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INNOVATIVE TREATMENT SOLUTIONS FOR SEWAGE SLUDGE RECOVERY ON A FP7 PROJECT ROUTES

Extended abstract

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Background

ROUTES is addressed to assess new routes in wastewater and sludge treatment focusing on three main objectives:

1. optimization of the sludge quality for agricultural use with the goal to produce a clean and full stabilized sludge through intensive stabilization processes with attention to a broad spectrum of parameters including micro-pollutants, pathogens and their indicators.
2. minimization of the sludge to be disposed by innovative technical solutions based on different approaches, either on the water or sludge treatment lines;
3. recovery of valuable resources before sludge disposal by producing a liquid fertilizer $[(NH_4)_2SO_4]$, biopolymers or optimizing methane production by anaerobic treatments.

Technical and economic assessment of the investigated techniques on laboratory and pilot scale were carried out in a typical benchmarking study. The whole set of data is then provided to the partner involved in environmental assessment where different impact categories are considered (global warming potential, acidification potential, eutrophication potential and photochemical ozone creation potential).

Intensive stabilization processes

Thermophilic digestion of thermal pre-treated secondary sludge

The performance of thermophilic anaerobic digestion (55°C) of thermal pre-treated activated sludge (T=135°C, θ=20 min) was studied carrying out semi-continuous digestion tests using lab-scale jacketed reactors (V = 7 L). The first test was carried out in parallel, feeding thermally pre-treated sludge to one reactor and untreated sludge to the other, with a residence time of 8 d. The anaerobic process was evaluated monitoring total and volatile solids (VS), soluble COD, soluble nitrogen and ammonia, surface charge, CST, biogas production and its composition during the test. In a second test the residence time was increased from 8 to 15 d.

In the first test higher VS destruction and biogas productions, with similar CH_4 content of about 65% by volume, were achieved with respect to the digestion of untreated sludge. The thermally hydrolysed digested sludge resulted richer in soluble COD with respect to the untreated one (1.1 g/L instead of 0.7 g/L) and showed a worse dewaterability (60% higher CST and 57% higher surface charge density). In the 2nd test a slight worsening of filterability was observed (17% higher CST and 32% higher surface charge density).

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Anaerobic + Aerobic combined process

The integration of an aerobic post-treatment for further biodegradation of residual VS sludge from the previous anaerobic stage (Kumar et al., 2006) was investigated. Experimental tests were performed in a lab scale cylindrical glass reactors (volume 7.4 L) operated in series. Sludge was fed to the anaerobic reactor once per day and an equivalent volume of digested sludge was extracted and fed to the following aerobic reactor. The first reactor operated under anaerobic conditions and was equipped with a thermostatic jacket and a control device keeping the temperature at 37 ± 0.5 °C. Sludge retention time (SRT) was controlled at 15 d. The second aerobic reactor was operated with a working volume of 4.5 L with air supply by a compressor automatically controlled to maintain a dissolved oxygen (DO) concentration around of 3 mg/L. Such an operating strategy prevented ammonia stripping. The aerobic reactor was operated at room temperature with an SRT of 12 d. Two series of tests were performed at the same operating conditions with secondary and mixed sludge respectively. Experimental results showed a satisfactory performance of the sequential digestion process with significant additional VS removal in the post aerobic digestion stage (25% for secondary sludge and 45% for mixed sludge). Nitrification efficiency ranging from 79% to 95% was observed for secondary and mixed sludge, respectively. Possibility of complete nitrogen removal by alternate aeration in the aerobic reactor was investigated with good results. Produced biogas in the two series of tests was in the range of the literature values [0.19-1.6 m^3/(kg/VS destroyed)] as reported in Speece (1988) and Bolzonella et al.(2005), demonstrating that a SRT of 15 d is suitable for a positive energy balance.

Assessment of sludge sanitation

Pathogens and pathogens indicators (*E. coli*, *Clostriudium* spores, presence/absence of Salmonella spp.) were monitored in different stages of the above intensive stabilization processes. A reduction of *E.coli* number, after thermal treatment, was observed during the all monitoring period in all the analyzed treated sludges independently on the treatments and operating conditions applied. As expected, thermal pre-treatment always reduced *E. coli* concentration below to the reference limit (500 CFU/g dry weight) of the European Draft Working document on sludge [1]. Similar performances were obtained by thermophilic anaerobic digestion, which reduced *E.coli* below detectable limits in 100% and 75% of the analyzed samples during respectively test #1 and #2. *Clostridium* spores were removed only by the thermal pre-treatment. No reduction of this bacterial indicator was in fact observed by thermophilic anaerobic digestion of raw sludge. Absence of *Salmonella* spp in 50 g wet weight was ascertained during all the sampling campaigns. As far as the sequential anaerobic/aerobic processes are concerned, data showed that the aerobic phase contribute greatly to the removal of microbial indicators. Removal of *E. coli* increased from 1.25 ± 0.39 log of the anaerobic treatment to 2.28±0.87 log of the complete process. All the samples showed a reduction of at least 2 Log10 of *E. coli* (CEE 2000). The absence of *Salmonella* spp. was achieved in all but one sampling campaigns. In this sludge digestion process, *Clostridium* spore concentration did not change from the sludge influent to the process effluent (both anaerobic and aerobic effluent).

Processes for biopolymer production

Polyhydroxyalkanoates (PHA) are biodegradable polyesters with comparable properties to some petroleum-based polyolefins. The production of these biopolymers can be achieved in mixed microbial cultures, which growth and selection is coupled to wastewater and solid residual treatment. In fact, PHA production involving microbial cultures treating wastewater is an effective strategy to decrease their production costs of conventional pure-culture PHA processes. In addition, PHA production further valorizes wastewater treatment by recycling carbon towards products and reducing sludge production. The most common approach for PHA production with wastewater treatment process is based on selectively growing/enriching PHA-storing bacteria in activated sludge through dynamic process configuration with respect to substrate feeding, i.e., alternating conditions of carbon source availability and unavailability (Dionisi et al., 2004) or electron acceptor availability, i.e. aerobic vs. anaerobic (Bengtsson et al., 2008). Substrate aerobic dynamic feeding (ADF) or feast-famine has been widely reported as appropriate enrichment approach (Dias et al., 2006). The main substrates used for the selective growth of PHA-storing bacteria and PHA production have been volatile fatty acids (VFAs), since VFAs are directly converted into PHA. Until now, a three-stage anaerobic-aerobic process configuration for PHA production and wastewater treatment has been investigated (Dionisi et al., 2004): (i) wastewater acidogenic fermentation for the VFA production, (ii) ADF enrichment of PHA-storing organisms by feeding with the VFA-rich stream and (iii) PHA accumulation by feeding with the same VFA-rich stream. PHA production from different industrial and solids streams has been demonstrated under such conditions (Coats et al., 2007).

In this project, the PHA production integrated to municipal waste management has been evaluated; as a novel approach, the selective growth of PHA-storing organisms is based on the readily biodegradable carbon sources (RBCOD) that is directly available in the municipal wastewater, in spite it is usually VFA-poor. In this way, the VFA-rich stream from the acidogenic fermentation of primary sludge was saved for the following PHA production. The feasibility of conducting wastewater treatment while also producing a functional biomass with PHA-storing ability was demonstrated at lab- and pilot-scale, by a sequence of four units: (i) wastewater treatment combined with enrichment and production of a functional biomass sustaining PHA-storage capacity, (ii) acidogenic fermentation of sludge for VFA production, (iii) PHA accumulation from VFA-rich streams, and (iv) PHA recovery and characterization. It was confirmed that the ADF regime allows the biomass selection/enrichment even with VFA-poor wastewater as well as the PHA accumulation was obtained from the VFA-rich stream from sludge fermentation, in spite of the latter feed was different from the one used for biomass selection. In these conditions, the PHA accumulation potential of the WW-acclimated biomass was around 30% (g PHA $gVSS^{-1}$), quite higher than by using un-acclimated biomass, even though lower than by using VFA-acclimated biomass. These results suggest that a) municipal wastewater treatment can be coupled to PHA production and b) VFAs for PHA accumulation can be produced via acidogenic fermentation of primary sludge: Both features makes it possible to substantially reduce the amount of the excess sludge to be disposed of.

Processes for obtaining a liquid fertilizer $(NH_4)_2SO_4$

In 2010/2011 the first air stripping plant of Switzerland was built at the WWTP Kloten/Opfikon. Besides a conventional air stripping plant with NH_3 stripper and sorber it consist of an additional column by CO_2 stripping for pre-treatment of the liquid sludge side-stream coming from sludge dewatering, in order to increase the pH of the sludge liquid thus reducing the soda dosage needed for NH_3 stripping. In the first year of operation, the conventional free ammonia stripping as well as the CO_2-pre-stripping were optimized by Eawag in terms of: optimal temperature, optimal pH and optimal air demand (air/sludge liquid flow). With increasing temperature of the sludge liquid, the free ammonia removal efficiency was clearly increased. At a pH of 9.3 and temperature of 60°C, removal efficiency in the range of 90% was reached. The ratio of air to sludge liquid has significant impact on the overall energy consumption of the plant; a higher air flow combined with higher pH resulted in higher removal efficiency. With a liquid flow of 5.25 m^3/h and an air flow of about 3.600 Nm^3/h (i.e. 685 Nm^3/m^3 of NH_3 reach liquid phase)at 60°C and a pH of 9.3 a removal efficiency of about 90% is reached With the scope of energy efficient and cost effective nutrient removal at WWTP's a removal efficiency of 90% for the air stripping plant is sufficient. A disproportionate effort would be necessary for the elimination of the remaining 10%. This residual load could be more efficiently removed by biological treatment in the WWTP. Further experiences in the second year of operation of the plant showed, that higher liquid flows in the range of 7 m^3/h result in a better distribution of the sludge liquid in the column. The air/liquid ratio of 685 was kept (corresponding to an air flow of 4.800 Nm^3/h). The N removal efficiency of the plant was kept at 90%.

In a second step the CO_2 stripper was put in operation. Different trials with different air flows were conducted. The air flow was in the range of 50 to 200 Nm^3/h. Operational results showed decrease demand of soda dosage in the range of 40% to reach a pH value of 9.3**.** Air flow rates higher than 40-50 Nm^3/h, corresponding to 8-10 Nm^3/m^3 liquid for the CO_2 stripper, did not take to a more efficient CO_2 stripping and decrease of base demands. Free ammonia losses by the off gas of the CO_2 stripper is in the range of 2 - 3% of the ammonia load to the plant.

Co-digestion of waste activated sludge with organic wastes

The main objective of this activity was the assessment of biogas production of biowaste mixtures with activated sludge in pilot-scale anaerobic co-digestion trials in mesophilic and thermophilic conditions. Preliminary tests were carried out on different organic-residues or biowaste, especially from the agro-sector, substrates such as onion, radicchio, potato, triticale silage, crops silage, and winery wastes (see Figure 1).

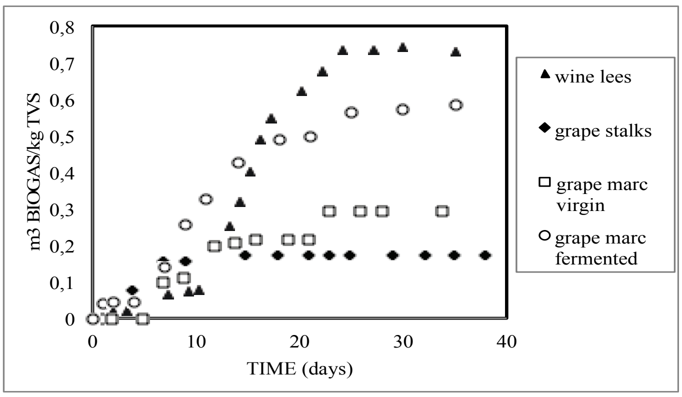

Fig. 1. Bio-methanation potential (BMP) tests with winery wastes in thermophilic conditions

These tests gave the maximum specific contribution in biogas production of each waste, considered as an indicator of the bio-methane potential when approaching to an anaerobic co-digestion process.

The anaerobic co-digestion of winery waste, i.e. wine lees (WL), and waste activated sludge was carried out in four parallel pilot scale continuous stirred reactors (CSTRs) of 230 L of working volume each, employed to study the combined influence of temperature, organic loadings (OLR) and hydraulic retention time (HRT) in co-digestion regime. The reactors were heated by a hot water recirculation system and two reactors were maintained at 37°C while others two at 55°C. The experimental protocol was designed to examine the influence of temperature on biogas production in co-digestion of WL and WAS. It was demonstrated that the co-digestion of WAS with WL cannot be sustained at an organic loading rates of 4.7 kg COD/(m^3 × d), both at mesophilic and thermophilic temperatures. The process, on the other hand, was very stable at lower loading conditions, 2.8 kg COD/(m^3 × d), especially at mesophilic temperature. The Specific Gas Productions (SGPs) were quite similar, 0.43 and 0.46 Nm^3 × kg COD fed^{-1} in mesophilic conditions and thermophilic conditions, respectively, for low loaded reactor, while considering for high loaded reactors the SGP increased from 0.37 to 0.49 Nm^3 kg COD fed^{-1}. The COD removal was 69% and 77%, respectively. From kinetic studies it was then observed that the system can produce about 70% of the biogas after 9 h, and 80% after in the first 12 hours after feeding, so the contribution of the easily biodegradable compounds directly used by the methanogens, such as acetate and ethanol, were predominant. The concentration of the polyphenolic compounds were 214 mg L^{-1} in thermophilic condition and 49 mg L^{-1} in mesophilic one. Comparison of degradation at different conditions revealed a strong influence of temperature, with more efficient phenol degradation in mesophilic conditions, according to the literature (Leven and Schnurer, 2005).

The digestate dewatering was quite poor in both mesophilic and thermophilic conditions. Values of the specific resistance to filtration (SRF) greater than $5×10^{12}$ m kg^{-1} were observed. With polymer dosages of at least 20 g/kg TS (Hidrofloc C 675-Hydrodepur) the SRF values still remained at high values around 10^{12} m kg^{-1}.

Concluding remarks

Sewage sludge management is often a critical issue in the wastewater treatment plants due to the unsuitable treatment for producing the right stuff to be finally used or disposed. The typical sludge outlet was the agricultural use but nowadays farmers seem not to be in favour with this approach. Presence of organic micropollutants and pathogens and undesiderable effects on soil are good arguments for stopping its further use. The project ROUTES has studied innovative techniques for an intensive stabilization of sludge with gain in methane production able to control the undesirable effects when sewage sludge is used on land. It was ascertained that pathogens can be controlled in thermophlic conditions and with thermal pre-treatments. Also a dual digestion system (mesophilic anaerobic + an aerobic stage) provided very good results of biodegradable solid removal. Good options for sewage sludge processing are also biopolymers production starting from the volatile fatty acids produced in an acidogenic phase. Recycling of liquid side-streams from the sludge dewatering is also critical in many WWTPs due to the very high ammonia load recycling. Its recovery as ammonium sulphate is an innovative way to recover a good fertilizer thus reducing this problem. Co-digestion of sewage sludge and organic solid wastes is a good opportunity to gain in biogas production when spare volume of digesters is available. In this cases attention should be paid to the final digestate dewaterability.

Keywords: ammonia recovery, biopolymers, pathogens, sewage sludge, stabilization

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