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Research article

Comparison of three different wastewater sludge and their respective drying processes: Solar, thermal and reed beds – Impact on organic matter characteristics

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ABSTRACT

Drying process aims at minimising the volume of wastewater sludge (WWS) before disposal, however it can impact sludge characteristics. Due to its high content in organic matter (OM) and lipids, sludge are mainly valorised by land farming but can also be considered as a feedstock for biodiesel production. As sludge composition is a major parameter for the choice of disposal techniques, the objective of this study was to determine the influence of the drying process. To reach this goal, three sludges obtained from solar, reed beds and thermal drying processes were investigated at the global and molecular scales. Before the drying step the sludges presented similar physico-chemical (OM content, elemental analysis, pH, infrared spectra) characteristics and lipid contents. A strong influence of the drying process on lipids and humic-like substances contents was observed through OM fractionation.

Thermochemolysis-GCMS of raw sludge and lipids revealed similar molecular content mainly constituted with steroids and fatty acids. Molecular changes were noticeable for thermal drying through differences in branched to linear fatty acids ratio. Finally the thermal drying induced a weakening of OM whereas the solar drying led to a complexification. These findings show that smooth drying processes such as solar or reed-beds are preferable for amendment production whereas thermal process leads to pellets with a high lipid content which could be considered for fuel production.

1. Introduction

Every year large amounts of wastewater sludge are produced worldwide. In European Union (EU), these amounts are expected to strongly increase up to 13 million tons dry sludge (DS) by 2020 due to the implementation of new urban wastewater treatment directives (Commission of European Communities). Sludge management (e.g. disposal) and treatment represent more than 50% of the construction and operating costs of a wastewater treatment plant (WWTP) (Murray et al., 2008; Pognani et al., 2011). According to several recent reports and as recently reviewed by Kelessidis, sludge management is mainly performed in EU by landfarming (direct or after composting), incineration (after drying), recycling in cement production (Lin et al., 2012; Cyr et al., 2012) and landfill (Kelessidis and Stasinakis, 2012; Linghong et al., 2014). Beside these worldwide used processes, new development in WWS disposal and treatment involving technologies such as wet oxidation (Urrea et al., 2014), supercritical water (Qian et al., 2016) and pyrolysis combustion (Chen et al., 2015) are studied.

While landfilling is massively abandoned in EU and with the expected large increase in sludge production, future trends in sludge disposal techniques are expected to be land farming (direct or after composting) and energy recovery processes (Biogas production) in order to reduce energy costs associated to sludge drying and incineration (Council Directive, 1999/30/EEC of 22 April 1999 relating to waste incineration; Kelessidis and Stasinakis, 2012).

A step of drying is commonly used before land farming. This step aims at reducing the volume of sludge (due to its high water content) and at sanitising. The different ways of drying are natural drying, mechanical drying or thermal drying. Sludge treatment processes generally have two main purposes: 1/thickening and dewatering whereby the sludge volume, and hence the costs of subsequent handling, transportation and disposal, are reduced (Uggetti et al., 2010), and 2/stabilisation through microbial decomposition of labile organic matter remaining in the sludge (Lasaridi and Stentiford, 1998). Moreover, sludge drying also results

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in an increase of its calorific value so it can be used as an efficient combustible source (Chai, 2007). As stated by Boesch et al., 2009, efforts have to be made to develop drying method in order to reduce the energy efficiency and the overall carbon footprint of sludge disposal installation. Indeed, as reported by Tchobanoglous et al., 2003 with their high total suspended solid content (TSS), WWS are considered as a potential renewable energy source with a chemical energy content ranged from 9 to 29 MJ kg^{-1} of TSS.

Pelletisation is a drying process which aims at producing fertiliser from sewage sludge. The sludge which can contain up to 97% water is pumped from the plant's storage tanks, mixed with a coagulating agent, and pressed with wide fabric belts. The resulting solid, called sludge cake, contains roughly 25% solids and 75% water. This sludge cake is then baked at 120 °C in "tumble-drying" ovens that destroy all pathogens and bacteria, remove up to 90% of the remaining water, and rotate the sludge into fertiliser pellets (Zhang et al., 2014).

The effect of thermal drying on sludge characteristics has been reported by Feng et al., 2014. It was demonstrated that the reduction of bound water content decreased the viscoelasticity of sludge facilitating further mechanical dewatering (i.g: filtration). Greenhouse drying is a sludge drying process in solar plants. The aim is an acceleration of the water evaporation rate exploiting the artificial green-house effect and avoiding the equilibrium of vapor pressure between sludge and air by controlled indoor air ventilation (Mathioudakis et al., 2013). Moreover, the greenhouse plant drying technology is characterised by a reduced environmental footprint compared to conventional outdoor drying beds method as well as low energy requirements in contrast to conventional thermal dryers (Bux et al., 2002). Mathioudakis et al., 2013, reported an organic matter content reduction by 5–21% and a maximum of three log reduction of total and fecal coliform concentration between 8 and 31 days of drying duration.

Reed bed (RB) systems for sludge dewatering have been reported for over 30 years (Edwards et al., 2001) and are now widely used throughout the world (Nassar et al., 2006). They involve low capital and running costs and represent a good solution for sludge management in small wastewater treatment plants. Typically, a RB system consists of at least 8 beds (Nielsen, 2003) planted with common reed (Phragmites australis (Cav.) Trin. Ex Steud). The sludge is distributed evenly over the surface of the beds through a system of loading pipes (Nielsen, 2003). The reeds are planted and rooted in a growth layer placed on top of the drainage layer (Nielsen and Willoughby, 2005). An underdrain system allows excess water from the sludge to be easily drained, while the sludge accumulates over layers of sand and gravel. The drained water is collected in a system of drainage pipes in the bottom of the beds, which also enhance the aeration of the sludge residue since they are connected to vertical aeration pipes (Uggetti et al., 2010). As sludge builds up in the beds, the reeds will extend their roots into the growing sludge layer. The beds of a RB system are loaded according to the following cycle: one bed is loaded for a period of a few days and then rests for several weeks while the next beds are loaded. The long resting period allows the sludge to dewater through gravity drainage and evaporation (Nielsen, 2003). A RB system has a life expectancy of 30 years or more. During this period each bed needs to be emptied every 8–12 years (Nielsen and Willoughby, 2005). Stefanakis et al., 2009, followed during three years, the reed beds sludge drying at pilot scale and demonstrated a relative good sludge mineralization. More precisely, they showed an increase of TSS content and a decrease of total phosphorous (TP) and nitrogen (TKN) concentration in dried sludge compared to influent.

The organic matter of WWS is constituted with residues of the influent, microorganisms and extracellular polymer substances (EPS). WWS is thus a complex mixture of proteins, polysaccharides, cellulose, hemicellulose, lipids, macromolecules with both aromatic and aliphatic structures and anthropogenic compounds (micro pollutants, polymers, detergents) (Parnaudeau and Dignac, 2007). In addition, as previously demonstrated (Jardé et al., 2005, 2003; Parnaudeau and Dignac, 2007; Réveillé et al., 2003) the relative amount of each compound is related to the wastewater origin (municipal, industrial, food processing) or to treatment conditions (e.g. composting). Many studies are dedicated to WWS characterisation in terms of global parameters (carbon, nitrogen contents, BOD, etc.) and specific compounds (lipids, proteins, humic-like substances, etc.) (Jardé et al., 2005), but few studies concern the structural characterisation at a molecular level.

Thermochemolysis-GC/MS is a powerful tool to characterize, at the molecular scale, complex organic mattermixture (Mathioudakis et al., 2013; Nielsen and Willoughby, 2005) and its evolution during waste disposal (composting, soil amendment, etc) (González-Vila et al., 2001; Hernández et al., 2002).

The objective of this study was to compare the OM characteristics of WWS which have been submitted to different drying processes. Indeed sludge composition is a key parameter that governs the choice of disposal techniques. For example, energy recovery from bio digester processes strongly depends on OM composition of the WWS (Kwon et al., 2013). Furthermore, sludge intended to be recycled in agriculture have to achieve limited metals (Cd, Cr, Ni, Pb…) and organic compounds concentrations (nonylphenol, organic halogens, polychlorinated biphenyls…) (Jardé et al., 2005).

In this study, the remnant organic matter from 3 WWTP was investigated at the global and the molecular scale using elemental analysis, infrared spectroscopy (FTIR) and thermochemolysis (THM). WWS which have been submitted to solar, reed beds and thermal drying were compared at different stages of the processes.

2. Materials and methods

2.1. Description of wastewater treatment plants and sludge line

Three French WWTP located near Poitiers (Vienne, France) were studied.

The WWTP of Poitiers, La Folie (LF) has a nominal capacity of 1,52,500 population equivalent (PE). Wastewater is collected from a semi-separative network (93% of the network's length is separative) and the treatment is based on classical activated sludge process (sludge retention time: 48 h) coupled with an intensive phosphate removal step using iron chloride. The WWS is purged from the settling tank and concentrated by flotation (using microbubbles) after lime addition (pH: 7.3–7.5) and exhibited a dried matter content ranged from 2.5 to 5%. After dewatering using filtration, the concentrated sludge (22% of dry content) is directly composted with green waste or thermally dried to 92–97% of dried matter and transform into sludge pellets which are incinerated or used as fertilisers (88–92% of dried matter). Dried sludge is obtained thanks to a thin film conductive drier working at 85 °C. The 6 mm pellets are produced using a dryer-pelletizer working at 120 °C. The sludge pellets are then stored at ambient temperature before agricultural recycling or incineration. The total sludge production is equal to 1357 tons of DS/year. Before drying the concentrated sludge is mixed with a cationic polymer (ZETAG, BASF France) at a concentration of 15 kg per ton of DS. 68% of the total WWS amount is used in co-composting and 32% is transformed into pellets. 3 treatment steps were sampled for this study: Floated sludge (LF-0), dry sludge (LF-85) and pellets (LF-120).

The WWTP of Sevres Anxaumont, is a small urban WWTP with a nominal capacity of 1000 PE and with a sludge production of 4 tons

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