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Self-heating of dried wastewater sludge

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ABSTRACT

We experimentally studied the occurrence of spontaneous self-heating of sludge after drying, to understand its nature, course and remediation. The sludge originates from primary and biological treatment of both municipal and industrial wastewater, the latter largely dominant (approx. 90% total organic carbon, mainly from local tanneries). Dried sludge is collected into big–bags (approx. 1.5 m^3) and landfilled in a dedicated site. After several years of regular operation of the landfill, without any management or environmental issue, indications of local warming emerged, together with smoke and smelling emissions, and local subsidence. During a two year monitoring activity, temperatures locally as high as 80 °C have been detected, 6–10 m deep. Experiments were carried out on large quantities of dried sludge (∼1 t), monitoring the temperature of the samples over long periods of time (months), aiming to reproduce the spontaneous self-heating, under different conditions, to spot enhancing and damping factors. Results demonstrate that air is a key factor to trigger and modulate the self-heating. Water, in addition to air, supports and emphasizes the heating. Unusual drying operation was found to affect dramatically the self-heating activity, up to spontaneous combustion, while ordinary drying conditions yield a sludge with a moderate self-heating inclination. Temperature values as well as heating time scales suggest that the exothermic process nature is mainly chemical and physical, while microbiological activity might be a co-factor.

1. Introduction

Wastewater treatment plants yield a large quantity of sludge in addition to purified water. Disposing of sludge may be a significant issue. Dehydrating and drying processes allow to largely reduce the sludge mass, before landfilling. Questions arise about the chemical and biological stability of dried sludge.

In the plant of our interest, quite large indeed, dried sludge is collected into PP, with waterproof PE internal layer, big–bags with a volume of approx. 1.5 m^3. Bags are subsequently landfilled in a dedicated site. After several years of regular operation of the landfill, without any management or environmental difficulty, local temperature unusually high have been measured. At the same time, landfill produced smoke and malicious odor. Locally, quite significant subsidence was measured, up to 2 m. After a systematic monitoring campaign, lasting more than two years, temperatures locally as high as 80 °C have been detected, in specific zones, typically 6–10 m deep. Local surface subsidence up to 2 m was measured, over a total depth of approx. 12–14 m.

While surprised by the significance of the process going on in the landfill, we started a systematic investigation, beginning with a literature survey on comparable scenarios. The self-heating on a large scale of different materials (carbonaceous material, MSW, municipal sewage sludge) has been reported (Riley et al., 1987; Moqbel et al., 2010; Escudey et al., 2008). Riley et al. (1987) focused on coal in barges, clearly admitting that exhotermic oxidation reactions take place, stressing the role of air. Moqbel et al. (2010) revert to laboratory to identify the auto-ignition temperature of synthetic MWS; they already observed the key role of oxygen to support chemical oxidation reactions. Escudey et al. (2008) carried out field tests on sewage sludge piles extending several meters, for 20 weeks, confirming that temperature could rise up to 90 °C, never causing self combustion, though reporting that it was observed in landfills in their region.

In the case of our dry sludge, the first hypotheses concerns the occurrence of some extraordinary biological activity. Literature reports contrasting opinions about that. Li et al. (2008) explicitly support the quantitative generation of heat by biological processes. Others (Poffet et al., 2008; Gholamifard and Eymard, 2009), claim that bacterial activity requires a longer induction time (days or weeks) and sufficient moisture degree. Finally, Yasuhara et al. (2010) like Fu et al. (2005) definitely exclude any connection between self-heating and the bacterial metabolism. The residual moisture in our case is always less than 15% (typically 10%), to prevent the onset of biological processes. However, loss of containment by a big–bag in the landfill, causes sludge to rehydrate, possibly triggering some biological activity. This activity, while

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initially aerobic, can evolve in anaerobic where oxygen lacks, with emission of biogas. Because of the measured temperatures, up to 80 °C, we hardly believe that biological processes are the principal ones taking place. The aerobic processes are known to operate up to a maximum temperature of 70–75 °C, while the anaerobic processes are not active above 60–65 °C. Furthermore, lot of water to rehydrate the sludge is required to provide a suitable environment for biological activity. The landfill is progressively filled by segregating limited deposition areas with LDPE sheets, to repair from rain, preventing quantitative rehydration to take place.

Self-heating is likely to occur because of hydration reactions involving salts and oxides in the inorganic fraction, as discussed by Fu et al. (2005) and Walker, 1967. They measured instantaneous heating of RDF and other solids after the addition of water because of what they called "wetting heat". The sudden heating is not compatible with any sort of growing bacterial activity. They proved that the temperature rose from ambient only after the addition of water. However, the hydration heat, if any exists in our case, can be easily overwhelmed by sensible and latent evaporation heat in case a large amount of water is used, as we experienced in remediation attempts successfully applied to the landfill.

We can exclude accidental or intentional ignition (fires, cigarettes, etc.) for two reasons. The dried sludge is not easily ignited and any ignition should develop mostly locally, while heating was observed in different zones within the landfill, with the highest temperatures in the deep of the waste.

The most likely cause was suggested by Poffet et al. (2008) who conjectured the presence of pyrophoric substances, able to chemically react with oxygen and water very exothermically. Authors (Li et al., 2008) observed self-heating, sometimes leading to self-combustion, of dried sludge from municipal wastewater treatments. They measured temperatures in excess of 600 °C. We were extremely surprised both by the resemblance of the case described in Poffet et al. (2008) with our experience, notwithstanding the supposed difference in the sludge origin, and the extent of the consequences. Interestingly, they remarked a significant presence of sulfur and iron, which is similar to our sludge, though the origin differs. Moreover, awareness of the possibility of fires development in dried sludge bunkers remains apparently underestimated in the management of solid wastes. It was certainly the case at the time of our landfill design, which occurred much earlier that 2008, when (Poffet et al., 2008) was published, but still a large uncertainty remains about the actual chemistry and likelihood of fire occurrence, in practice. Poffet et al. (2008) carried out further small scale investigations in small isolated vessels (Dewar type), as already suggested by Shea and Hsu (1972) reporting that an oxygen flow causes a quicker and more intense heating of the sludge than an inert flux. They also observed that water supports the heating, already suggesting that exothermic reactions could occur, like hydration of metals transition salts. It is known indeed (Zhao, 2006) that the ferrous sulfide, FeS, largely present in the sludge, can react with oxygen (air) at ambient, temperature, with a significant heat of reaction (up to 2500 kJ/mol, according to literature). As expected, the smaller the granules size, the faster the exothermic reactions develop, because of the higher interphase (gas–solids) surface. Also the environmental temperature affects the maximum temperature that solids can achieve, apparently because of a competition between heating by reactions and cooling by heat transfer to the ambient (with lower ambient temperature, the thermal dispersion increases).

Being able to reproduce the self-heating of the sludge under controlled conditions is a prerequisite to understand the chemical and physical mechanism, eventually leading to control the heat release and to prevent run-aways. Here we report about large, big–bag scale investigations highlighting the basic features and magnitude of the self-heating phenomena.

What was studied here could be considered one of different phenomena, including the so called smoldering, not well understood yet, though amenable to dramatic consequences. Definitely, they deserve a scientific investigation. Here we report the beginning of our study, i.e. observations on the large scale.

2. Materials and methods

2.1. Sludge

Experiments focused on dried sludge, resulting from a single wastewater treatment plant, mainly received from the local industrial tannery district. Sludge is collected both from the primary settling tank (2/3 of total solids produced in the plant are from raw wastewater) and from floatation (due to bacterial activity). The plant of our interest is quite large (1.5 millions equiv. inhabitants) resulting in a total annual mass flow of sludge suspension, at approx. 95% water, in excess of 420,000 tons/y. It is evident the need of reducing the volume. A first dewatering process raises the solids concentration of sludge to 25–32%, then drying brings it to an average of 89% in ordinary conditions. Still, the average production rate of dried sludge approaches 72 tons/d.

Details of dewatering and drying are worth discussing, because they may play a role in determining the final activity of the resulting solids. Dewatering is mechanically achieved by filterpresses, where water-laden sludge is squeezed in several tissue-confined chambers. Before filtering, ferrous chloride and organic flocculant are added to the suspension; the first one binds the sulfide ions as insoluble ferrous sulfide, to limit the emission of H_2S in working areas and helps with the latter the dewatering capacity of sludge, improving the flocs aggregation thus facilitating the release of water. Dewatered sludge is conveyed to two storage silos ($100\ m^3$ each) through screw conveyors.

Subsequent drying is achieved thermally, by different methods. Two equal lines, L1 and L2, each one with a 4 t/h evaporation capacity, operate with direct solids heating by convection, with hot gas produced by a natural gas burner. A low concentration of oxygen (7–12%) is maintained in the drier to reduce the dust explosion hazard. Two additional equal lines, L3 and L4, each one with a 2.6 t/h evaporation capacity, were recently added. These are based on thin film evaporation down hot surfaces, externally heated by heat transfer oil. During construction and start-up of L3 and L4 lines, a support line, L5, with a 2 t/h evaporation capacity, was in operation, and produced some of the tested sludge. This combined both direct and indirect drying methods at the same time, both realized as described above.

Eventually, sludge in the form of powder with granules of approx. 2 mm mean size, with 85–92% dry solid content and 0.7 kg/L apparent density, is stored in big–bags subsequently moved to a dedicated landfill. The average composition is shown in Table 1 for the most significant elements.

Note the low concentration of heavy metals except for chromium, largely used in the tannery activities, reaching up to 4%wt of solid substance. Iron (up to 2 wt.%) is due to additions at different treatment stages: as $FeCl_3$ after biological treatment, to remove phosphorous from wastewater and improve clarification, furthermore it is added as $FeCl_2$ before dewatering, as discussed above. Another important figure is the total sulfur content, up to 2 wt.%; compared with the small concentration of sulfate and sulfide, it suggests the presence of elemental sulfur. Sludge has a peculiar odor, changing from dewatered to dried; its further change upon self-heating indicates the occurrence of chemical transformations, to a different extent.

Due to its composition and origin, mainly industrial (tannery) wastewaters, sludge must be disposed according to specific