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Anaerobic co-digestion of sewage sludge with OFMSW

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Abstract. Anaerobic co-digestion of sewage sludge with Organic Fraction of Municipal Solid Waste (OFMSW) appears to be an interesting solution to increase the biogas production of WWTP (WasteWater Treatment Plant) under-loaded digesters. In this study developed by the Department of Chemistry, Physics and Environment of Udine University, the co-digestion process potential of two companies in the Friulian region (AMGA - Azienda Multiservizi SpA and NET SpA) was analyzed and investigated by several laboratory tests. In order to achieve an integrated solution to upgrade the Udine WWTP towards co-digestion and maximize the biogas production, different pretreatments were tested in bench-top reactors. Sewage sludge and organic waste were treated by different techniques: ultrasound and thermal treatment were chosen to enhance the solubilization of particulate matter and make it available to bacterial metabolism, optimizing the anaerobic process as a whole. To verify the effectiveness of these pretreatments, BMP tests (Biomethane Potential Tests) were carried out.

Key-words. Anaerobic co-digestion, sonication, thermal pretreatment, BMP.

1. Introduction. Anaerobic digestion is a biological process that, under oxygen-depleted conditions, involves the degradation and stabilization of organic matter and leads to the formation of biogas: a mixture of methane (50-60%) and carbon dioxide. Biogas can be used as a biofuel in power generation systems to produce heat and energy. In the light of current global consciousness of environmental sustainability, anaerobic digestion is regarded as a promising process, both as a renewable energy generation scheme and a waste stabilization method (Botheju 2011).

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Anaerobic digestion is one of the most important treatments in sewage sludge disposal. Anaerobic digestion, if properly managed, can be an energy source process. Mass reduction, methane production and improved dewaterability of sludge are the most important advantages of anaerobic digestion (Aldin 2010).

The anaerobic digesters design criteria are based on empirical methods rather than on biochemical process equations, anaerobic digesters oversizing being the main consequence of the traditional empirical design. Co-digestion of sewage sludge with Organic Fraction of Municipal Solid Waste (OFMSW) may be one of the most viable solutions to improve the efficiency of oversized WWTP digesters. Anaerobic co-digestion consists of the anaerobic digestion of a mixture of two or more substrates with complementary characteristics, so that biogas production is enhanced by the combined treatment. The anaerobic co-digestion of sewage sludge and OFMSW can be considered as an excellent alternative to dumping, composting, incineriting of organic waste (Sosnowsky 2008), it is also an attractive waste treatment practice in which both pollution control and energy recovery can be achieved.

The main issue for the co-digestion process lies in balancing the C/N ratio (operative range from 20 to 70): co-digestion offers a correct nutrient supply to the anaerobic digester, enhancing the process as a whole. But the right combination of several other parameters in the co-substrate mixture, such as macro and micronutrients, pH/alkalinity, biodegradable organic matter and dry matter is also relevant (Hartmann 2003). In co-digestion it is very important to choose the best blend ratios in order to favor positive interactions (positive synergisms, nutrient and moisture balance), to avoid inhibition (ammonia, lipid degradation products) and to optimize methane production (Mata Alvarez 2011).

Many studies have demonstrated that the co-digestion of sewage sludge (SWS) with OFMSW increases the biogas production up to 50-100% (and more in particular cases) compared to sludge digestion, both in pilot and full-scale plants (Sosnowsky 2003, Bolzanella 2006, Caffaz 2008, Zupancic 2008). Indeed in the OFMSW-SWS system, both basic components of the sewage sludge (mixture of primary and secondary sludges) play an important role in co-digestion: the N content of secondary sludge can supplement a possible deficit of nutrients in the other co-substrate (OFMSW), whereas the higher biodegradability of the primary sludge provides an additional contribution to the increase in biogas production potential (Mata Alvarez 2011).

Anaerobic digestion is achieved through four main stages: hydrolysis, acidogenesis, acetogenesis, methanogenesis, carried out by several synergistic bacterial groups. Sludge hydrolysis has been typically considered as the rate-limiting step of anaerobic digestion (Eastman 1981). In order to improve hydrolysis and anaerobic digestion performance, several pretreatments can be considered: mechanical, thermal, chemical or biological treatments, causing the lysis or disintegration of sludge cells. Intracellular matter is released and becomes more accessible by anaerobic microorganism (Brugier 2005). Sonication and thermal pretreatment were tested on co-substrates (SWS and OFMSW) to verify the increase of soluble compounds and the consequent effect on microbial anaerobic populations in terms of biogas production and sludge dewaterability. Since the amount of energy which can be obtained by organic wastes digestion depends on the efficiency of the combined process, the operational optimization of this process is strategically relevant.

2. Case study: AMGA WWTP in Udine. Udine WWTP is an activated sludge plant for 200.000 p.e. It treats a flow equivalent to 100.000 p.e., the remaining capacity being used for liquid waste disposal. In the future an additional flow of 30.000 p.e. is anticipated from nearby municipalities.

Sewage sludges from primary and secondary clarifiers (after biological treatment) are collected in a thickener for water/sludge separation. Thickened sludge (3-4% as total solids) is treated in a double-phased anaerobic unit with 2 primary mesophilic digesters and 1 secondary "cold" digester with a thickening function. The sludge production in Udine WWTP is much lower than the designed value, consequently the existing anaerobic digesters present

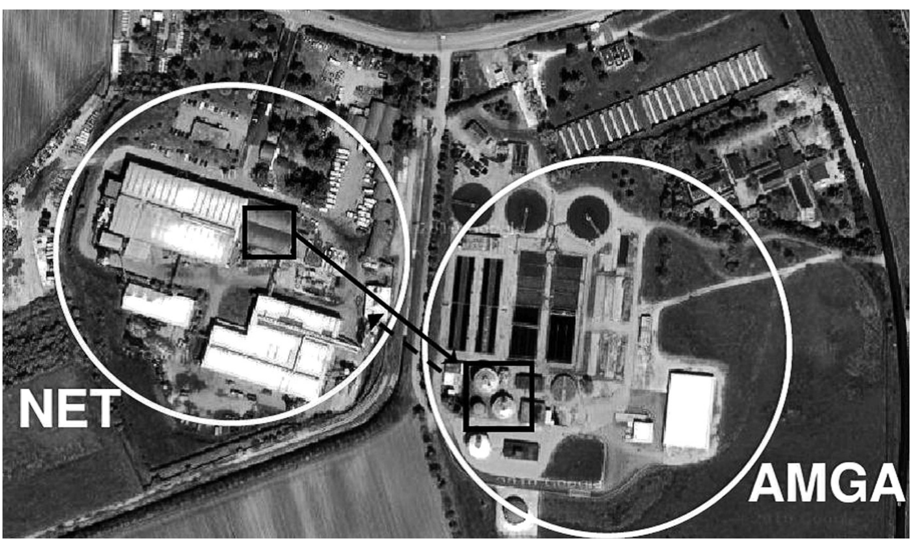

Figure 1. Aerial view of the geographical proximity between the AMGA WWTP and the NET waste treatment plant, in evidence the OFMSW storage area and the anaerobic digestion unit.

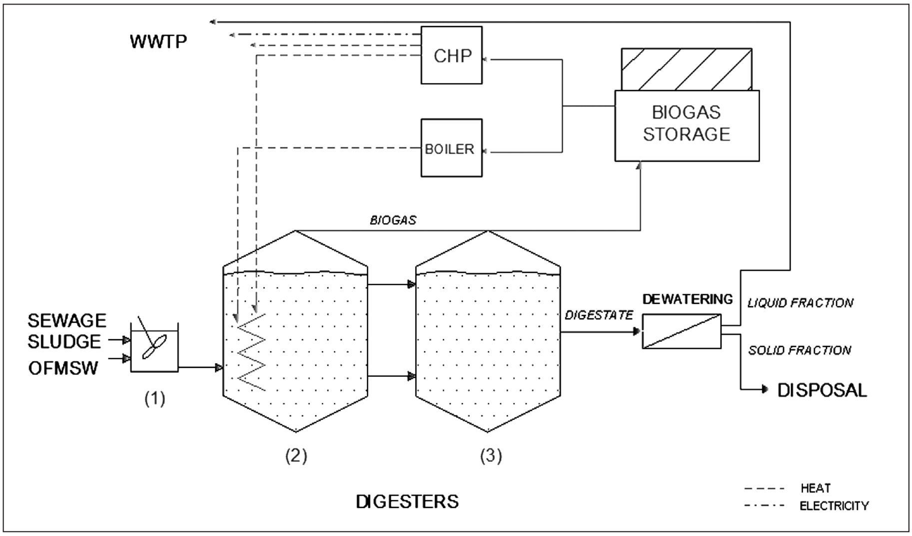

Figure 2. Anaerobic digestion unit adaptation to SWS-OFMSW co-digestion process. (1) mixing tank (2) primary digester (3) secondary digester.

more than 50% of extra capacity, so the co-digestion of other organic waste is advisable.

Close to the Udine WWTP area, the NET centre for organic waste composting is located (Figure 1), so the classified organic fraction of municipal solid waste could be easily available for co-digestion processing without major transportation and facilities costs. Moreover digestate could be composted for its final disposal inside the NET plant.

Organic waste from households needs to be pre-treated before it can be put in a sludge digester, to maintain a wet stream (max. 10% TS) and to avoid abrasive phenomena and blockage of pipes (due to inert and plastic materials). Crushers, magnetic separators, rotating drums and hydropulpers can separate organic waste from undesirable materials. Water treated at the AMGA plant could be used and added to obtain optimum water quality to be fed into the digester. To optimize anaerobic digestion with co-digestion, the process needs to be modified by adding a pre-treatment unit, a pipe connection to the sewage digesters, a CHP and a biogas storage facility (Figure 2) obtaining a new process.

3. Pretreatment and BMP tests. In this study, attention has been focused on pre-treatment technologies to optimize the co-digestion process in terms of higher biogas production and digestate final quality. The aim is to achieve an increase in the substrate content of dissolved organic matter and consequently to enhance the substrate availability for bacterial metabolism. Ultrasonic and thermal pretreatments effects were investigated.

Ultrasound technology is based on the disruptive action of ultrasonic waves on the fluid particles (related to the cavitation phenomena): sonication has the advantage of being a no-touch, no-chemical and no-moving-mechanical-parts technique compared to other disintegration methods (Neis 2001). The acoustically-induced cavitation creates shockwaves with high mechanical shear forces and/or sonochemical reactions resulting in the destruction of flocculent sludge structures and cell material. The combination of bubble oscillation and the resulting vacuum created by the collapse of the bubble leads to strong mechanical forces that can erode solid particles (Thiem 1997). In research studies, ultrasound technology has been widely tested as pretreatment of anaerobic digestion: for sewage sludge biogas enhancement ranges from 24% to 140% in batch systems and from 10% to 45% in continuous or semi-continuous systems (Carrere 2010).

In our experience the batch tests were carried out at six sonication times (5-10-15-20-30-60 minutes) using the ultrasonic processor UIP250 (Dr. Hielscher) at a 24 kHz frequency. Ultrasonic treatment was performed on sewage sludge (3% TS) from AMGA WWTP and on milled and diluted OFMSW (5% TS) from NET solid waste plant. DOC (Dissolved Organic Carbon), COD (Chemical Oxygen Demand) and absorbance (λ = 254 nm) were selected to measure the content of dissolved organic matter in the supernatant samples. Due to the high shocks induced by ultrasonic waves, the substrate liquid phase was enriched in the dissolved organic component, increasing with treatment time. After 15 minutes sonication, DOC increased up to 83% and 19% in sewage sludge and OFMSW respectively (Figure 3). 15 minutes was taken as the sonication reference time, because it appeared to be a treatment time that could be easily applied to full-scale plants, ensuring a good compromise between effectiveness and affordability. Results showed that ultrasonic pretreatment of OFMSW was not effective as a sewage sludge pretreatment; for this reason, the thermal pretreatment effect was investigated. In 58 °C-heated OFMSW (15 minutes treatment), DOC increased up to 30% compared to the untreated OFMSW. The other measured parameters confirmed these trends.

Moreover bench-top reactor tests were implemented to assess the substrates anaerobic biodegradability. The reactor was immersed in a temperature-controlled, stirred-water bath to maintain mesophilic anaerobic conditions (37 °C) and was connected to a biogas flow measurement system. The biogas production was monitored for 5 days. The organic substrates were inoculated, at a definite volumetric ratio, with anaerobic sludge taken from a full-scale digester.

Comparing the biogas production of untreated and sonicated OFMSW

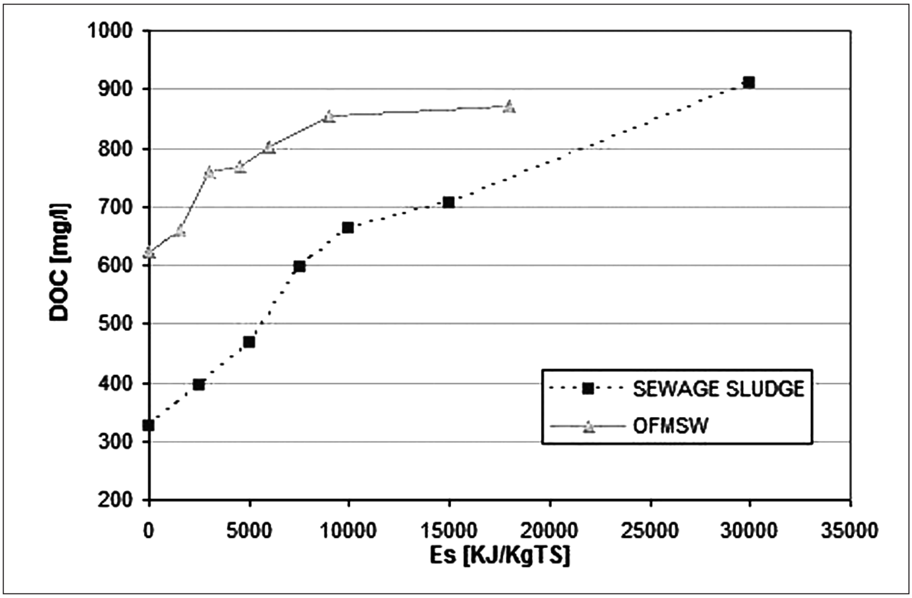

Figure 3. Ultrasound pretreatment batch tests, DOC vs. supplied energy.

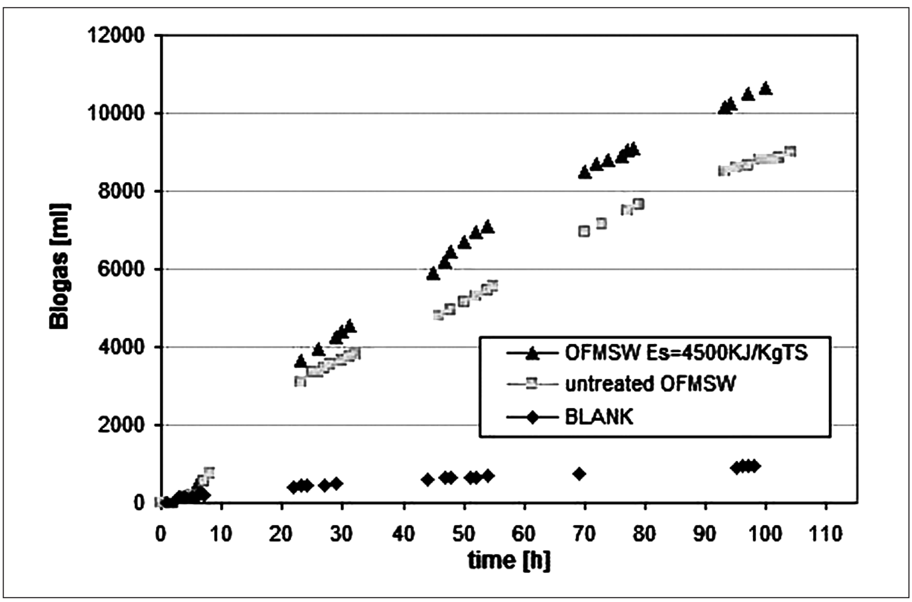

Figure 4. Biogas volume produced by sonicated OFMSW (Es = 4500kJ/kgTS), untreated OFMSW and blank test.

(5% TS), a positive effect was observed when ultrasonic pretreatment was used. With sonicated OFMSW, biogas production increased up to 25% compared to the untreated sample (Figure 4). The specific biogas production (SGP) was higher for pretreated OFMSW than for untreated OFMSW, 0.278 instead of 0.210 m^3biogas/KgVSfed. Further investigations are in process to better understand the process performances.

4. Discussion. Based on these preliminary positive tests results, future research will attempt to complete the laboratory tests for all the organic substrates considered, in order to verify pre-treatment effectiveness by pilot-plant reactors and to implement the ADM1 model (Anaerobic Digestion Model no. 1) simulating the co-digestion of sewage sludge with OFMSW for full-scale digesters in different operational scenarios, so as to identify the optimal working conditions.

This study has highlighted the real potential of designing co-digestion processes in the local situation of the AMGA and NET companies. The co-digestion process solution, if properly managed, could be a sustainable and profitable organic waste disposal method: in the vicinity of Udine WWTP (AMGA) organic wastes are available from NET solid waste treatment plant, treatment volumes by oversized digesters are also available, and the processed liquid waste (supernatant) can be recycled at the WWTP influent, the treated water can be used for waste dilution and a significant improvement in biogas production can be achieved. The digestate could easily be composted for closing the C/N cycle with reintegration in agricultural fields. The investment return period is usually short, typically the OFMSW addition step has an approximate payback time of 4-5 years. Finally, in addition to the production of renewable energy, using anaerobic digestion to treat organic waste produces greater reductions in greenhouse gas (GHG) emission than the aerobic options (Mata Alvarez 2011), so a local synergism could bring our territory nearest to the European target of “20-20-20” for 2020.

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