Developing a synthetic pit latrine sludge and a process for its fluidisation

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Abstract

A synthetic pit latrine sludge is currently being developed as part of an investigation into the mechanical emptying of pit latrines. The relevance and motivation for the project is first explained in relation to the current state of provision of sanitation around the world. The objectives of the investigation are defined and a holistic analysis presented on the potential effects of this research on pit latrine emptying. The existing state of knowledge of the physical properties of pit latrine sludge is discussed, including the baseline data which will be replicated in this study. The results of a pilot study are presented along with the proposed methodology and experimental design. Finally a schedule of work is given for the remainder of the investigation.

Keywords: pit latrine, sludge, emptying, fluidisation

Introduction

At the World Summit on Sustainable Development in 2002 an additional Millennium Development Goal target was agreed "To halve, by 2015, the proportion of people who do not have access to basic sanitation"[1] and yet an estimated 2.6 billion people still lack access to improved sanitation, contributing to 1.8 million deaths per year from diarrhoeal disease[2]. Half of the world's urban population will live in slums by 2030[3], presenting a unique challenge as many houses do not have space for individual toilets and those that do will typically be unable to dig a new pit when their latrine is full.

Desludging existing pit latrines is therefore vital for providing a sustainable sanitation service in high density urban settlements. The *vyura* (frogmen) of Dar Es Salaam manually empty pits – spending up to six hours at a time waist deep in faecal sludge[4] without any protective clothing. They are victimised by local communities and at risk from various diseases as well as the collapse of unlined pits[5].

Various mechanised pit-emptying technologies (PETs) have been developed for high-density urban settlements with limited access. The most common type pumps waste out of the pit, either by hand (eg. MAPET – Manual Pit-latrine Emptying Technology[6]) or using a motor driven vacuum pump (eg. UN-Habitat Vacutug[7].) Vacuum-based systems minimise human contact with pit contents, reducing disease transmission, odour and flies. However most devices can only generate a few metres of static head and are therefore limited to extracting the liquid fractions of waste at the top of a pit[8]. Combined with the limited capacity of households to pay for complete pit emptying[9], this leads to the progressive build up of highly viscous and dense sludge at the bottom of pits, which becomes 'unpumpable' for typical vacuum systems after around two years of consolidation.

Project overview

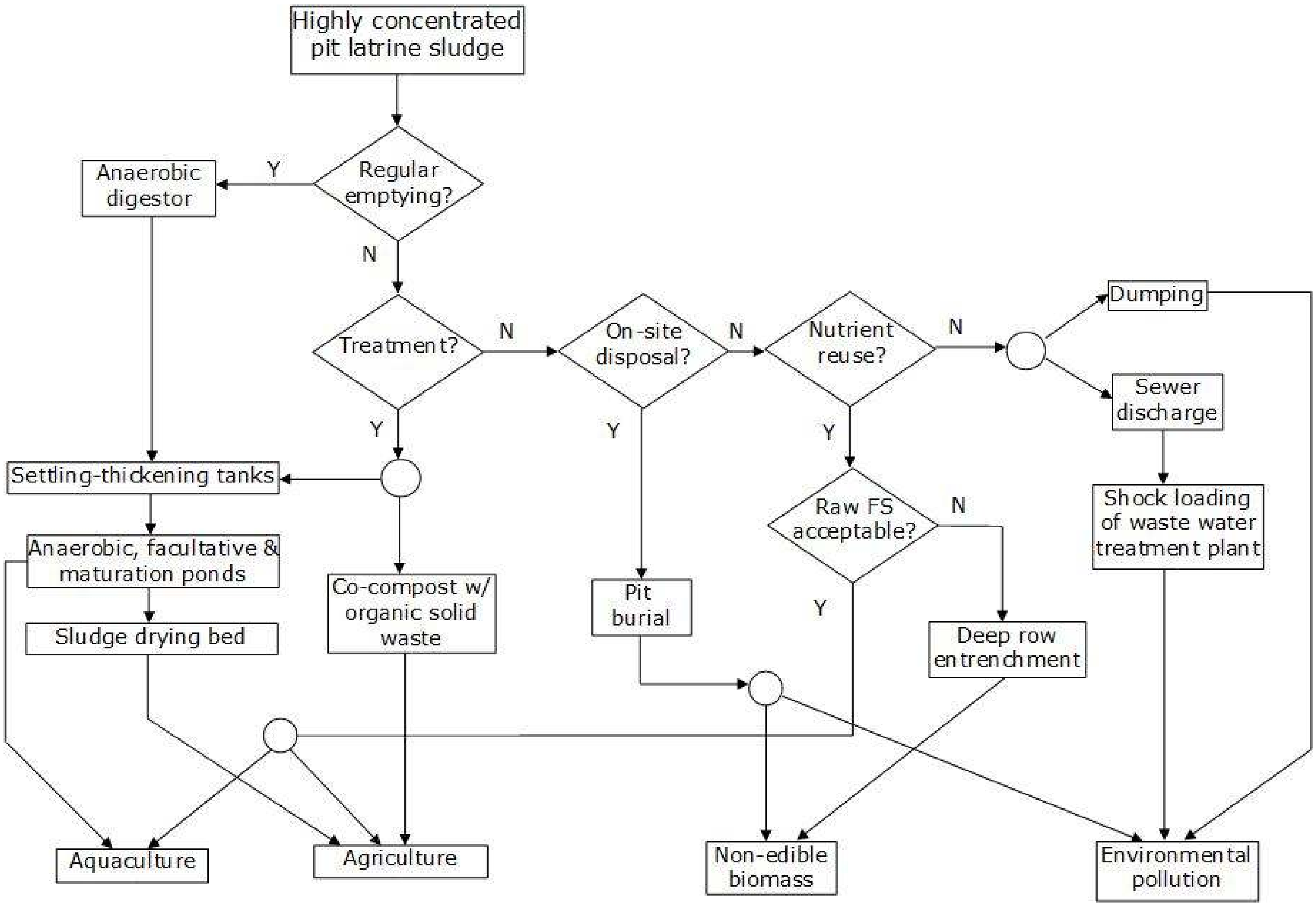
The focus of this project is to develop a safe synthetic sludge with the same physical properties as pit latrine sludge. This will enable performance comparisons of different PET prototypes as well as facilitating their development by removing the health and safety constraints associated with faecal sludge. A field testing procedure will also be developed to gather more data on faecal sludge, which varies greatly with diet and anal cleansing methods. In the second phase of the project a fluidisation process will be developed to extend the capability of a vacuum-based system. This research contributes to a UN-Habitat project on improved pit latrine design for mechanical emptying. If successful it will be followed by full-scale testing and field validation to identify any scaling effects.

Holistic analysis

The need to empty pit latrines is undisputed, however it is important to consider the effects such a system might have in an unplanned settlement and its surrounding environment. There is currently no standard practice or recognised best practice for the disposal of pit latrine sludge and "Appropriate low-cost treatment options for such FS [faecal sludge] need as yet to be developed."[10] In Kibera, Nairobi, it is common to discharge sludge into the sewerage system[11] whereas in Dar es Salaam pressurised discharge into a settlement lagoon or landfill site often occurs.

Various treatment and disposal options have been considered, as highlighted in Figure 1, which primarily focus on solid-liquid separation[12]. Disposal of pit latrine sludge to an existing wastewater treatment plant is unacceptable and uneconomical, as even a relatively large plant can't treat more than a few loads per day, at significant cost[13] - for example the Durban wastewater treatment works had to be shut after receiving a large shock load of pit latrine sludge[14]. There is also potential for reusing nutrients from faecal sludge in agriculture, however this is controlled by cultural acceptability.

Figure 1: Treatment options for concentrated faecal sludge from pit latrines



The fluidisation process suggested by this investigation will have two significant effects. Firstly, it will increase the solids content and volume of sludge that can be removed from pits, which could result in increased environmental dumping if suitable haulage and treatment processes are not implemented. There is a particular need for the development of decentralised treatment[12] as sludge transport is often the most time-consuming and costly part of the process.

Increasing moisture content just 2% requires 4-18L of water per cubic metre of sludge, which could be problematic in settlements like Kibera where due to "Water shortages and high prices of water, it [is] not always possible for owners of latrines to afford the water."[7] However it may be possible to recirculate low density sludge from the top of the pit for fluidisation, removing the need for injecting fresh water.

Existing knowledge:

The only comprehensive investigation into the flow behaviour of pit latrine sludge, to the best of the author's knowledge, was published in 1985 by the International Reference Centre for Waste Disposal (IRCWD)[A] using data from Botswana. The report[15] presents the density, water content and viscometer scale reading of 47 samples of pit latrine sludge, which were the limit of what various vacuum tankers were able to extract from pits. This data has been digitised and analysed to investigate the effect of water content on sludge density and viscosity, as shown in Figure 3.

Two things are immediately clear – firstly that sludge is highly variable (viscosity ranges from 2-65 scale units, density from 1027-1989kg/m^3) and secondly that there is no correlation between viscosity and water content, whereas density is strongly negatively correlated to water content.

A Now the Department of Water and Sanitation in Developing Countries (Sandec) at the Swiss Federal Institute of Aquatic Science and Technology (Eawag)

Figure 2: Effect of water content on sludge properties

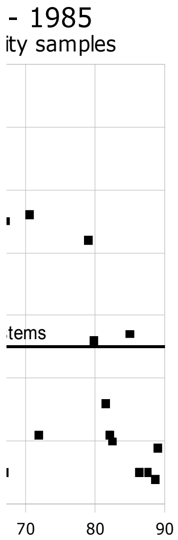


Figure 2 (a): Viscosity – water content

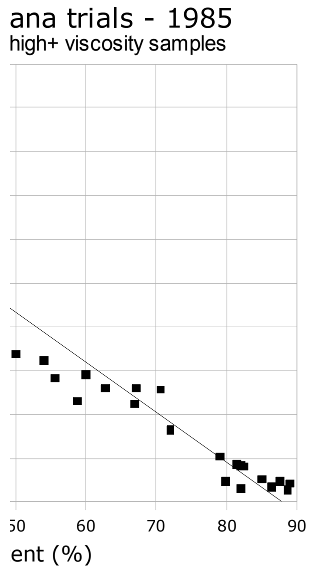
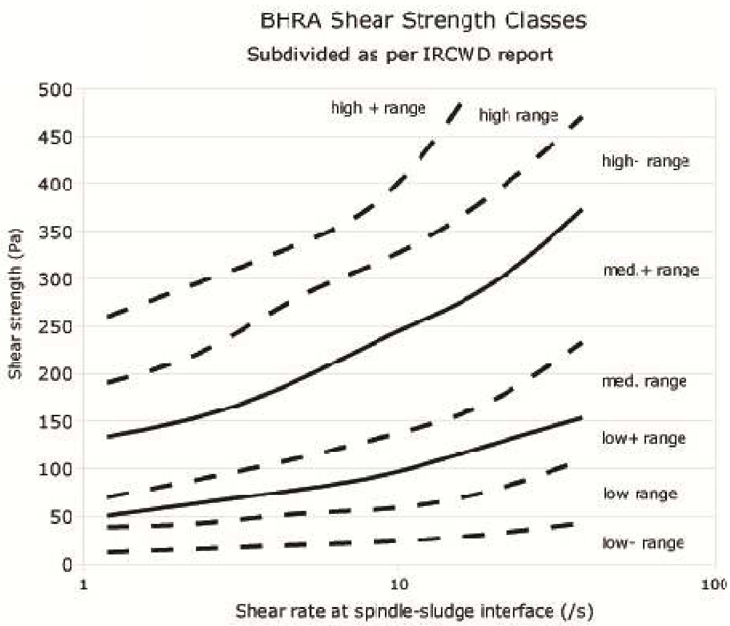


Figure 2 (b): Density – water content

The behaviour of consolidated pit latrine sludge is more similar to a soil than a fluid, therefore undrained shear strength has been selected as the indicator of 'pumpability' in this investigation. This is in contrast to the IRCWD report which used viscosity to characterise flow behaviour.

In order to replicate the IRCWD data it was first necessary to convert it from 'scale reading at nominal speed' to 'shear strength at shear rate'. For a cylindrical spindle it can be shown that the shear rate at the spindle-sludge interface is twice the rotational speed[16] and the viscometer manual provides conversion factors to convert readings into shear strength. The sludge flow classes defined in the IRCWD report have been converted into shear strength classes, as shown below in Figure 4.

Figure 3: Shear strength classes derived from IRCWD viscosity classes



There is evidence in the literature that a relatively small increase in water content, of order 2%, can have a "dramatic effect on sludge fluidity...[reducing] resistance to flow 30-300 fold."[17] A UN-Habitat trial using the Vacutug also found that the injection of a relatively small volume of water followed by a burst of compressed air has a marked fluidising effect on consolidated 'unpumpable' sludges. Water floating above the sludge is mixed into the denser fractions, producing a less viscous and lighter sludge that can be readily pumped. The key criterion in both cases is that the water must be injected into the bottom of the latrine – if water is added from the top it has no mixing effect.

Apparatus:

A mini ball penetrometer, specially developed for testing low strength marine muds, will be used for shear strength measurements. The penetrometer uses a local measurement device within the ball to eliminate shaft resistance and bending moments which would affect a load cell at the top of the shaft[18]. The output voltage is calibrated by placing masses on top of the penetrometer. The gain is set at 100, a tradeoff between a large full-scale deflection and higher noise. Shear strength is then calculated as the penetration resistance divided by a correction factor, N_b. For remoulded samples a value of 15~20 is appropriate[19].

The penetration rate is calculated to give a shear rate of 9.5 rad/s, the reference rate used in the Botswana study. The shear rate at the surface of a ball penetrometer can be estimated as twice the penetration rate divided by the ball diameter[20] giving a required penetration rate of 120mm/s.

Methods:

Phase 1: Sludge characterisation

Materials considered for the synthetic sludge include compost, clay, sand, maize meal, shredded newspaper and wallpaper paste. It was decided to start with a simple mixture of compost, clay, sand and water to investigate how varying its relative composition changes its density and shear strength.

The synthetic sludge will be batched and used immediately and can be considered remoulded. This will ensure that any fluidisation effect is purely due to dilution and aeration, rather than sensitivity of the synthetic sludge. This eliminates the risk of overestimating the fluidisation effect due to the artificial sludge being more sensitive than actual pit latrine sludge. It will also simplify the laboratory procedure as the sludge will be homogeneous with depth and sludge samples can be modified, remixed and immediately reused, resulting in a fraction of the amount of waste that using separate, consolidated samples would produce.

Samples of compost will be oven dried to determine water content. The sand and clay are supplied in dry form. All sludge samples for the first phase of testing will be made up in 20L buckets. An initial mix will be made with equal parts (by dry mass) of sand, clay and compost, with sufficient water added to give a moisture content of 10%. The moisture content will then be increased by 2% increments until a cohesive mix is produced which can be tested. One sample will then be weighed and oven dried to calculate the actual moisture content and another used to calculate density, according to standard procedures.

A pilot test will be carried out, at penetration rates of 5, 10, 20, 50, 100 and 200mm/s. The same sludge will also be tested using a viscometer at speeds of 100, 60, 30, 12 and 6rpm to generate a full DTS curve[15]. The larger size of the ball penetrometer and the use of a data-logger should reduce the variability in readings and will therefore require fewer repetitions.

The moisture content will then be increased 2%, samples taken to calculate moisture content and density, and the test procedure repeated. This process will continue until four different sludges have been tested. Welch's t-test will be used to find the significance of any difference between the shear strength from the viscometer test at 45.2rpm and the penetrometer test at 120mm/s. The required penetration rate will be determined and used for all subsequent tests.

The water content that produces a sludge with 'medium' shear strength[B] will then be used while the composition of the sludge solids is varied. The dry proportion of compost, clay and sand will each in turn be increased from 50% to 80%, with the other two components kept in equal proportions. A t-test will be used to determine whether the slopes of the resulting regression lines are significantly different from zero.

Phase 2: Fluidisation testing

The second phase of this project will investigate the fluidisation process and attempt to optimise it for a sludge that cannot otherwise be pumped. The time taken to pump out a latrine is negligible in comparison to that for wash-down and transport to the point of disposal, therefore the parameter to optimise is the percentage removal of sludge rather than the time taken for emptying. The key variables to control are the water injection volume and pressure, and the number of fluidisation cycles required. Investigations from offshore drilling suggest that the volume, rather than pressure, of the injected water is critical[21].

Testing will be carried out at laboratory scale using a 100L pressure vessel connected to a waste tank and a vacuum pump which can generate approximately ±0.3bar. A sludge of density 1700kg/m^3 and shear strength 200Pa will be

B According to the BHRA shear strength classes shown in Figure 5 selected for the pilot test of fluidisation. This represents one of the least pumpable sludges from the Botswana trial, which found a shear strength limit of around 100Pa (at the reference shear rate) for vacuum-based systems. A 75L batch of sludge will be mixed in a concrete mixer and then transferred to the waste tank for testing. Samples for water content, density and shear strength will be taken before and after each attempt at fluidisation. The first fluidisation cycle will only inject pressurised air, all subsequent cycles will inject sufficient water to increase moisture content by 0.5%, followed by a blast of air. After injecting water and air, an attempt will be made to empty the waste tank, and the volume of sludge remaining will be recorded. This process will be repeated until at least 90% by volume of the sludge has been removed from the tank.

The data collected from the pilot test will provide an indication of the volume of water required for fluidisation. Subsequent batches of sludge will be tested to determine the relation between the volume of water injected and the percentage sludge recovered, as well as the effect of changing the injection pressure. The significance of changes in flow behaviour due to fluidisation will be quantified using paired t-tests. Once a procedure has been optimised for fluidising this particular sludge, it will then be tested on a range of sludges with higher density and shear strength to determine its 'performance envelope'.

Schedule of work

Laboratory work was started in mid-January and is forecast to be complete by the end of March.

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