reactor (Campo et al., 2019) returned B_0 and k values of 0.147 Nm^3/kg VS added and 0.085 d^{-1}, respectively.

The comparison between the two tests carried out at 38 and 55 °C in reactors with volumes larger than those usually employed in AD experimentations, proved that the thermophilic conditions makes the kinetic of the AD process faster. Faster kinetics allow to shorten the residence time of the substrate into the digester and, consequently, to reduce the volume of the digester. However, the study must be completed with energy and economic balances to demonstrate the effective applicability of a thermophilic process for the treatment of WAS in a full scale WWTP.

References

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