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TRANSFORMATION TOWARDS SUSTAINABLE
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Microbial evaluation of the viscous heater for commercial applications in faecal sludge treatment

D. Peguero, G. Foutch, J. Smay, T. M. C. Sahondo, L. P. Xaba, T. P. A. Hayangah, R. C. Sindall, C. A. Buckley & H. N. Bischel (USA)

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Risk of infection from human pathogens by contact with untreated faecal sludge (FS) poses a threat to worker health. The aim of this study was to assess the commercial potential of a 1000 L h^{-1} viscous heater (VH) to minimise this risk as a component of a black soldier fly larvae (BSFL) production pipeline. Changes in source material properties during sludge processing, temperature stability and microbial treatment efficacy were evaluated. Inactivation of heterotrophic bacteria in FS treated in the VH was measured at 60 ℃ and 80 ℃. Approximately 1- to 3-log inactivation was observed, independent of residence time. Maintaining temperature stability proved difficult with variable sludge viscosity and manual control of flow rate and engine power. Adding operational controls based on effluent temperature would compensate for variable sludge properties. Preparing FS for treatment in the VH proved challenging due to the small particle size required and the large quantity of detritus present.

Introduction

Interest in the viscous heater (VH) technology (Figure 1) was expressed by The Biocycle, a company based in Durban, South Africa, for commercial application as a treatment of faecal sludge (FS) prior to growth of black soldier fly larvae (BSFL). BSFL growth is core to several of the company product lines for its use as animal feed. Currently BSFL is grown in FS, which contains pathogens that are a health hazard to process operators. Pretreatment of the sludge used to grow BSFL could significantly reduce this health hazard. The primary objectives of the present study were to evaluate the effectiveness of a large-scale VH reactor for *in situ* bacteria inactivation in FS and to assess the temperature stability of the reactor at different set-points. Further, operational experiences and challenges were documented to assess the commercial potential of the VH technology for pretreatment in BSFL growth operations.

The output of the VH reactor is heat-treated sludge that can be used directly or further processed into more market attractive forms. The VH consists of a pump that feeds the sludge into a reactor which contains a rotating inner core driven by a motor. This rotating inner core operates at specified rotational speeds to generate a desired temperature in the sludge (Belcher et al. 2015). Open to the atmosphere, the VH can achieve temperatures approaching 100ºC. Operating with back pressure is required to achieve sterilization temperatures. The temperature inside the reactor is monitored by four thermocouples. If steady-state operation is achieved, the temperatures generated (>80 ˚C) are expected to efficiently inactivate microorganisms in the sludge. For example, 90% of *Ascaris* (helminth worm) eggs were inactivated in a laboratory study at 70° C in water, and complete inactivation was observed at 85° C (Belcher et al., 2015). However, such high temperatures may be costly and unnecessary in areas where *Ascaris* is not a public health threat. Using this previous study as a guideline, varying operational conditions were applied to find an effective temperature to inactivate total heterotrophic bacteria, while minimizing energy consumption and thus reducing system costs.

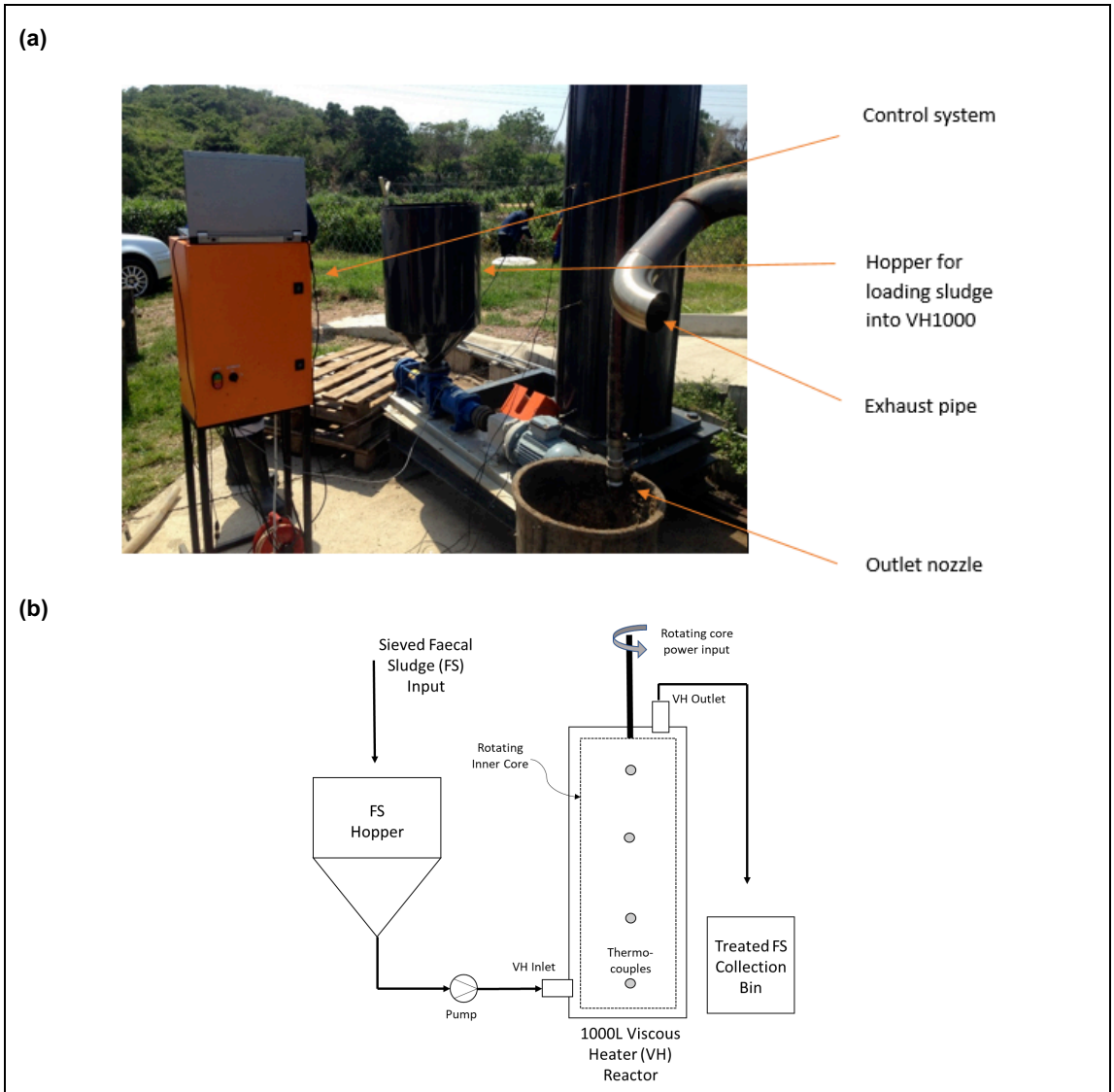

Figure 1. Photo (a) and schematic (b) of the viscous heater (VH) system.

Methods

Reactor development

The VH was developed based on the concept that fluid between a stationary cylindrical outer shell and a rotating inner core will convert mechanical energy to heat by molecular friction and that temperature throughout the viscous fluid can be controlled by the speed of the inner core and flow rate. This concept was tested at the lab-scale (1.0 L h^{-1} and 38 L h^{-1}), and computational fluid dynamic (CFD) models were used to verify its operation (German et al., 2017). Once the concept was proven, VH reactors at a range of scales (200 L h^{-1} and 1000 L h^{-1}) were tested, first with mashed potatoes as a FS simulant and then with FS. The present study makes use of the largest experimental reactor (1000 L h^{-1}) at a commercial BSFL treatment site in Durban, which processes up to 20 tonnes of FS per day. The cost of treating FS is approximately $0.05/kg including both operational and capital costs.

Sludge preparation and reactor operation

FS from urine diversion toilet (UDT) vaults was collected from households in eThekwini Municipality (which covers Durban and the surrounding areas) and transported to The Biocycle site for BSFL treatment. FS was taken from the receiving bay and large detritus (e.g., contraceptive devices, menstrual hygiene

management products, artificial hair extensions, rags) and household waste was manually removed using rakes and shovels. The sludge was mixed with water to make a slurry with approximately 65 % moisture content. This prevented blockages in the sieves and provided a sludge consistency that could flow through the VH. Sieving was carried out using a trash-ram that consists of a steel bucket, which can hold approximately 25 L of sludge, and a manually controlled piston to force the sludge through a sieve. Sludge was sieved in stages to 10 mm then 5 mm. Inactivation of bacteria in the sieved FS was subsequently assessed at VH set-points of 60℃ and 80℃. Each condition was tested in duplicate on different operation days. Five or six different residence times (1 to 6 minutes) were tested for each temperature set-point. To monitor temperature, four thermocouples were installed on the reactor. The sequence of the thermocouples was as follows from inlet to outlet: T4, T3, T2, T1. The thermocouples were evenly spaced along the height of the reactor.

Heterotrophic bacteria analysis

Approximately 5 g of FS was sampled from the reactor output at each residence time. The samples were transported to the lab and processed on the same day as collection. Each FS sample was vortexed in 45 ml of sterile phosphate buffered saline (PBS; 2mM $MgCl_2$, 0.3 mM KH_2PO_4, pH 7.2). Samples were serially diluted in PBS, typically to six to ten-fold dilutions, and 1 ml of each of three dilutions was plated on petrifilm dryplates (3M Company). The plates were incubated according to manufacturer protocol at a temperature of 37 to 40 ˚C for 24 and 48 hrs to determine heterotrophic plate counts (HPC). Periodic liquidation of some of the petrifilm gel was observed after 48 hours; however, results from 24- and 48-hour plate counts were found to be consistent when the gel remained intact.

Sludge properties

Ammonia, chemical oxygen demand (COD), total solids (TS) and volatile solids (VS) were measured in the FS before and after VH treatment according to Standard Methods (Eaton et al., 2002). Sludge viscosity was characterized using a MCR72 cone cup rheometer. All tests were carried out at the Pollution Research Group's FS laboratory at the University of KwaZulu-Natal.

Results and discussion

Reactor operation and temperature stability

Temperature in the reactor is controlled by the viscosity of the influent sludge, the influent flow rate and the rotation speed of the inner reactor core. Sludge viscosity is correlated with moisture content, which was measured and adjusted by the addition of water. Influent flow rate was easily controlled from the CFD model; however, the rotational speed of the inner reactor core could only be controlled manually from the engine chamber. This made temperature control challenging and maintain the temperature throughout the reactor for the duration of the sludge residence time was not always possible (Figure 2).

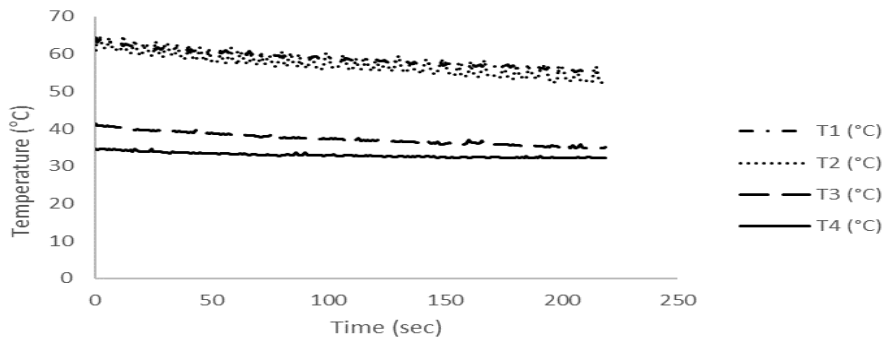

Figure 2. Temperature measured by the four thermocouples in the VH reactor for a retention time of 3 minutes and a flow rate of 558 L h^{-1}, with a 60˚C temperature set-point (11/30/2017)

Microbial treatment efficacy

Initial concentrations of heterotrophic bacteria in FS ranged from $1x10^7$ to $4x10^7$ colony forming units per gram (CFU/g). After heat treatment for one minute at either 60℃ or 80℃ operating temperature, HPC declined to $1x10^5$ to $7x10^5$ CFU/g. Approximately 1.5- to 2.5-log inactivation was therefore rapidly achieved at this residence time (Figure 3). The greatest inactivation of heterotrophic bacteria was observed at the VH set-point of 80℃ after one minute of treatment, which corresponded to an influent flow rate of 1440 L h^{-1} (Figure 4). Longer residence times at the same temperature set-points were achieved by decreasing the flow rate. Contrary to expectation, no increase in inactivation was observed with increased residence time. In fact, for several of the longer residence times tested, inactivation efficiency decreased. For example, only 1-log inactivation was observed on November 30, 2017 at 60℃ and a 3-minute residence time. This was attributed to lower temperatures measured in the reactor relative to the desired set-point. The temperature was measured as low as 30℃ on thermocouple 4 (the inlet) for the 3-minute residence time test (Figure 2).

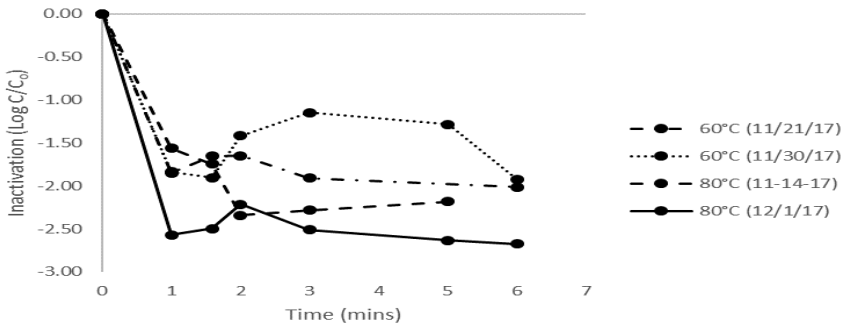

Figure 3. Inactivation of heterotrophic bacteria in faecal sludge during viscous heater treatment

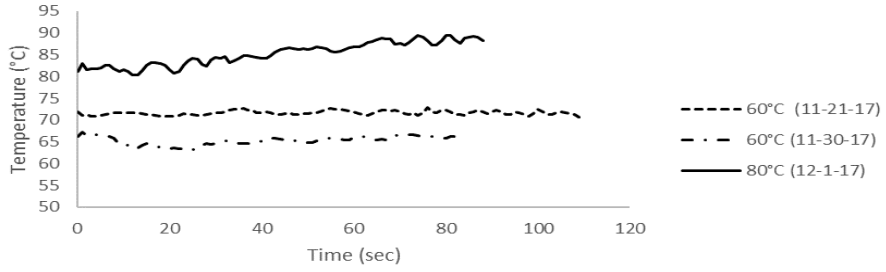

Figure 4. Temperature stability at the VH reactor outlet (T1) for tests conducted with 1-minute residence time, flow rate of 1440 L h^{-1} and the temperature set-point as indicated

Sludge characterization

For VH technology to generate sufficient heat for microbial inactivation the fluid needs to appear as paste. The mean solids content for the untreated FS and 1-minute treatment was approximately 66% and 74%, respectively. An alternative for measurement of moisture content, that may be useful for future adjustments of moisture content in the field, is the slump text where a cylindrical sample of sludge is placed on a surface and the diameter of the spreading sludge is measured after a fixed time. Previous experience has shown that when the solids content of FS exceeds 20%, the heating occurs with moderate operational RPM (between 700 and 1100 RPM) and flow rates. As the percent solids decreases, an increase in RPM and/or decrease in flow rate (increased residence time) is required. Detritus must be removed to a maximum size less than 10mm, preferably nearer 5mm. No significant change in COD or ammonia was observed during treatment.

Conclusion

Successes and failures

Sludge preparation

The large quantity of detritus present in FS from UDT vaults in Durban was problematic as the FS needed to be sieved to 5 mm before it could be processed by the VH. This was to prevent blocking of the small annular gap, which is 10 mm in diameter. The manual removal of detritus and the sieving process used were labour intensive and subjected workers to the same risks of handling untreated FS that treatment by the VH aims to avoid. A primary analysis of the detritus contained within a 100kg sample of FS taken from the receiving bay showed that approximately 33 % of the material was detritus. The majority of this (21.5 %) could be manually removed, and a further 9 % could be removed by sieving to 5 mm. The remainder of the detritus was between 5 mm and 1 mm in size. Further analysis of FS collected from UDT vaults and Ventilated Improved Pit (VIP) latrines is necessary to understand if these results are representative of FS across Durban. Furthermore, methods to remove detritus from FS streams (or better, to prevent it from entering them in the first place) need to be considered.

Reactor operation for microbial inactivation

The VH was found to be effective for 1-3 log inactivation of heterotrophic bacteria when operated at elevated temperatures (60℃ or 80℃). However, maintaining elevated temperature throughout the full residence times tested proved to be difficult and resulted in variable observed inactivation at longer residence times. Manually setting a higher temperature set-point (e.g., 90℃) may resolve this issue by forcing higher temperatures as a baseline. Alternatively, operational controls based on effluent temperature could be used to account for variable sludge properties. Longer residence times at a given temperature did not appear to provide significant additional inactivation, and longer retention times were difficult to achieve with the current reactor configuration. Therefore, it appears more efficient to run the VH1000 for shorter amount of time at the highest flow rate (1440 L h^{-1}) and higher temperature to achieve treatment. This would also address the issue that at long residence times (i.e., low flow rates) the pump would sometimes stall.

If the FS temperature achieved is high (e.g., 100℃ may be observed even during the 80℃ set-point), operators should be aware of the safety hazard associated with hot sludge exiting the hose. More precise temperature control would be valuable to maintain consistency in inactivation and control over safety with reactor operation. Conservative temperature set-points are expected to provide value in reducing health risks associated with downstream use of the sludge following VH1000 treatment.

Commercialization potential

The results of this study demonstrated that, with some added control, the VH can operate at a commercial scale for the inactivation of microorganisms in FS. The BioCycle indicated continued interest in including such a commercialised technology as part of their production pipeline. Addressing the issue of detritus in FS, and the unsuitability of manual picking to remove it, remains an important challenge to overcome. Similar interest in the VH has been shown by other sanitation businesses in East Africa, where the upstream operations of collection, emptying and transport of FS is likely to result in far less detritus.

By operating the VH1000 at full-scale, a number of design improvements were identified and recommended. Several macerator pumps are under investigation to determine if detritus can be chopped into sufficiently small pieces that can also be treated in the VH. This would provide added benefit by reducing costs of disposal of the removed detritus, which presently has to be treated as hazardous waste. Additionally, reconfiguration of the layout of the reactor components was recommended to allow for more ergonomic operation that is safer for workers operating the system. Specifically, the use of heat shields or insulation around the engine turbine, rotating cylinder and the exhaust and an improved layout to separate the locations of material handling and systems control are expected to increase safety during operation.

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References

EATON, A. D., CLESCERI, L. S., RICE, E. W. & GREENBURG, A. E. (eds.) 2005. *Standard Methods for the Examination of Water and Wastewater,* Washington D.C.: APHA-AWWA-WEF.

BELCHER, D., FOUTCH, G., SMAY, J., ARCHER, C. & BUCKLEY, C. 2015. *Viscous Heating Effect on Deactivation of Helminth Eggs in Ventilated Improved Pit Sludge*. Water Science and Technology Vol 72, No 7, pp. 1119–26.

GERMAN, C.L., PODICHETTY, J.T., MUZINGHI, A., MAKUNUNIKA, B., SMAY, J., and FOUTCH, G.L. 2017 *Computational fluid dynamics analysis of a high-throughput viscous heater to process feces and a faecal simulant using temperature and shear rate-dependent viscosity model.* Journal of Water, Sanitation and Hygiene for Development, washdev2017103.

Contact details

Daniela Peguero is a graduate student in the Environmental Engineering program at the University of California, Davis, with a strong interest in community development and improving sanitation and hygiene globally. Dr. Heather Bischel is an Assistant Professor in the Department of Civil & Environmental Engineering at the University of California, Davis with an interest in safe and efficient reuse of water resources and sustainable sanitation to improve environmental and human health.

Daniela Peguero
University of California Davis
One Shields Ave. Ghausi 3109;
Davis, CA 95616 USA
Email: dapeguero@ucdavis.edu

Heather N. Bischel
University of California Davis
One Shields Ave. Ghausi 3109;
Davis, CA 95616 USA
Tel: +1 530 752-6772
Email: hbischel@ucdavis.edu
https://faculty.engineering.ucdavis.edu/bischel/

Rebecca Sindall
Pollution Research Group
University of KwaZulu-Natal
Email: sindallr@ukzn.ac.za

Christopher Buckley
Pollution Research Group
University of KwaZulu-Natal
Email: buckley@ukzn.ac.za

Tapuwa Sahondo
Pollution Research Group
University of KwaZulu-Natal
Email: sahondot@ukzan.ac.za

Tom Hayangah
Pollution Research Group
University of KwaZulu-Natal
Email: hayangaht@ukzn.ac.za

Lindelani Xaba
Pollution Research Group
University of KwaZulu-Natal
Email: xabal@ukzan.ac.za

Gary Foutch
University of Missouri-Kansas City
Email: foutchg@ukmc.edu