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Advanced composting and bio-drying as an opportunity to recover material and energetic resources from sludges

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Abstract:
The need to change the current paradigm from linear economy to circular economy makes the recovery of resources from waste effluents one of the current and future technological priorities. In this context, sewage sludge represents a great challenge and at the same time a great opportunity for the recovery of resources, both material, and energy. Within the framework of the H2020 SMART Plant project, BETA Tech. Centre is developing two technologies to maximise resource recovery from different types of sludge. Firstly, phosphorus-rich biofertilisers are being produced through **advanced dynamic composting** processes treating sludge from EBPR and SCENA processes. Secondly, cellulose-rich sludge is being treated through **biodrying** processes to produce biomass fuel with a calorific value similar to that of pine chips.

Keywords: biofertilisers, biomass fuel, resource recovery

The continuously increasing population is bounded inevitably to an increasing waste production. For instance, it is estimated that in 2020, 13 million tons of dried WWTP sludge will be produced in Europe, while it can be considered a renewable source of materials and energy. Some technologies such as anaerobic digestion, composting or thermal energy recovery (TER) are widely used for sludge treatment. However, these technologies still have some limitations: high investment costs, operational challenges (e.g. biogas cleaning, excess of moisture for TER, etc.), low value of the products (compost and digestate), etc.

Consequently, in the framework of SMART-Plant project, two technologies are being developed to recover both, materials and energy from sludge. Firstly, through an **advanced dynamic composting** of P-rich sludge from a SCENA system, biofertilisers rich in phosphorus are produced. Secondly, through a **biodrying system** treating cellulosic sludge, biomass fuel with a calorific potential equivalent to pine chips is produced. Specific advanced control systems were developed for the mentioned processes which allow the reduction of their operational costs and GHG emissions. The pilot plants built for this purpose were operated for 8 months in a real environment (WWTP of Manresa). Briefly, the pilots consisted of two reactors with an operating volume of 100 L. A diffusion net in the bottom was used to distribute supplied air while leachate was also collected. Monitored parameters were: temperature, moisture, airflow, and O_2 and CO_2 contents in exhaust gases. Labview

2017 software was used to monitor and control the systems. Customised dynamic control systems were developed for both processes. Initial mixtures of sludge and bulking material were optimised with final ratios of 1:3 (bulking agent: sludge) for both processes.

Figures 1 and 2 show the performance profiles of the systems. As can be observed, both profiles are different since main objectives are also different. Therefore, composting process is aiming to reach the highest stability of the compost while reducing the operational costs; and biodrying is intending to remove as much moisture as possible in the shortest time and consequently reducing the organic carbon that is being biologically oxidised to maximise the lower heating value (LHV) of the biomass fuel obtained and reducing the operational costs. In particular, in the composting process, the optimal oxygen uptake rate (OUR) is used as the main control parameter to provide the required aeration to the process (Puyuelo et al., 2010), and to reduce the aeration costs. In the biodrying process, airflow is controlled by a decision-based algorithm based on temperature range of the process, to maximise the evaporation and water extracting capacity of the air. An effective drying was achieved in 12 d, whereas, the process can be shortened up to 9 d to avoid an excessive organic carbon mineralisation and maximise the calorific value of the biomass fuel obtained.

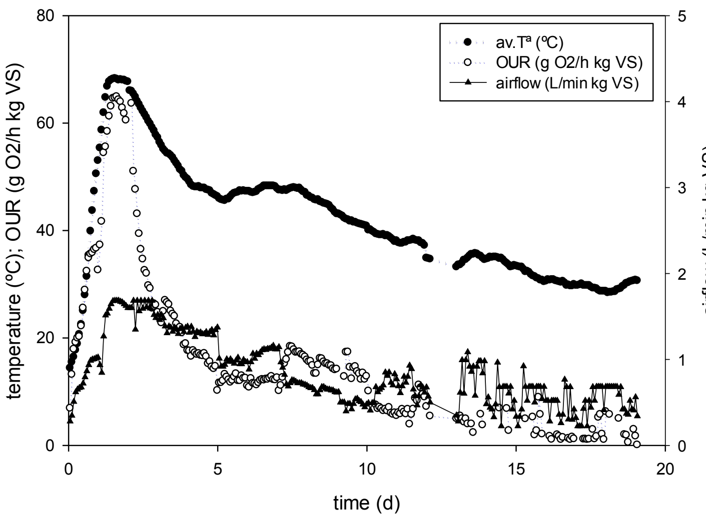

Figure 1 Temperature, airflow, and OUR profiles during P rich sludge composting trial.

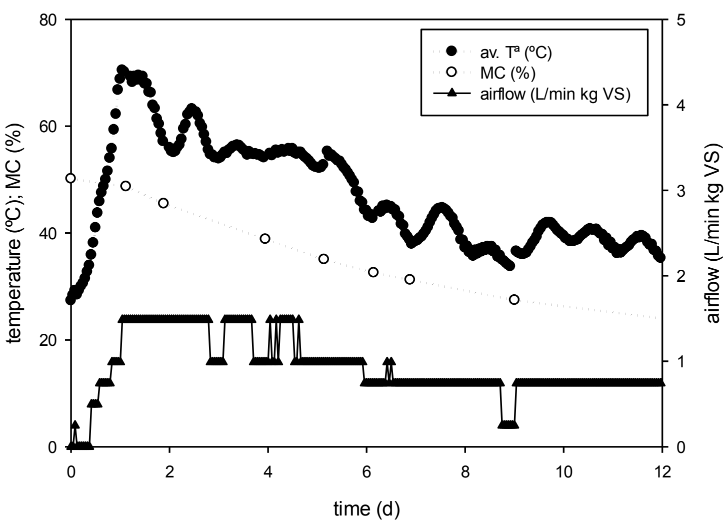

Figure 2 Temperature, airflow and MC profiles during cellulosic sludge biodrying trial.

Tables 1 and 2 show the main analytical parameters of the final products obtained, according to their final use. After the curing stage that lasted 60 d, the compost produced was very stable, reaching the required stability values (< 1 $gO_2h^{-1}kgVS^{-1}$). P content in the final composted product can be considered in the high range of values compared to a conventional compost with a P content between 1.1 and 1.9% (d.b.) (Jakubus, 2016). In the biodrying process, a final moisture content (MC) of 24.7% was achieved, fairly below the required MC to guarantee an effective combustion process in a conventional biomass boiler (Navaee-Ardeh et al., 2010). LHV of final product was higher than the values found in the literature for similar processes ranging between 4.8 and 10.2 $MJkg^{-1}$ (Winkler et al., 2013; Hao et al., 2018).

GHG emissions were also monitored in both processes. Emission factors of N_2O, CH_4 and tVOC were considerably lower than the values found in literature, while NH_3 emissions in composting were found to be within the range of the values for conventional sludge composting at industrial scale (Gonzalez et al., 2019).

Accordingly, LCA's of both processes have been made showing good results from sustainability and circularity point of view.

Table 1 Final P rich product parameters of the composting trial.

Parameter	P-rich compost
Moisture content (%, w.b.)	45.6 ± 0.1
Organic matter (%, d.b.)	68.8 ± 0.2
TKN (%, d.b.)	**3.9 ± 0.1**
Phosphorous (%, d.b.)	**2.42 ± 0.05**
Potassium (%, d.b.)	**0.65 ± 0.01**
C/N	**9.5**
pH	6.26 ± 0.03
Conductivity (mS cm^{-1})	2.78 ± 0.07
DRI 24h (g O_2 kg VS^{-1} h^{-1})	0,74 ± 0.02
AT_4 (g O_2 kg VS^{-1})	60 ± 2

Table 2 Final biomass fuel product parameters of the biodrying trial.

Parameter	Biomass fuel
Dry mater (%, w.b.)	76.3 ± 0.1
Organic matter (%, d.b.)	88.7 ± 0.4
HHV (MJ kg TS^{-1})	**17.14 ± 0.05**
LHV (MJ kg^{-1})	**11.66 ± 0.05**

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