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Rheological characterisation of concentrated domestic slurry

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ABSTRACT

The much over-looked element in new sanitation, the transport systems which bridge the source and treatment facilities, is the focus of this study. The knowledge of rheological properties of concentrated domestic slurry is essential for the design of the waste collection and transport systems. To investigate these properties, samples were collected from a pilot sanitation system in the Netherlands. Two types of slurries were examined: black water (consisting of human faecal waste, urine, and flushed water from vacuum toilets) and black water with ground kitchen waste. Rheograms of these slurries were obtained using a narrow gap rotating rheometer and modelled using a Herschel-Bulkley model. The effect of concentration on the slurry are described through the changes in the parameters of the Herschel-Bulkley model. A detailed method is proposed on estimating the parameters for the rheological models. For the black water, yield stress and consistency index follow an increasing power law with the concentration and the behaviour index follows a decreasing power law. The influence of temperature on the viscosity of the slurry is described using an Arrhenius type relation. The viscosity of black water decreases with temperature. As for the black water mixed with ground kitchen waste, it is found that the viscosity increases with concentration and decreases with temperature. The viscosity of black-water with ground kitchen waste is found to be higher than that of black water, which can be attributed to the presence of larger particles in the slurry.

1. Introduction

Critical evaluation of our current sanitation system has led to the introduction of a new sanitation paradigm (see e.g. Kujawa-Roeleveld et al., 2006; Tervahauta et al., 2013; Zeeman et al., 2008). The new paradigm is based on source separation of the waste (as depicted in Fig. 1) and minimizing the use of water for transport. This source separated waste consists primarily of faecal matter from vacuum toilets, toilet paper and grinded kitchen waste arising from the use of food waste disposers. These domestic waste streams are subsequently treated with the objective to minimize energy use during treatment while maximizing the recovery of resources present in the wastewater, namely: bio-energy (generated from the anaerobic transformation of organic material), nutrients (nitrogen, phosphorus, potassium and sulphur), and water.

Although significant advancements have been made with respect to treatment processes in the new sanitation systems, the collection and transport aspects of the wastewater bridging source (e.g., households or industrial complexes) and treatment facilities, have been grossly neglected. Transport of the collected slurries is of particular interest when the new paradigm will be applied in a large scale. For any further development of the 'source-separated sanitation' approach, both transport and treatment are inseparable parts of the entire sanitation system and requires full assessment in order to evaluate its potentials for future waste handling (Larsen et al., 2009).

In order to design and operate a transport system for source-separated **C**oncentrated **D**omestic **S**lurry (CDS) composed of **B**lack **W**ater (BlW) that consists of human faecal waste, urine, and flushed water from vacuum toilets and **G**rinded **K**itchen **W**aste (GKW), detailed knowledge about the physical properties of transported liquid, particularly its rheology, is essential (Chilton et al., 1996; Slatter and Thomas, 1995; Thomas and Wilson, 1987). It has been shown that even the basic aspects of a pipeline design, for example the expected flow regime (laminar or turbulent) and pressure drop, can be misjudged without a rigorous understanding of the rheology (Eshtiaghi et al., 2012).

Food waste disposers (FWD) are an integral part of the new

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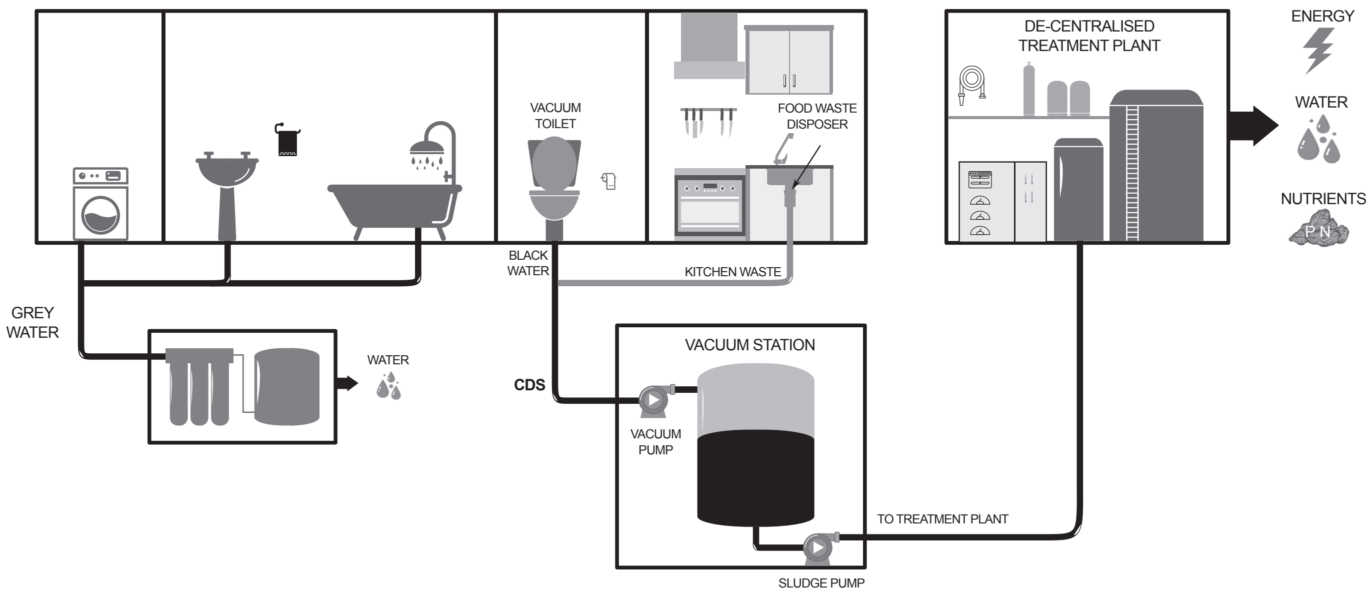

Fig. 1. Schematic representtion of a sanitation system according to decentralised sanitation and reuse concept.

sanitation paradigm. They macerate the kitchen food waste and dispose them into the sewer system. FWDs have been identified by many researchers as an effective domestic food waste management strategy (Iacovidou et al., 2012a; Lundie and Peters, 2005; Nakakubo et al., 2012). They may increase resource recovery in particular when connected to an anaerobic digester (Braun and Wellinger, 2003; Iacovidou et al., 2012b). Although many researchers have recommended FWDs, they have also indicated that for a large scale implementation or for higher market penetration, the implications of FWDs environment and conventional sewer system with respect to its transportation need to be examined, an overview of this can be found in (Iacovidou et al., 2012a). Therefore, it is only important that the transport of these GKW is assessed.

1.1. Current state-of-art

The state of the art on the solids content of wastewater in traditional sewer systems is summarised in the book *Solids in sewers* (Ashley et al., 2005). Although it provides great details regarding the origin and physio-chemical properties of the wastewater, rheological properties have not been characterised. It is common that a viscosity close to pure water is considered for the design of traditional sewer systems (Hager, 2010). However, CDS is much less diluted compared to the traditional domestic waste (Tervahauta et al., 2013); therefore, it is expected to have a considerably larger (apparent) viscosity.

Many studies have investigated the rheological behaviour of the primary, secondary, and aerobic/anaerobic digested sludge in treatment plants as summarised in (Eshtiaghi et al., 2013a, b; Ratkovich et al., 2013). It was concluded that the sludge is a non-Newtonian fluid showing a shear-thinning thixotropic behaviour. On the existence of the yield stress, no agreement was found. However, the obtained results are not directly applicable to the CDS, because primary and secondary sludge do not represent fresh faecal sludge and they undergo different treatments that change the structure of suspended organic matter present in the slurry. A study on fresh faecal sludge by (Woolley et al., 2014), is the only available literature on this. Unfortunately, their study doesn't give much information on procedure and collection to make the study useful for analysis. The inclusion of waste from FWDs also increases the flow complexity of these slurries. Apparently, the rheological knowledge of sludge in treatment plants cannot be directly used to reliably estimate the rheological properties of CDS; therefore, proper measurement needs to be conducted to investigate these properties. The current work presents measurements that were carried out to characterise the rheological properties of CDS. The

Table 1
Summary of investigated concentrations.

Slurry 1: Faecal		Slurry 2: Faecal + GKW	
Concentration (% TSS wt./wt.)	Concentrating method	Concentration (% TSS wt./wt.)	Concentrating method
11.2	Centrifugation	3	Gravity
10	Centrifugation	2.6	Gravity
7.2	Gravity	2.1	Gravity
5	Gravity	1.8	Gravity
3.9	Gravity	1.2	Gravity
3.2	Gravity	1	Gravity
2.6	Gravity	0.8	Gravity
1.8	Gravity		
1.4	Gravity		
0.7	Gravity		
0.4	Gravity		