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Sewage sludge drying process integration with a waste-to-energy power plant

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ABSTRACT

Dewatered sewage sludge from Waste Water Treatment Plants (WWTPs) is encountering increasing problems associated with its disposal. Several solutions have been proposed in the last years regarding energy and materials recovery from sewage sludge. Current technological solutions have relevant limits as dewatered sewage sludge is characterized by a high water content (70–75% by weight), even if mechanically treated. A Refuse Derived Fuel (RDF) with good thermal characteristics in terms of Lower Heating Value (LHV) can be obtained if dewatered sludge is further processed, for example by a thermal drying stage. Sewage sludge thermal drying is not sustainable if the power is fed by primary energy sources, but can be appealing if waste heat, recovered from other processes, is used. A suitable integration can be realized between a WWTP and a waste-to-energy (WTE) power plant through the recovery of WTE waste heat as energy source for sewage sludge drying. In this paper, the properties of sewage sludge from three different WWTPs are studied. On the basis of the results obtained, a facility for the integration of sewage sludge drying within a WTE power plant is developed. Furthermore, energy and mass balances are set up in order to evaluate the benefits brought by the described integration.

1. Introduction

Sewage sludge is a mixture of organic and inorganic matter and its composition strongly depends on the treatment and on the wastewater origin (Dai et al., 2007). It contains various types of pollutants, such as polychlorinated biphenyls, polycyclic aromatic hydrocarbons, dioxins and heavy metals (Zn, Pb, Cu, Cr, Ni, Cd, Hg and As). Literature analyses different kinds of sewage sludge and contains detailed considerations about sewage sludge pollutants content (Dai et al., 2007; Manara and Zabaniotou, 2012; Fytili and Zabaniotou, 2008; Li et al., 2009).

Sewage sludge from municipal WWTPs can follow different disposal routes. In Europe, the most common solution adopted by EU countries is agriculture reuse as fertilizer. Many authors investigated the potential risks associated with agriculture reuse. In fact, due to several kinds of pollutants contained in the sludge (Dai et al., 2007; Manara and Zabaniotou, 2012; Fytili and Zabaniotou, 2008), the reuse on land needs to be carefully monitored in order to avoid problems for human health and for the environment. Sewage sludge landfilling represents another option for sewage sludge, but this solution should be marginal since the European Landfill Directive (99/31/EC) bans sewage sludge landfilling. Mono or co-incineration are another possible alternative (Åmand and Kassman, 2013; Lin and Ma 2012; Chin et al. 2008; Otero et al. 2002; Liu et al. 2012), especially in those countries where agricultural reuse of sewage sludge is limited or even not allowed (i.e. The Netherlands).

Nowadays, innovative solutions and processes for sewage sludge treatment and management are being developed: the most feasible focus on sludge valorization as an energy resource and act by raising its heating value. Pyrolysis process realizes the thermal degradation of the chemical molecules of fuel in an inert atmosphere between 300 °C and 500 °C, and has been indicated by many authors as one of the most promising solution (Zhang et al. 2014; Manara and Zabaniotou, 2012; Cao and Pawłowski, 2012; Fonts et al., 2009, 2012; Gascó et al., 2005; Hossain et al., 2009; Khiari et al., 2004). Gassification represents another interesting thermochemical process (Manara and Zabaniotou, 2012; Nipattummakul et al., 2010): gassification converts the carbonaceous content of sewage sludge into a combustible gas and into ash. Gassification is realized at higher temperature if compared with pyrolysis (typically over 500 °C) and in a net reducing atmosphere.

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Energy recovery from sewage sludge, independently from the process adopted, maintains relevant limits associated with the high water content of sewage sludge. Dewatered sludge from WWTPs, in fact, still has a moisture content that may range from 70% to 90% in weight, which usually prevents its energy content from being recovered directly. A thermal drying stage is therefore necessary to reduce moisture content, but it requires a high amount of heat.

This paper proposes an innovative solution for the management of sludge disposal based on the concept of plant integration. In particular, sewage sludge thermal drying is performed by collecting the flue gas of a WTE power plant and using it directly without the use of a heat exchanger. The main concept of the integration is to decrease sewage sludge water content (about 75% by weight after mechanical treatment) through the recovery of waste energy carried by the flue gas. The integration of sewage sludge drying and WTE power plant also benefits the WTE power plant in terms of overall efficiency, since waste heat is valorized. The thermally dried sewage sludge has a high LHV and can be used to produce energy by means of direct burning, pyrolysis–gasification or co-combustion with Municipal Solid Waste (MSW) in the WTE power plant. The advantages provided by the described integration to global efficiency are substantial: as a first effect, the heat used for sludge drying returns at higher enthalpy when sludge is burned; moreover, heat that would be wasted is recovered, providing further benefit to the whole process. The enhancement to general efficiency and the global energy balance is therefore doubled, because the enthalpy benefit is obtained by means of the exploitation of waste heat.

Paper assessment starts from samples analysis of sewage sludge collected from three different WWTPs. These data are necessary for the preliminary design of the integration of sewage sludge thermal treatment within the WTE power plant. In particular, moisture, volatiles distribution and LHV will be analyzed. In view of analyses results, a Process Flow Diagram (PFD) of the plant integration is then proposed, and energy and mass balances are set up to evaluate the benefits brought by the integration.

2. Material and methods

Samples were collected from three Italian WWTPs, each one having a different size (here expressed in terms of m^3/day of wastewater entering the treatment plant on average and of population equivalent): Calderara di Reno (2,500 m^3/day, 32,000 PE), Rimini (30,000–35,000 m^3/day, 440,000 PE) and Forlì (40,000 m^3/day, 250,000 PE). The choice of analyzing samples from a small-size, a medium-size and a large-size plant has been made, to evaluate the influence of the plant size on the dewatered sludge characteristics. Analyses were carried out in collaboration with Hera Spa (a multiutility provider operating in Italy) and CSA (Centre for Environmental Studies) Group Laboratories of Rimini (Italy).

2.1. Sample collection

Samples representative of different treatment stages have been collected from each of the three plants and stored at 4 °C in the CSA laboratories, following the procedures indicated by PD CEN/TR 15310-1:2006. Each sample collected before the dewatering stage consisted of 6 liters of matter, while 2.5 kg was the sampling mass collected after mechanical drying. The first treatment plant, located in Calderara di Reno, is the smallest one. In this plant wastewater first undergoes a fine screening, then a grit and oil removal process. After passing through an oxidation tank, a first clarification occurs in secondary decanters and sludge from the bottom is sent to thickeners. Finally, a centrifuge carries out the dewatering process. In this plant, samples were collected from the thickeners (sample C1) and from the dewatered sludge repository (sample C2). The WWTP of Rimini is larger and more complex: wastewater treatment starts with screening processes followed by a grit and oil removal stage. After a primary clarifier, four tanks perform the denitrification process, before sludge is moved to the oxidation tanks. Pre-thickening precedes an anaerobic digestion stage, after which sludge is sent to thickeners. Finally, belt presses carry out the dewatering process. Samples were collected from the pre-thickener (sample R1), from the second stage digester (sample R2) and finally from the belt press (sample R3). The last WWTP is the largest one and treats the wastewater produced in the province of Forlì. Focusing on this WWTP main processes, after a first fine screening there is a grit and oil removal stage and a pre-aeration tank follows. Then, after two primary clarifiers, sewage sludge is sent to the pre-thickeners. A digestion stage follows, then sludge arrives in the post-thickener. Finally, the dewatering process takes place thanks to a belt press and a filter press. Sample collection was made at the pre-thickening stage (sample F1), at the digester (sample F2) and after the belt press (sample F3).

2.2. Water content and dry matter percentage analysis

Water content and Volatile Organic Compounds (VOCs) analyses were performed on the samples following the procedure indicated by the European Standards EN 12879 and EN 12880. These standards require that a capsule filled with part of a sample is first dried at 103–105 °C at least for 30 min, then heated up to 550 ± 25 °C. Variations in the weight at these two steps represent, respectively, the dry matter and the fixed solids that are contained in the original sample. For the drying process, a forced air thermostatic oven "Fratelli Galli G-Therm 115" with a certified ±0.3 °C accuracy at 150 °C was used. The further heating step, instead, was performed in a "Nannetti" KL20/12 muffle furnace with a ±2 °C accuracy at 1280 °C. After the heating process, the samples were kept in a desiccator until ambient temperature was reached. Then, a "IKA Werke MF 10 basic" mill brought the treated samples to 0.5 mm granulometry. The microbalance used for weighing the samples is a "Chyo Balance Corporation JL-200", and has a four decimal place accuracy. Other traditional laboratory equipment was used in order to prevent the samples from being contaminated by air and other external agents during the analyses.

2.3. Heating value determination

Two different analyses were performed to quantify the Higher Heating Value (HHV, which is the energy obtained by bringing the products of the combustion back to the reference temperature of the reactants) and the Lower Heating Value (LHV, which is defined subtracting from the HHV the latent heat of vaporization of water) of the sewage sludge samples: first a CHNS (Carbon, Hydrogen, Nitrogen and Sulfur), then a Mahler calorimeter analysis. For the CHNS analysis a "Carlo Erba Elementar Analyzer EA1108" was used (following EN 15104), and the Higher Heating Value (HHV) and the LHV of the samples were then calculated thanks to the Dulong-Petit law (Eqs. (1) and (2)):

$$HHV = ((C * 34,032) + (H * 142,228) + (S * 9326) + (O * 17,778))/100 \ [kJ/kg] \quad (1)$$

$$LHV = HHV - (H * 22,604)/100 \ [kJ/kg] \quad (2)$$

where C, H, S, and O is the mass percentage content of every element. To confirm the results of the CHNS analysis, the Lower