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A field study of lignite as a drying aid in the superheated steam drying of anaerobically digested sludge

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ABSTRACT

Dried sludge is preferred when the sludge is either to be incinerated or used as a soil amendment. This paper focuses on superheated steam drying which has many benefits, because the system is totally enclosed, thereby minimising odours and particulate emissions. This work reports on field trials at a wastewater treatment plant where anaerobically digested sludge is dried immediately after being dewatered by belt press. The trials showed that unlike previous off-site tests, the sludge could be dried without the addition of a filter aid at a low production rate. However, the trials also confirmed that the addition of the lignite (brown coal) into the anaerobically digested sludge led to a more productive drying process, improved product quality and a greater fraction of the product being in the desired product size range. It is concluded that these results were achieved because the lignite helped to control the granule size in the dryer. Furthermore neither *Salmonella* spp or *E coli* were detected in the dried samples. Tests on spontaneous combustion show that this risk is increased in proportion to the amount of lignite used as a drying aid.

1. Introduction

1.1. *The sludge disposal problem*

Sludge is the residual semi-solid particles that are left behind after the treatment of industrial wastes, sewage treatment, pulp and paper processing and water treatment. It is generally formed by the decantation and removal of as much free water as possible from the waste product. The world's production of sludge has been increasing due to population growth and urbanization (Davis, 2008). The water content of sludge can be as high as 98% and this is the most important factor affecting the disposal of sludge. Water removal is difficult because the sludge contains organic particles which are cellular in nature and other molecules which can bind water tightly.

The disposal of sludge has become more of an issue in recent years, as the sludge provides a good breeding place for bacteria, micro-organisms and some pests, like mosquitoes. There are three accepted disposal options for sludge produced from municipal wastewater treatment plants: (i) stockpiling on-site (common in Victoria, Australia), (ii) land application

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(common in the UK) and incineration (common for continental Europe) (Davis, 2008). Stockpiling is no longer viewed as a sustainable solution for a large urban treatment plant. Land Application has advantages and disadvantages. The advantage is that nutrients in the sludge are usefully employed. One key disadvantage is the possibility that residual chemicals within the sludge will re-enter the food chain and there is also the risk of contamination of waterways due to run-off (Davis, 2008). Furthermore, transport of a high liquid content material can be costly and the transport adds to the environmental burden. Application of a dried product as a fertiliser or soil amendment reduces the cost of transport and the risk of run-off, but has its own handling issues. Incineration also has significant disadvantages. Unless the sludge is partially dried, fossil fuels will be consumed to ensure complete combustion. There will also be atmospheric emissions from the combustion process and any ash produced will still need to be disposed of. Across the globe, the cost of handling and disposing of sludge has been estimated as 45% of the total cost of wastewater treatment (Davis, 2008). Although there is no perfect solution to the disposal of sludge, both land application and incineration will benefit from drying the sludge, if this can be done economically.

1.2. *Drying sludge*

There are many different types of industrial dryer and most have been tested with sludge. A review by Navaee-Ardeh et al. (2006) summaries for a wide range of different drying technologies the advantages and disadvantages of each method for pulp and paper mixed sludge. The drying mediums are usually air or steam. Drying in air can be by natural convection to the atmosphere or in heated and/or dehumidified air in different process dryers. The main parameters that affect air drying operations are the air temperature, the relative humidity and the velocity of the air. Industrially, the mechanical dewatering of a sample is usually followed by the thermal drying process, which is the most common way of drying a sludge sample. According to Vaxelaire and Puiggali (2002), the dewatering of samples via filtration-compression does not affect the drying kinetics of the sample.

Superheated steam (SHS) has the potential to use only 20%–50% of the energy required by dryers using hot air or flue gas (Mujumdar, 2014). These savings occur when the steam generated in a superheated steam dryer is used for other heating purposes. Further savings are possible due to higher heat transfer coefficients and increased drying rates in the constant and falling rate drying periods, at high steam temperatures. The constant rate drying period can also be longer in superheated steam drying and this provides a higher drying rate for prolonged periods of time. This increases the efficiency of the processing operation which can lead to a reduction in the size of the equipment and the capital costs or cause an increase in the output (Mujumdar, 2014). This provides a tradeoff for the higher capital cost of the superheated steam dryer when compared with conventional hot air systems.

The use of superheated steam as the drying medium instead of hot air also means that there is an oxygen free environment during drying which prevents oxidizing side reactions or combustion occurring during the drying process and this implies a safer drying environment if the material is combustible (Mujumdar, 2014). Superheated steam dryers are designed in such a way that they are closed systems and the exhaust can be collected and condensed. Similarly dust can be collected before it is released to the environment. A major advantage of SHS drying of sludge is that odour is effectively contained. A disadvantage of SHS drying compared with air drying is the higher temperatures required.

1.3. *Types of superheated steam dryer*

There are two main types of superheated steam dryer; fluidised bed dryers and rotating drum dryers. There are advantages and disadvantages of both processes, but in general the particle size needs to be carefully controlled in fluid bed systems and agglomeration will cause fluidisation failure. Agglomeration is also a problem in rotating drum dryers, but even with some agglomeration, flow can be maintained down the barrel of the drum, by providing a small downhill slope for the particles to tumble down. However, when drying at a constant rate in either type of dryer, the time required for drying is proportional to the mass of water trapped within the particle which in turn is proportional to the particle size. Heat transfer is proportional to the total particle surface area and the smaller the particle, the greater will be the surface area per unit mass. Therefore, control of the particle size is very important for obtaining uniform drying performance.

There are two main categories of rotating drum dryer: externally heated dryers where the heat is passed through the dryer wall and does not come in contact with wet solid (Hatzilyberis et al., 2000) and direct heat transfer dryers where the steam passes through the dryer itself which provides direct heat transfer between the steam and solid. This paper focuses on the latter, rotating drum superheated drying system, which is shown in the flowsheet in Fig. 1 and is presented in more detail in the next section. This is a general purpose type of steam dryer and this configuration has been used for drying a very wide range of products in addition to sludge, such as pet foods, wood chips, coal, biomass, mustard seeds, paper pulp, brewers and distillers spent grain, corn stover, sugar beet, hydrolysed feathers and nickel ore. One of the particular benefits of superheated steam for the drying of sludge is in the sterilization of biological products. The higher temperatures of greater than 100 °C within a SHS dryer provide the conditions necessary for pathogen elimination without the risk of fire or explosion. However, there is still a need for sufficient residence time in the dryer for the core of the particle to be sufficiently treated.

1.4. *Particle size*

Two phenomena, agglomeration and breakage are critical for controlling the distribution of the particle size, which in turn is critical for controlling the rate of drying. Both phenomena are controlled by the cohesive forces which hold an aggregate of particles together. Since the type of actions experienced by particles inside the SHS rotary drum resembles the one