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Determination of spontaneous combustion of thermally dried sewage sludge

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ABSTRACT

The general purpose of this research was the determination of self-ignition tendency of thermally dried sewage sludge. Eight Spanish plants located in Madrid, Barcelona and Málaga were selected to develop this study and ten samples were collected. Three different testing methodologies for studying the self-ignition of dusts have been undertaken. Thermogravimetric techniques, self-ignition temperature analyses and UN Division 4.2 tests were developed. The results of these analyses showed the risk of self-ignition during storage and transportation of these substances.

1. Introduction

The volume of wastewater produced worldwide has increased dramatically due to the large global population growth and industrialization (Eurostat, 2013). Dried sewage sludge is a product of high interest in the near future due to the different potential uses, including its use as a fuel (Fodor and Klemes, 2012; Rulkens, 2008). However, some cautions must be considered since dusts show high risk of self-ignition (García-Torrent et al., 2012), and produce explosive atmospheres as a dust–air mixture (Proust, 2006).

In 2006 the explosion of the sewage treatment plant in Besós, Barcelona, killed a worker and seriously injured two others (Europa Press, 2006). In this plant, sludge from purification of wastewater is subjected to a dehydration treatment using centrifuges and subsequent drying and pelletization. Cause of explosion in sludge dryer still unknown.

In the particular case of the wastewater treatment there are present risks of explosive atmospheres in different phases of the process due to the digestion gases generated in the treatment of wastewater that can form explosive gas-air mixtures. The dry sludge solids can also generate explosive dust clouds.

Chemical properties of sewage sludge are related to ignition parameters and the ignition risk may be reduced by means of preventive measures (Nifuku et al., 2005). It is well known that the main influential parameter on ignition risk is the particle size: the smaller the particle size, the greater ignition hazard (Eckhoff, 2009).

During the process of thermal drying, sewage sludge humidity sharply diminishes below 10% or even less, so that storage of sludge is facilitated for long periods. However, the drier the product, the larger quantities of fines are produced and the ignition risks associated to the powdered products generated in the process greatly increase (Rulkens, 2008; Zerlottin et al., 2013).

Flammability and explosibility properties of sewage sludge samples from different origins in Spain collected at different seasons were determined by measuring ignition and explosion parameters: Minimum ignition temperature with the dust forming a cloud (MITc) or deposited in a layer (MITl), Lower explosive limit (LEL), Minimum ignition energy (MIE), Maximum explosion pressure (Pmax), Characteristic constant (Kmax), Limiting oxygen concentration (LOC) (Fernandez-Anez et al., 2014)

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Self-heating and self-ignition risks associated with dusts have been evaluated for agricultural materials by Ramírez et al. (2009), due to the importance of the characterization of those materials to avoid these risks. Several experimental techniques can be used to characterize the thermal behaviour of materials, taking into account that the thermal behaviour of sewage sludge presents several differences with other well-studied materials as coal, as the weight loss during sludge combustion takes place not in one step as for coal but in two (Otero et al., 2002). Due to this differences several studies were conducted showing that due to the devolatilization of sewage sludge, in the co-combustion of coal and sewage sludge, the activation energy may decrease with the addition of sewage sludge (Folgueras et al., 2003). Furthermore, the devolatilization of materials depends on several parameters, being the main one the presence of hydrogen inside the structure of the samples (Arenillas et al., 2003).

These relations and the variability of these parameters on sewage sludge have been studied. In addition, the risk of self-ignition during the transport of sewage sludge has been also studied following the procedure for classification of dangerous goods for transportation developed by the United Nations (United Nations, 2009).

2. Experimental methodology

Ten samples have been collected in eight wastewater treatment plants from three regions in Spain: Catalonia, Madrid and Málaga, The origin of the samples collected, together with their moisture contents and average particle sizes are detailed on Table 1.

The chemical composition is detailed on Table 2. Carbon (C), hydrogen (H) and nitrogen (N) were measured as percentages following EN 15104:2011 standard and sulphur (S) content was determined following the A method of ASTM D4239 standard. Oxygen content (O) was determined as the complementary part of these values, taking into account that the sum of these five elements has to represent one hundred percent.

As stated, dried sewage sludge con produce explosive atmospheres and give rise to fires and explosions. Among possible ignition sources are exothermic reactions, including self-ignition of dusts. A number of experimental techniques can be used to characterize the thermal susceptibility of bulk solids and their thermal stability.

2.1. Thermal susceptibility

Thermal susceptibility is the term used to group the diverse parameters that allow the study of the thermal behaviour of solids and to determine their spontaneous combustion tendency (Querol Aragón et al., 2000). Parameters included in this group are: Maciejasz Index (MI) as a measure of reactivity and avidity for oxygen when sample is attacked with oxygen peroxide, Temperature of emission of flammable volatiles (TEV) as a sort of flash point for solids, Thermogravimetry test (TG), Differential Scanning Calorimetry (DSC), Activation energy (Ea) and Characteristic oxidation temperature (Tcharact.). The meaning and the experimental procedures for these parameters are described in detail by Ramírez et al. (2009). The DSC analysis allows determining the characteristics of the combustion reaction of solid fuels as shown in Fig. 1.

Table 1
Collected samples.

Sample	Origin	Apparent moisture (%)	d50 (μm)
SEW-1	Barcelona	7.3	67.9
SEW-2	Barcelona	7.0	339.5
SEW-3	Barcelona	12.1	100.4
SEW-4	Madrid	6.2	382.2
SEW-5	Madrid	6.5	397.2
SEW-6	Madrid	7.2	385.9
SEW-7	Madrid	6.2	382.5
SEW-8	Malaga	6.9	27.3
SEW-9	Barcelona	4.1	74.4
SEW-10	Madrid	8.3	286.3

Table 2
Chemical composition.

Sample	C (%)	H (%)	N (%)	S (%)	O (%)
SEW-1	37.43	4.91	3.01	0.61	21.84
SEW-2	28.48	3.56	2.96	0.84	16.06
SEW-3	33.72	4.94	5.00	1.63	10.81
SEW-4	34.72	4.70	4.46	1.24	10.08
SEW-5	35.76	4.74	4.52	1.31	8.67
SEW-6	31.90	4.77	5.01	1.21	15.41
SEW-7	31.73	4.69	4.89	1.14	15.75
SEW-8	36.13	5.19	4.51	4.90	12.17
SEW-9	38.30	6.33	3.72	1.08	12.07
SEW-10	33.40	6.24	4.37	1.23	13.06

Three characteristic parameters are obtained with this analysis, the Initial Exothermic Temperature (IET), the Final Exothermic Temperature (FET) that is the starting point and the end of the combustion reaction and the Change of Slope Temperature (CST), representing the temperature at which the slow combustion changes to a quick combustion. Before the IET, dehydration of the sample takes place. Afterwards, combustion starts as a slow reaction between IET and CST and quicker until FET.

Through conventional thermogravimetry test, another parameter can be determined in order to better define the thermal susceptibility of dusts: their apparent activation energy (Ea). The Ea of the sample is calculated at the point of maximum weight loss by means of a simple mathematical model applied to a set of points around that of maximum weight loss in a suitable representation of the recorded test points. The activation energy is related to the rate of weight loss, leading to the estimate of an "apparent activation energy" from the slope of least-squares line fitted to the selected test data. Thermodynamic and mathematical basis of Cumming's equation, based on first order reaction characteristic equations, simplifies and provides the estimate and use of this activation energy, turning it into a typical parameter of the sample representing the easiness for the reaction to take place.

Additionally, thermogravimetric technique is also applied to the study of self-ignition susceptibility by modifying test conditions when an oxygen stream is introduced. As a consequence of this oxidant contribution, sample behaviour can be very different during testing and a step or sudden loss of weight is observed, associated to a rapid combustion and produced at a characteristic temperature in every substance. Thus, from this unique value of the "characteristic temperature" powdered substances can be easily classified.

2.2. Classification of substances liable to spontaneous combustion

Transportation or storage of large quantities of products showing thermal susceptibility can lead to self-ignition. The classification of substances liable to spontaneous combustion according to the recommendations on the transport of dangerous goods comes from ONU N_2+N_4 tests (United Nations, 2009), so that substances classified as Division 4.2 are considered as liable to undergo dangerous self-heating processes. The classification