TECHNICAL BRIEF

March 2018
The WRC operates in terms of the Water Research Act (Act 34 of 1971) and its mandate is to support water research and development as well as the building of a sustainable water research capacity in South Africa.

Understanding Solar Thermal Drying of Faecal Sludges

A Water Research Commission (WRC) study explored the use of solar drying of faecal sludges. The data obtained during the project could be used for the design of solar drying plants, improvement of existing technologies and innovation of further ones.

Background

The provision of safe and hygienic toilets requires that each step in the sanitation value chain is functional. For on-site sanitation, this value chain can be summarised according to: capture, storage, emptying / collection, transport and treatment / re-use (see Figure 1).

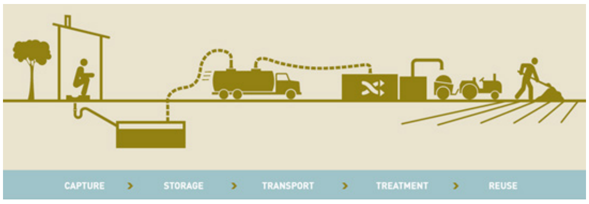


Figure.1 The faecal sludge management (FSM) sanitation value chain. Source: Bill & Melinda Gates Foundation (2010).

In South Africa, the emptying of latrines and variants is usually performed using manual labour. The collected sludge is then transferred to landfill or in rural areas, buried in trenches. The latter technique is technically challenging in urbanised spaces where space is limited.

This has led to a significant investment in the development of technologies – known technically as *Faecal Sludge Treatment Processors* (FSTPs) – designed to treat faecal sludges at decentralised locations. An example of this, is the *Latrine Dehydration and Pasteurisation* (LaDePa) machine developed in Durban; a containerised solution that, as the name indicates, dries and pasteurises faecal sludge.

In 2016, the Water Research Commission (WRC) funded study led by the Pollution Research Group, University of KwaZulu-Natal, sought to optimise the LaDePa process. The study generated valuable information of the drying rates of faecal sludge, specific to infra-red treatment.

Drying represents a critical process for the treatment load of faecal sludge. It enables moisture to be removed from the sludge and to reduce the pathogen load in the faecal material. The loss of moisture leads to the decrease of the mass and volume of the material reducing costs related to transportation and storage.

The reduction of the pathogen load leads to a less risk during handling. Drying can be the final treatment before reuse or a pre-treatment step before further processing (example: pyrolysis or combustion).

During the study, it was revealed that faecal sludge dewatering and drying information is generally lacking in field as is a basic understanding of the processes occurring under different drying treatment techniques. This information is highly valuable to design engineers as many FSTPs include dewatering and drying steps in their sludge processing.

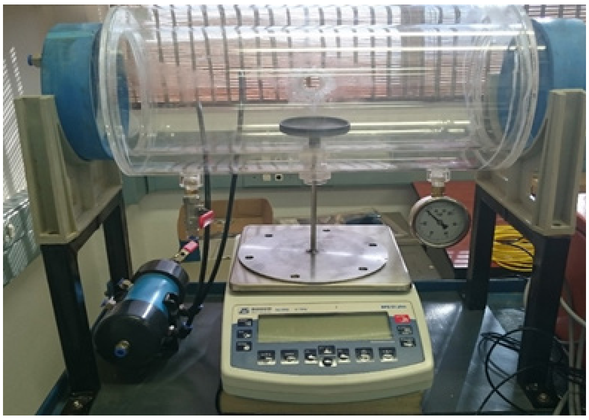
Follow-up study

As an extension of the above work, WRC Research Project K5/2582, was initiated to expand on the knowledge base gained from the LaDePa project by investigating solar drying and understanding the kinetics involved in the process as means to pre-treat faecal sludge.

In the faecal sludge sector, the use of solar energy for drying has been minimal, with only a few cases. The use of drying beds in a greenhouse have been explored in Uganda, Ghana, Rwanda and Senegal (Muspratt et al., 2014; Seck et al., 2015, Pivot, 2016).

Possible reasons for the low use of solar drying is the lack of awareness about this type of technology, as well as a lack of knowledge and data for the design of plants that could dissuade sanitation practitioners from using solar drying technologies. Motivated from these gaps, a fundamental study was conducted in this project to characterise faecal sludge solar drying.

The data obtained during the project could be used for the design of solar drying plants, improvement of existing technologies and innovation of further ones. This study developed a thermos balance to measure the kinetics and calculate the energy balance during solar drying at different conditions, the information of which is crucial for the design and development of solar driers



Setup of the sample support in the solar drying rig.

Main results

This project led to the generation of valuable data and knowledge, based on the learnt lessons and gained knowledge during the literature survey, conceptualisation and experimentation phases of the project. Further, the project enabled the identification of parameters to take into account during the development and operation of a solar drier for faecal sludge treatment, which are summarised in the below guidelines.

Potential of faecal sludge solar drying

This work confirmed the great potential of faecal sludge solar drying. Compared to conventional drying beds where the sludge is exposed at the open-air, solar drying has a greater performance. However, this gain in performance requires higher capital costs, so the implementation of a solar drying technology has to be planned with insight in order to make it worth the investment. The advantages that solar drying plant can bring are the drastic reduction of processing time, a better product quality, a better control of the drying conditions, the possibility to treat higher loads of sludge, among others.

Dr Santiago Septien Stringel with eThekwini Municipal engineer, Lungi Zuma.

Applicability of faecal sludge solar drying

Moisture removal rate around 1 – 2 ton/m^2/year could be expected in locations with similar irradiance than that of Durban in summer, for a solar drier operating in optimal conditions. Based on these figures, drying rates up to 3 ton/m^2/year could be attained in locations with higher solar irradiance, such as Mumbai (India) and Dakar (Senegal).

Faecal sludge could be applied in different scales, from on-site sanitation facilities to faecal sludge treatment plants. Thereby, large-scale solar driers could be developed for faecal sludge treatment plants, and small and medium size solar driers could be incorporated in on-site sanitation technologies or transfer stations after pit emptying.

Site selection

A solar assessment is a necessary step for the selection of the most appropriate site for the implementation of a solar drying technology, and provides data for the design, sizing and operation strategies of the process. For this, information should be obtained about the irradiance and meteorological conditions from the location where the solar drying technology could be installed. This information includes, but it is not limited to, the average year irradiance and air temperature, the variations along a year and their evolution through the last years. This data can be obtained from solar maps, local weather or radiometric stations, commercial software and consulting groups.

Orientation

In order to maximise the solar energy received in average during a year, the solar drier should be aligned in the west – east axis and face the opposite direction of the hemisphere of the planet where it has been installed, i.e. south direction in the north hemisphere, and north direction in the south atmosphere.

At a given season, the solar drier could be tilted at the optimum angle to receive the maximum of solar irradiance, which will depend on the geographical location. For small size solar driers, tilting seems a reasonable option as it does require high investment, complex equipment and a skilled labour able to operate it compared to automated tracking systems.

Enclosure

Solar drying in a transparent enclosure exhibits a better drying performance than open-air drying, such as drying beds. According to the experimental results from this investigation, the benefits of an enclosure are the most noticeable in overcast conditions, where faecal sludge drying was possible unlike at the open-air.

The temperatures inside the enclosure are higher compared to the ambient conditions, due to a greenhouse effect created by the transparent walls. Besides, the enclosure protects the sludge from the wind that can cool it. Higher temperatures are positive for the drying process performance, as they tend to increase the moisture removal rate.

Moreover, the enclosure avoids the rehydration of sludge from wet air or rainfalls, enables to operate at controlled conditions, prevents the proliferation of pests developed from the sludge (pathogens microorganisms, insects, etc.), and limits the risks of contamination of the environment.

Efficiency of a solar drier

The efficiency to harness the solar thermal energy by a solar dryer could be expected to be comprised between 60 to 90%, for a system with good thermal insulation. Most of the losses would be due to the reflectance and absorbance of solar radiation by the transparent walls of the enclosure and reflectance by the sludge. These losses cannot be avoided but can be limited by using transparent material with the highest transmittance possible and by adding to the sludge additives to increase its absorbance.

Disposition of the sludge

It is important to consider how the sludge will be arranged in the solar drier. In order to increase the performance of the process, the sludge layer thickness should be minimized and the surface area maximized in the extent of the possible. A thinner sludge layer with a higher surface area would decrease the drying time, lead to a more homogeneous drying in the sludge, and limit heat and mass transfer limitations. In contrast, more space would be required to treat the same amount of sludge at a lower thickness, but this can be compensated by the lower residence time required to achieve the moisture content target. Alternatively, stirring and mixing strategies mechanisms can be implemented in order to increase the surface area, enhance the heat and mass transfers and homogenize the sludge.

Crust formation

A crust can be formed at the surface of the sludge during solar drying and cause the drop of moisture removal. In this study, crust formation was suspected to be induced by solar radiation and intensified under operating conditions leading to a fast depletion of moisture at the surface, such as high air temperatures or velocities. Therefore, the development of means to mitigate crust formation in a solar dryer is critical. Mechanical means, as stirring and mixing, could be employed for this, as well as chemicals could be added to the sludge to avoid the structural changes provoking the crust formation. If solar radiation is proven as one of the precursors of crust formation, indirect solar drying, where only the air stream for drying will be heated by solar thermal energy, could be applied.

Ventilation

Ventilation in the drying chamber is necessary in order to evacuate the evaporated moisture and avoid the accumulation of vapour in the air, which can rise its relative humidity and lead to a subsequent drying rate decrease. If the air gets saturated in vapour (relative humidity = 1), drying can stop to occur. Apart from this, the vapour from the air can condense on the walls of the drying chamber, causing the formation of droplets that can reduce the penetration of solar radiation and lead to the risk of rehydration of the sludge.

During the experiments, the increase of the ventilation rate was identified as a cause of crust formation. In addition to this, the introduction of large volumes of air can cool the surface of the temperature of the sludge. Both crust formation and cooling of the sludge have a negative effect on the drying performance, so they have to be avoided. This way, the optimal ventilation rate should be enough high to evacuate the moisture in the drying chamber and avoid a rise of air humidity, but without exceeding levels that can drop the drying performance due to the crust formation or cooling of the sludge.

Pre-heating the air before its introduction into the drying chamber is an option that can theoretically accelerate the drying process, by decreasing the air relative humidity and increasing the moisture evaporation rate. Nonetheless, hot air in the drying chamber can also enhance crust formation during solar drying, as noted during the experiments.

Air pre-heating and high ventilation rates could improve significantly the drying performance if the methods to avoid crust formation are applied with success.

Odour management

An odour management strategy has to be setup in the exhaust air stream from the ventilation system that can carry out olfactory compounds, and in the handling of the dried product where odours may remain after the treatment.

Variability as function of the seasons and weather conditions

One of the major challenges of solar drying is the variability of solar irradiance, which can lead to an inconstant performance. The solar irradiance changes from one season to another during the year. It tends to increase from winter to summer and decrease from winter to summer. Within a same season, the weather conditions influence the solar irradiance. As demonstrated in this work, a considerable better performance is obtained during sunny than overcast conditions. The same results could be expected by the comparison of the drying performance in summer with respect to winter.

In order to cope with this variability that can be more and less important according to the geographical location, different measures can be taken into place. For instance, auxiliary heating sources could be utilized as an energy backup, such as solar water heaters, fuel, electricity from the grid or from a renewable source, and heat pumps. Likewise, energy storage systems could be employed in order to store the solar thermal energy during irradiation peak hours and use it in moments with low or null irradiance.

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