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EDITORIAL

Effective management of sewage sludge

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The EU research project *ROUTES* funded under the 7th Framework Programme was carried out for 3 years starting from May 2011. Eighteen partners strictly cooperated in the scientific, technical, and management activities. The EC contribution was about 3.4 million € in front of final accounted eligible costs of about 5.5 million €.

The main objectives were to investigate new processes and techniques in the water and sludge line of the WWTPs focused on the following tasks:

- Optimization of the sludge quality for agricultural use by producing a clean and stabilized sludge
- Minimization of the sludge to be disposed by innovative technical solutions
- Recovery of products in sludge processing with an intrinsic value, such as ammonium sulphate and biopolymers
- Setting up of different innovative techniques and approaches to open new solutions for sludge management (sludge disintegration and pumping to centralized plant, sludge co-digestion with organic wastes, wet oxidation and use of VFA-rich liquid residues for biopolymer production, sludge processing separation between primary and secondary sludge)
- Assessment of fate and effects of some organic and inorganic micropollutants in sludge amended soil

Technical part of the project included the study of different treatment solutions able to solve typical problems of sludge management in wastewater treatment plants (WWTPs) according to their capacities and local situations. These solutions were integrated in 10 sludge processing schemes, either as single techniques or as a train of interconnected processes, each one compared to a reference flow sheet. Reliability, complexity, easy integration with existing structures, flexibility, social and legislative issues, produced side-steams and wastes, consumption of raw materials and chemicals, electricity/fuel consumption, energy balance, and operating costs were the pillars of this technical assessment. The paper no. 1[1] fully describes this approach. Mass and energy balance, which are the fundamental prerequisites of this technical assessment, are discussed in the paper no. 2[2]. Results of the technical evaluation were the input data for environmental assessment carried out considering different impact categories, like global warming potential, eutrophication potential, acidification potential, and photochemical smog potential.

Among the treatment solutions under study, the enhanced stabilization processes were one of the key points of *ROUTES*. The intention was to improve sludge quality for agricultural use paying attention to organic micropollutants, pathogens and pathogen indicators and new bioassay tests for phytotox-

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[1] Methodology for technical and economic assessment of advanced routes for sludge processing and disposal
[2] Mass and energy balances of sludge processing in reference and upgraded wastewater treatment plants

icity and ecotoxicity assessment. The papers no. 3[3] and no. 4[4] deal with this subject. The papers no. 5[5], no. 6[6], and no. 7[7] describe the results obtained by three different enhanced stabilization processes.

Biopolymers (i.e., polyhydroxyalkanoates PHA) production and recovery from sewage sludge processing using mixed cultures is a new frontier to minimize sludge production recovering at the same time a valuable product. A four-stage process was studied in *ROUTES*:

I. Acidogenic anaerobic fermentation for transforming primary sludge COD into volatile fatty acids (VFAs)
II. Selection, enrichment, and production of PHA-storing biomass in an aerobic-activated sludge SBR reactor under dynamic feeding at high organic load
III. PHA production/accumulation where excess biomass with increased PHA-storage capacity from the 2nd stage is saturated in PHAs using as substrate the VFAs produced in the 1st stage
IV. Downstream processing of PHA-rich biomass and PHA recovery.

The paper no. 8[8] describes how the biopolymer enrichment in biomass can be performed and why this new process can be profitably conjugated with sludge minimization.

Paper no. 9[9] discusses a process of ammonium sulfate recovery from the liquid side-stream separated in digested sludge dewatering. In fact, to avoid an ammonia overloading to the biological process, ammonia should be removed from this side-stream. The process was tested on a full-scale plant including alkalinisation, air stripping, and acidic scrubbing, producing an ammonium-sulphate solution suitable for agricultural use. The innovation of this process consists in the adoption of an air pre-stripper before the alkalinisation step to reduce the CO_2 concentration in the main stripper thus sparing sodium hydroxide consumption.

Wet oxidation (WO) batch and full-scale tests were performed using different kinds of sludge in order to investigate the effect of process conditions on WO efficiency. It was observed that the main parameters affecting performance are temperature and reaction time (optimal values T=250 °C and θ=60 min). Wet oxidation modelling led to the determination of kinetic parameters as a function of sludge characteristics (origin, VSS/TSS ratio) and a conceptual model was proposed. A residual organic content of 5÷15 % was detected in the solid residue after WO. The BOD_5/COD ratio of the liquid effluent after treatment (always greater than 0.5) did not seem to be influenced by the different types of sludge. The paper no. 10[10] describes the results on the full-scale plant of Grassobbio (BG) and how the WO process can be modelled.

As far as WO liquid residue is concerned, anaerobic treatability was assessed and a COD removal efficiency in the range of 30÷50 % was obtained at a HRT=33 d and pH=7÷8. A CH_4 content in biogas of 70÷75 % was detected (paper no. 11)[11].

Paper no. 12[12] gives an example of the application of the environmental assessment to WO.

An important work package of the project, in terms of budget and man months, was addressed to study the fate of contaminants in sludge-amended soil through batch and column percolation tests. Equilibria and kinetics of sorption/desorption were assessed in different conditions. This work package included the assessment of ecotoxicity and phytotoxicity of sludge samples mainly derived from activities on enhanced stabilization (paper no. 3[3]). Pathogen and pathogen indicator regrowth during sludge storage were also studied. Finally, laboratory data on fate and effects of micropollutants in sludge-amended soils were compared with data obtained from various fields sites treated with sewage sludge for several years.

Other basic research activities dealt with the assessment of microbial diversity in sludge samples produced in enhanced stabilization processes (paper no. 13[13]) and with the use of a microbial electrolysis cell to recover by-products at the cathode contemporarily reducing sludge production (see the paper no. 14[14]).

[3] Quality assessment of digested sludges produced by advanced stabilization processes
[4] Hygienization performances of innovative sludge treatment solutions to assure safe land spreading
[5] Innovative two-stage mesophilic/thermophilic anaerobic degradation of sonicated sludge: performances and energy balance
[6] Hybrid alkali-hydrodynamic disintegration of waste activated sludge before two stage anaerobic digestion process
[7] Sequential anaerobic/anaerobic digestion for enhanced sludge stabilization: comparison of the process performance for mixed and waste activated sludge
[8] Sludge minimization in municipal wastewater treatment by polyhydroxyalkanoates (PHA) production
[9] $(NH_4)_2SO_4$ recovery from liquid side streams
[10] Wet oxidation of sewage sludge: full-scale experience and process modelling
[11] Anaerobic treatability of liquid residue from wet oxidation of sewage sludge
[12] Techno-economic and environmental assessment of sewage sludge wet oxidation
[13] Microbial diversity in innovative mesophilic/thermophilic temperature phased anaerobic digestion of sludge
[14] Effect of the anode feeding composition on the performance of a continuous-flow methane-producing microbial electrolysis cell

The practical results of this project were to produce robust data on the enhanced stabilization processes especially regarding their effectiveness on pathogen and organic micropollutant removal and to set up a rigorous methodology for comparing the proposed technical solutions with the reference ones considered as the state of the art. Fate of organic and inorganic contaminants and effects on soil fauna in sludge-amended soil were assessed both on laboratory and field studies, thus increasing the confidence on the most sensitive parameters and on the use of bioassay tests. The final paper no. 15[15] of this special issue discusses the EU policy on sewage sludge utilization on land, the expected contribution of the *ROUTES* project to this policy, and the state of the art of sludge processing in Europe.

Giuseppe Mininni is a chemical engineer and worked since 1976 at the Water Research Institute of the Italian National Research Council in the field of sewage sludge processing. He carried out research activity on technological characterization, chemical conditioning, mechanical disintegration by ultrasounds, anaerobic digestion, mechanical dewatering, thermal drying and incineration. He coordinated several international (LIEF+ ENER SLUDGE, FP7 ROUTES) and national research projects funded by Ministries (Environment, Research) public and private companies and utilities.

He carried out research activities also in the field of solid waste processing and management and is currently consultant of the Italian Ministry of the Environment for the assessment of projects for contaminated sites remediation. He is author of about 60 papers.

[15] EU policy on sewage sludge utilization and perspectives on new approaches of sludge management