Project Update - 4503

Mechanisms of spontaneous combustion in biosolids stockpiles

This fact sheet summarises the work by Dr Rachael Aganetti, WaterRA PhD student (2013-15) based at Victoria University and supervised by Professors Graham Thorpe and Jun-De Li [Victoria University] and Dr Aymeric Lamorlette [Aix-Marseille Université].

What are biosolids?

A suspension of organic and inorganic solids is formed at various points of the waste water treatment process, during both anaerobic and aerobic digestion. The result is the formation of different types of sludge which may also assist in the treatment process itself, as in the case of waste activated sludge, which actively feeds on incoming waste water [1]. When there is too much sludge in the system, it is removed and undergoes further treatment prior to its beneficial reuse.

When the sludge is removed it is in a liquid form containing as little as 2% dry solids and through various methods of dewatering this is converted to a dry solid content of between 35-92% depending on the process used [2]. Processes include centrifuge, belt or filter press, drying pans and more.

Once dried, and now known as biosolids, the material is stored under particular conditions to reduce any remaining pathogens and odours, after which the biosolids may be considered for beneficial reuse [3].

Why are biosolids a cause for concern?

Once dried, biosolids are often formed into large stockpiles of as much as 15,000 tonnes of solids. The biosolids must be stored in this condition for more than three years to ensure that the product stabilises according to the guidelines of the Victorian Environmental Protection Agency [3].

During the first year of storage, however, the biosolids are susceptible to a self-heating phenomenon which can result in spontaneous combustion of the material. Smoke emanates from the sloped surfaces of a stockpile which is a sure sign of internal smouldering, and temperatures above 100°C have been measured. To control thermal events it is common practice to spread the material. As a result, the intervention by local fire brigade workers may be required if a fire becomes serious. Not only do these events divert local resources such as the fire brigade when they might be required elsewhere, but the smoke poses a potential health concern to staff and firefighters if they are in close contact with concentrated smoke.

Why do biosolids catch on fire?

Spontaneous combustion has been described as "a cascade of reactions and a series of circumstances" that lead to an event of thermal runaway [2]. The initial increase in temperature is attributed to heat-generating biological activity which, combined with a well thermally-insulated material and limited airflow, allows heat to accumulate [4]. Microbial respiration can raise the temperature to around 70-80°C at which point the microbial organisms die or become dormant [4,5]. However, physico-chemical reactions can also be initiated, such as oxidation, slow pyrolysis and adsorption or condensation.

Water activity has been identified as playing a major role in the initiation and support of the self-heating process, and a range of 20-45% moisture content has been reported as critical [4,6,7]. Oxidative reactions dominate at high temperatures, with chemical oxidation of dry materials noticeably increasing at around 80°C where moisture can facilitate these reactions [4]. Once this temperature has been reached it is difficult to halt the process of thermal runaway.

The size of the stockpile is likely to determine whether an event of spontaneous combustion will occur, since the only mechanisms of heat dispersion are diffusion and advection. The material is porous, made up of particles of varying size packed together with channels and pockets of air in between them. Accumulated heat is conducted through the particles and the interstitial air to the surface of the stockpile. The temperature gradients in the stockpile give rise to buoyancy-driven flows and these can be augmented by wind-driven flows that may promote combustion reactions. When stockpiles are formed they are compacted by the vehicles used to construct them. As a result the biosolids are compacted in the middle of the stockpiles and this results in oxygen depletion that prevents or slows spontaneous combustion. However, on the slopes of the stockpile the permeability is likely to be higher allowing oxidation reactions to take place. The larger the stockpile, the harder it is for dispersive processes to counter the generation processes and lose accumulated heat.

How is the problem being investigated?

To gain deeper insights into the problem of spontaneous combustion, researchers have turned to computational fluid dynamics to simulate the process numerically. Since the process of self-heating is well defined it is a matter of selecting an appropriate model for each process. Models of self-heating have been developed for other organic materials such as coal, compost and grain and provided a useful basis for the development of numerical models specifically for the self-heating of biosolids [8].

Such a model has been used to investigate the dynamics of self-heating and a correlation between the pile size, permeability and thermal kinetics was determined. It was identified that a critical permeability exists whereby advective processes can actively supress an event of thermal runaway. When the permeability is less that the critical value there is a risk of spontaneous combustion, as oxidative reactions are refuelled with insignificant cooling flow.

This finding is significant in that treatment plant operators may have some control over the permeability of a stockpile through the particle size by means of pelletisation – however this solution may be operationally expensive.

The validity of the numerical models can be verified through experimentation, therefore field experiments were carried out with the intention of capturing a thermal event. A biosolids stockpile at the Western Treatment Plant was used for a nine month program of measurements of the temperature within the centre. Minimal temperature variation was observed, which supports the hypothesis that a low permeability results in a potential oxygen depletion within the centre of the stockpile.

Laboratory tests of the material confirmed a low permeability, and numerical simulations of extremely low permeability stockpiles were carried out to determine the magnitude and significance of flow within the pile.

The lack of flow, coupled with oxygen depletion in the centre of the stockpile, results in a spatial shift of the location of thermal runaway toward the sloped edges of the stockpile. It was found that the permeability of the stockpile plays a major role in the dynamics of self-heating. Initial numerical investigations were made using a homogenised permeability, however upon examination of the distribution of particle size of the biosolids at the Western Treatment Plant (Figure 1), it was concluded that the use of a randomly distributed permeability based on this distribution yielded more accurate results (Figure 2) where the thermal locations were more localised within the slopes of the stockpile due to oxygen depletion in the centre of the stockpile.

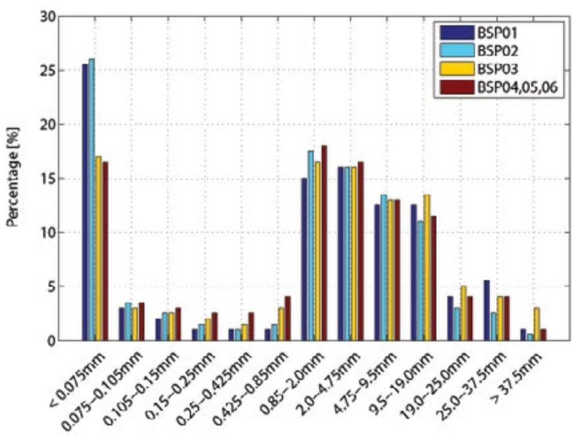

Figure 1: Particle size distributions of the biosolids at the Western Treatment Plant [9]

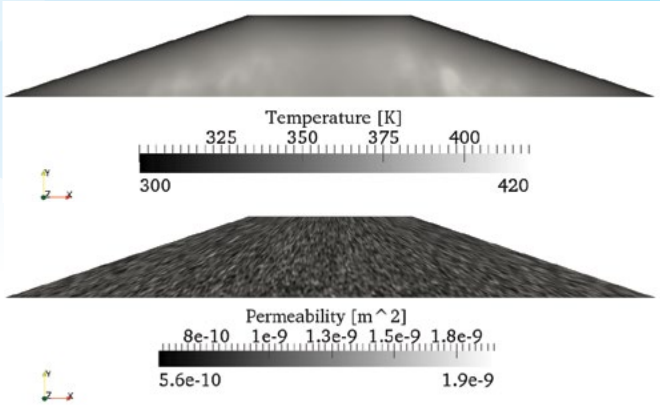

Figure 2: Output of a simulation of a self-heating stockpile of biosolids with a randomly distributed permeability based on the distribution shown in Figure 1.

Alternative stockpiling methods that require numerical investigation include covering the pile with an impermeable layer, increasing the initial moisture content to provide self-quenching or packing the edges to ensure a reduction in permeability – such methods may be more viable from an operational stance, but still require validation.

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