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Research article

Rheological characteristics of faecal sludge from VIP latrines and implications on pit emptying

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ABSTRACT

This work aims at characterizing the rheological properties of faecal sludge from Ventilated Improved Pit (VIP) latrines and their implication on pit emptying. Faecal sludge was sampled from 3 pit latrines located in the eThekwini Municipality (Durban, South Africa). Samples were taken at different positions within the pit. For each of the samples, measurements in the rheometer in triplicates were performed in order to determine their rheological properties, and their moisture and ash content were measured also in triplicates. Experiments in the rheometer were performed for samples for which its moisture content was modified. In order to better understand the influence of water addition into the pit. During pit emptying, calculations were carried out from the experimental data, based in the criteria set in the Omni-Ingestor initiative, carried out by the Bill & Melinda Gates Foundation.

Faecal sludge exhibited a shear thinning behaviour, i.e. a decrease in viscosity with increasing shear rate, and presented a yield stress comprised between 500 to 1000 Pa. This needs to be surpassed in order to overcome the elastic resistance of the sludge to flow. Similar viscosities were found for the samples from the different pits, irrespective of the position within the pit, except for the sample from the bottom of one of the pits for which it was not possible to induce a flow. This sample had a considerably lower moisture content (67% wet basis) compared to the other samples (around 80% wet basis), probably due to a higher biodegradation as it was the most aged sludge in the pit.

According to the experimental results and calculations, the pumping requirements during pit emptying will decrease drastically by increasing the moisture content of the sludge. The addition of water into the pit would then facilitate the pit emptying operation by reducing the head and power required for pumping. However, this practice would require employing considerable amounts of water and handling higher volumes of sludge, which would lead to longer pit emptying times and increase the difficulty of the operation. For example, increasing the moisture content of the sludge from 75 to 90% will reduce the head and power of the pump by a factor 100, but will triplicate the amount of water in the sludge and, consequently, the time for pit emptying. Therefore, a compromise has to be made between increasing the pumping feasibility and adding water to the pit.

1. Introduction

Pit latrines are the predominant form of sanitation in low-income countries, particularly in Africa, because of their low-cost (Cairncross et al., 2010; Habitat, 2008; Jain, 2011). The main inconvenience with this type of sanitation facility is that the pit eventually fills up and thus the latrine cannot be used any further (Strauss et al., 1999; Thye et al., 2011). This causes a major problem in densely populated areas, as there is a lack of space for the relocation of the toilets, whilst the accumulation of high amounts of faecal sludge can lead to the spread of waterborne diseases and pollution of the environment. Hence, the safe emptying of the full pit is a necessity for sustainable faecal sludge management. The collected sludge has to be treated for pathogen inactivation and resource recovery, such as water for reuse, compost, fertilizer, biofuel, chemicals and construction materials (Dodane and Ronteltap, 2014).

Safely organized pit emptying, transportation and processing of faecal sludge are crucial for the sustainable management of pit latrines. Technological solutions have been developed in order to overcome the challenges related to the handling of faecal sludge, which is a biohazardous material with potentially high pathogen content. Pit emptying devices have been designed in order to avoid traditional manual

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emptying practices where the worker is exposed to a high biological contamination risk (Mikhael et al., 2014; O'Riordan, 2009). These pit emptying technologies include pumping systems (among diaphragm pumps, trash pumps, Gobbler), pit screw augers and vacuum systems (Mikhael et al., 2014; O'Riordan, 2009). Efforts have being made in order to provide improved technical solutions for pit emptying within the Omni-Ingestor (OI) project (Strande, 2014), funded by the Bill & Melinda Gates Foundation (BMGF). The initiative Sanitation Fund Research for Africa, funded by the BMGF and the Water Research Commission from South Africa, places particular emphasis on the development of innovative techniques for pit desludging in Sub-Saharan African countries (Pillay and Bhagwan, 2014).

The rheology of faecal sludge is an important parameter for the design and operation of pit emptying devices, as well as certain treatment process technologies, such as the viscous heater that pasteurizes the sludge after heating the material by viscous friction (Belcher et al., 2015). Currently, there is no enough information in literature on the rheological characteristics of faecal sludge. Only a few papers from the same authors deal with the rheology of human faecal material (Woolley et al., 2014b, 2014a). These papers focused on the study and modelling of the change of viscosity of fresh faeces with shear rate as a function of the moisture content and temperature. The results highlighted the shear-thinning and thixotropic behaviour of the faecal material, which was also observed for other types of slurry material such as sewage sludge and cattle manure (Amiri et al., 2012; El-Mashad et al., 2005; Ghafoori et al., 2007; Seyssiecq et al., 2003). In the study of Woolley et al. (2014a, 2014b), fresh faeces also exhibited a decrease of viscosity by increasing the temperature or the faeces moisture content. Like this, the viscosity decreased from 5 to 1 Pa s by increasing the moisture content from 67.5 to 85% at a shear rate of 100 s^{-1}. Increasing the temperature of the sludge from 10 to 50 °C reduced the viscosity from 450 to 275 Pa.s, at a shear rate of 1 s^{-1}.

Nevertheless, the characteristics of fresh faeces, manure and sewage sludge differ to those of faecal sludge from pit latrines, in properties such as the moisture content, aging and degradability degree, which should lead to a different rheological behaviour. Zuma et al. (2015) and Bakare et al. (2012) found that the physico-chemical properties of faecal sludge can vary as a function of the latrine and position within the pit. Moreover, as pointed out by Niwagaba et al. (2014), the properties of faecal sludge can differ largely from one sanitation facility to another, due to diverse factors such as the local diet, disposal of trash and grey water, water infiltration and drainage of leachate. Biodegradation occurs within the pit and the degree of biodegradation depends on the age of the faecal sludge (Nwaneri, 2009; Nwaneri et al., 2008). In fact, the most aged faecal sludge situated at the bottom of the pit tends to be more biodegraded than the fresh sludge layers above it. Environmental conditions, such as temperature or water from rainfall that can be infiltrated into the pit, can affect the properties of the sludge. This variability could then have an influence on the rheological characteristics of the sludge.

The present work was performed under the context of the “Reinvent The Toilet Challenge” program, initiated by the BMGF in order to improve the access to sanitation of people living in poverty (BMGF, 2012). This study aims to fill in the gap of knowledge on the rheological characteristics of faecal sludge, and to provide useful data to researchers and sanitation practitioners for the design of pit emptying equipment. The rheology of faecal sludge is an important of ventilated improved pit (VIP) latrines from the eThekwini municipality were characterized. Additional experiments were conducted by increasing the moisture content of faecal sludge, in order to simulate the material obtained from common pit emptying practices where water is added to the sludge in order to increase its ability to be pumped. From the experimental data, calculations were performed in order to better understand the influence of the sludge moisture content during pit emptying. The effect of temperature on the rheological characteristics was not included in this work, as the temperature in the laboratory during the experiments, namely 20 °C, was similar to that in the eThekwini municipality, varying in average between 18 and 25 °C along the year.

Note that the term “feacal sludge” employed in this study denotes the waste from VIP latrines whereas “fresh faeces” refers to the waste dealt in the investigation of Woolley et al. (2014a, 2014b).

2. Material and methods

2.1. Feedstock: faecal sludge from VIP latrines

The feedstock in this study was faecal sludge of VIP latrines from the eThekwini Municipality (Durban metropolis, South Africa). This type of on-site sanitation facility was designed in order to improve conventional pit latrine by reducing odours and the number of flies within the toilet. The VIP latrines consist of an enclosed brick superstructure with a door, a pit with a concrete slab cover and a ventilation pipe that pulls out the malodorous. The pipe is installed with a fly screen at the top, which prevents flies from entering the latrine.

2.1.1. Collection

The VIP latrines selected for sampling were from different locations in the peri-urban area from the eThekwini municipality but the socio-economic environment was the same between the different cases. For practical reasons, the sludge collected from only three VIP latrines were included in this study, although a considerably more important number of pits would be suitable in order to have a better statistical representation of the population. Nonetheless, the sludge from the three pits did not exhibit any visible peculiarity and presented characteristics that were representative of the faecal sludge found typically in the VIP latrines from the municipality, as demonstrated in section 4.1.

Faecal sludge was sampled from different sections of the pit. Sampling was performed according to a diagram proposed by Zuma et al. (2015), where the pit is divided vertically into a back and front section, and four horizontal layers, as depicted in Fig. 1. Note that the age of the sludge increases from section 1–8. This division of samples was done for two pits (pit 1 and 2). For a third pit (pit 3), the samples from the different sections were mixed in order to give an average representation of the content. The amount of sludge collected per sample was of a few litres.

In the eThekwini municipality, the VIP latrines are usually emptied in a 5-year cycle (Zuma et al., 2015), so it can be assumed that the age of the sludge was of 5 years at the bottom of the pit while it was more recent at the top, with an intermediary age between the bottom and top layers. The average age of the sludge can be then assumed to be 2.5 years. Pit emptying was performed manually without water addition, by using tools as shovels for digging and pitchfork to remove the big pieces of trash. Sampling was done using a spatula to put the sludge into containers for its transportation. During these operations, faecal sludge did not undergo considerable shear stress, so the rheological properties can be considered not have been significantly affected. Fig. 2 displays how pit emptying and sampling proceeded.

2.1.2. Storage

After collection, the samples were transported to the laboratory of the Pollution Research Group and stored in a cold room at 4 °C in order to preserve their properties. The samples were kept in closed containers in order to avoid desiccation. Non-homogeneous debris larger than 5 mm were selectively removed through sieving.

2.2. Analytical test

Different analytical tests were performed on the faecal sludge samples using the Standard Operation Procedures from the Pollution Research Group (PRG, 2014).