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Solar drying of faecal sludge from pit latrines in a bench-scale device

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Solar thermal energy for drying proposes could be employed as a cost-effective solution for faecal sludge treatment. In despite of its great potential, this option has not been enough applied, and there is a lack of knowledge in literature to allow for its emergence. The present work aims at providing data and knowledge to the sanitation practitioners in solar drying, through an experimental work with a custom-designed bench-scale apparatus. Depending on the experimental conditions, the moisture content of the sludge could be reduced from 60% to 20% after 5 hours of solar drying, with an average drying rate varying between 0.5 to 0.8 kg/h/m^2. The most favourable conditions for drying were during sunny weather conditions and for lower thickness of sample. A crust formation was observed to occur at the top of the sludge and may explain the lower drying rates than expected under certain conditions.

Introduction

Solar energy is an abundant and free source of energy in the world, particularly in major part of the developing countries. This could benefit populations from unfavourable areas where the access to energy is unavailable or too expensive. Solar energy can be directly converted into electricity by the means of a photovoltaic system, or into heat by a thermal system.

One of the possible use of the heat from solar thermal energy is for drying, which has a great potential application in the sanitation sector. Drying represents a critical part of faecal sludge treatment, which is necessary for a well-achieved faecal sludge management chain and contribute with the improvement of sanitation worldwide. It enables to remove the moisture from the sludge and to kill the pathogen population found in the faecal material.

Conventional drying beds are traditionally employed for the dehydration of faecal sludge. These represent a low-cost technology but they lead to a long treatment and inefficient pasteurization of the sludge (Cofie et al., 2006; Dodane and Ronteltap, 2014). In other hand, thermal drying systems can achieve a better performance, but they usually require high operating costs. For example, in the eThekwini municipality, an infrared dryer, LaDePa (Latrine Dehydration Pasteurization) was developed to treat the faecal sludge from 30,000 pit latrines (Harrison and Wilson, 2012). It consumes 8 liters of diesel per hour for the operation of the machine (equivalent to 6.6 dollar per hour in February 2018). This cost could not be afforded by many municipal entities in developing countries.

Solar drying is one of the most ancient application of solar energy, practiced particularly for food and crops conservation. Since then, there have been technological breakthrough in this area, but the deployment of solar drying technologies have not yet widely commercialized (Belessiotis and Delyannis, 2011). This can change as the use of solar energy is gaining relevance in the actual context where efforts are made to reduce the energetic dependence to fossil fuels to tend towards sustainability.

Solar drying offers a good opportunity to meet with the specifications of faecal sludge drying as a cost-effective solution. Besides, solar energy could be the perfect source of energy for an eventual in-situ drying system, particularly in isolated places with restraint access to energy. Traditionally, solar drying has been employed in drying beds where the faecal sludge is let it dry at the open-air. Nevertheless, this practice presents an important number of disadvantages, such as: high labour costs, large area and long time requirements, inability to control the drying process, risk of exposure to the pathogen content from the sludge for the workers, risk of proliferation of diseases or pests feeding from the sludge, among others. The use of a solar thermal system for drying is an attractive option to increase efficiency, to yield to a higher quality product and to operate in controlled conditions, compared to the traditional open-air drying methods (Jain and Tiwari, 2003). In a solar thermal system, the faecal sludge should be placed inside a transparent enclosure, which will avoid its rehydration after rainfall and cooling from the wind, and will create a greenhouse effect to increase the drying temperature and so the drying rate. An adequate ventilation system should be installed in order to avoid humidity accumulation in the air inside the enclosure.

The use of solar thermal energy system for drying has been minimal in the sanitation sector. A few cases of faecal sludge drying in greenhouses have been reported (Muspratt et al., 2014; Seck et al., 2015). A few on-site sanitation technologies, consisting in a urine diversion dry toilet where the faecal fraction is dried by solar thermal energy, are commercially available, such as the MAITRI toilet (RaVikas, 2016), SANI SOLAR toilet (3P-Technik-Sanitation, 2016) and the Earth Auger (Earth-Auger, n.d.).

Possible reasons for the low use of solar thermal systems for faecal sludge 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. This situation has been different for sewage sludge where positive results have been demonstrated. In 2006, an approximately number of 70 greenhouse solar drying plants in operation could be found in European countries, the United States and Australia (Seginer and Bux, 2006). The plants in Mallorca (Spain), Oldenburg (Germany) and Managua (Nicaragua) are able to treat up to 30,000 tonnes of sludge per year (Socias, 2011; Thermo-System, n.d.; Meyer-Scharenberg and Pöppke, 2010).

In order to explore the use of faecal sludge drying in a solar thermal system, a fundamental study was conducted in order to characterize the process using a bench-scale device. Faecal sludge from pit latrine was used as feedstock for this study as this type of waste is abundant in Africa. As expected output, the generated data and knowledge could support the design of solar drying plants, improvement of existing technologies and innovation of further ones. This could promote the efficient use of solar energy for faecal sludge drying, which is a comprehensive way to conciliate sustainability and sanitation. Note that in this work the use of a solar thermal system for drying is referred as solar drying (different to open-air drying as conventional drying beds).

Materials and methods

A bench-scale experimental rig was designed and constructed for this study. This apparatus consisted essentially in a thermobalance, installed at the roof of the Chemical Engineering building (latitude: 29°52'08.1" S; longitude: 30°58'46.6"E), at the University of KwaZulu-Natal, Durban, South Africa. The sample was exposed to the solar radiation inside a transparent box and it was placed on a crucible linked to a balance so as to measure the loss of weigh during drying and determine the kinetics of the process. Airflow was induced in the drying chamber, in order to remove the evaporated moisture. The air stream could be optionally heated before introduction into the drying box. The humidity, temperature and flowrate of the air stream were measured at different points. The temperature of the sample was also monitored. The data was continuously logged and recorded in a computer. The drying rig was stored in a shed when it was not used for protection against bad weather and thefts. The diagram and a photograph of the drying rig are depicted in Figure 1.

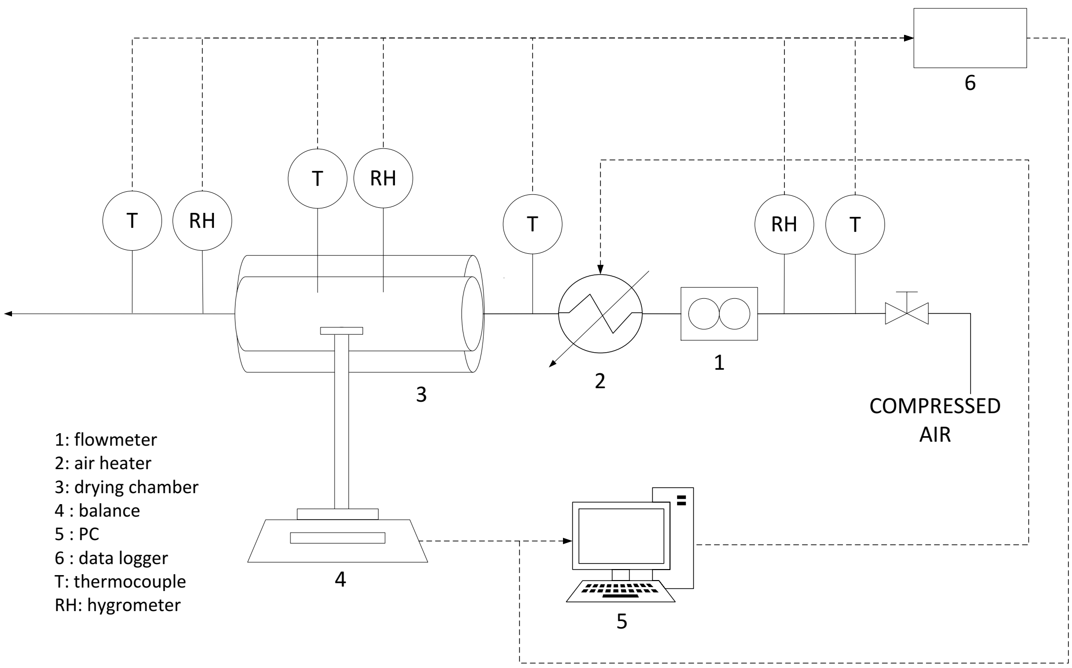

Figure 1. Solar drying rig diagram

The feedstock selected for the experiments was faecal sludge from ventilated improved pit latrines. The sample was taken during pit emptying in the eThekwini municipality (Durban, South Africa). In the laboratory, the faecal sludge was stored in a cold room at 4ºC in order to stop any biological degradation and preserve its properties in the extent of possible. Prior to the experiments, the sludge was screened in order to remove the trash as textile, plastic and metal detritus.

The experimental campaign in the solar drying rig was performed in the spring season. Prior to the experiments, the faecal sludge was spread as a thin layer on a circular crucible, which was then placed at the top of the weighing system. A second identical sample, placed at the open-air nearby the drying chamber, played the role of control. Its mass was monitored by manual weighing each two hours in a scale. The experiments started at 10 AM and finalized at 4 PM. The effect of the following parameters were studied:

- The weather conditions (sunny and overcast);
- The flowrate of the air stream inside the drying chamber (air velocity of 0.5 and 1 m/s);
- The heating of the air stream to introduce into the drying chamber (no heating and at 60ºC);
- The size of the sample (5 and 10 mm thickness).

Results and discussions

Figure 2 presents the average drying rate and final moisture content after 5 h of solar drying at different conditions. It also includes a comparison between the sample in the drying chamber and the control exposed at open-air during the study of weather conditions effect. The temperature of the sludge ranged mostly between 35 and 50°C without exhibiting a particular trend in the different experiments, and was higher than the ambient temperature that rarely exceeded 35°C. No difference between the temperature of the sludge at the surface and the core was observed under the explored conditions, so the heating of the sample could be considered as isothermal.

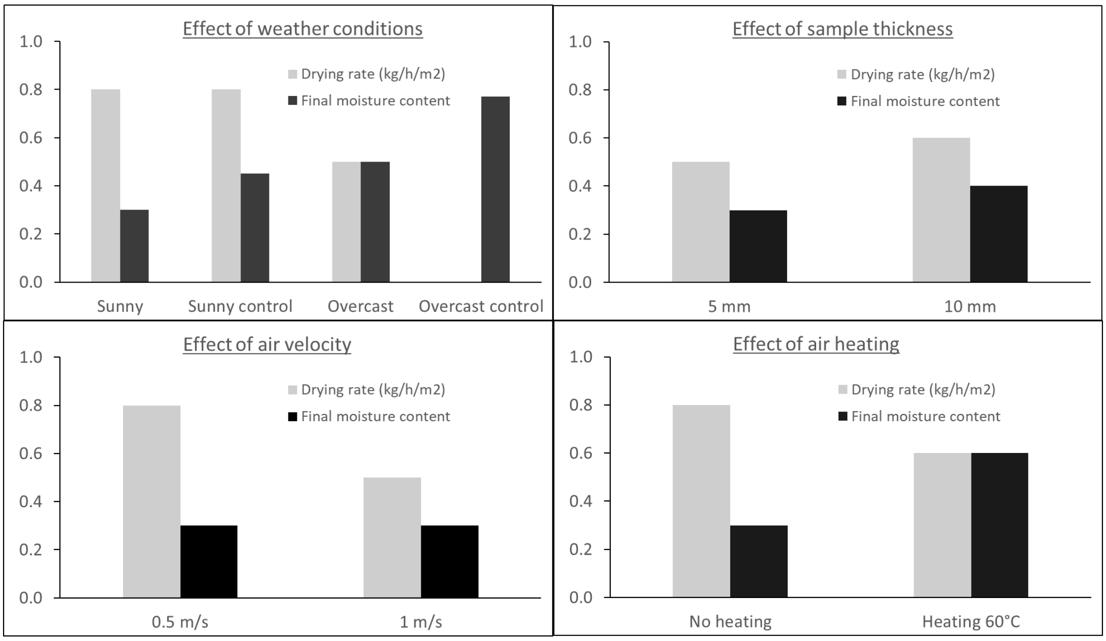

Figure 2. Drying rate and final moisture content after 5 hours of solar drying experiments at different conditions

It can be seen that sunny weather conditions led to faster drying rate and lower moisture content after 5 hours of experiment, compared to overcast conditions. This result could be expected as solar irradiance is the highest in sunny conditions. In the opposite, the clouds in overcast conditions reflects and absorbs part of the solar radiation, decreasing consequently the amount of irradiance reaching the ground.

Drying inside a transparent enclosure (sample within the drying chamber) occurred considerably faster than when exposed to the open-air (control sample). This difference was drastic in overcast conditions, where no drying was observed for the open-air sample. Indeed, transparent enclosure prevents heat losses to the environment by protecting the material against environmental factors, such as the wind that can cool the surface of the sludge. Besides, it creates a greenhouse effect as a transparent material is opaque to the long wave infrared radiation emitted by the sludge.

The increase of the sample thickness led to a drying rate decrease, as classically found for processes whose rate is controlled by transfer phenomena. By increasing the thickness, the path of the moisture to reach the surface from the core is longer, leading to a lower drying rate. Under the explored conditions, the temperature at the core of the sludge was the same between the 5 and 10 mm thickness sample. Therefore, the increase of thickness did not have an effect in the heat transfer by increasing the resistance to heat penetration within the material.

Surprisingly, the increase of air flowrate and temperature decreased the drying rate and lowered the final moisture removal after 5 h of solar drying. The opposite trend could be expected as a higher air velocities and drying temperatures leads to faster heat and mass transfer rates, and more energy available for moisture evaporation, which should induce theoretically to a faster drying rate. A crust formation was observed to occur at the top of the dried sample, and exhibited a particularly strong hardness during the experiments at 60°C. It was then hypothesized that higher air flowrate or temperature led to a faster depletion of moisture in the surface of the sludge and consequently to a faster crust formation. This should create a resistance of mass transfer of moisture to the environment, causing a drop of the overall drying rate. The combination of high temperature with solar irradiance could also have an structural effect on crust formation, making it harder.

This works demonstrated the feasibility of solar drying of faecal sludge, with similar performance to that reported for sewage sludge. For example, moisture from sludge is removed at a rate of 1 – 2 tonnes per year per m^2 in the Mallorca plant (Socias, 2011), which is similar to the values calculated from the data gathered in this study. The benefits to employ solar thermal system in terms of moisture removal, compared to conventional drying beds have been verified through experiments. It is expected that this work will increase the interest of sanitation practitioners for solar thermal systems for drying. The data and knowledge generated form this investigation could assist for the design, construction and operation of solar drying systems.

Conclusion

This work investigated the solar drying of faecal sludge from ventilated pit latrines in a latitude of 30° South, in the spring season. After five hours of drying, the moisture was removed at a rate of 0.5 to 0.8 kg/h/m^2 and led to a final moisture content between 20 and 60%, depending on the operating conditions. The temperature of sludge was higher than ambient temperature, varying between 30 to 50°C. The most favourable conditions for drying were obtained during in sunny weather conditions and for lower thickness of sample. A crust formation was observed to occur at the top of the sludge. This phenomenon was assumed to be the cause of an unexpected lower drying rate in conditions in which drying should be enhanced (i.e. higher air flowrate and temperature). As possible explanation, the surface of the sludge could be rapidly depleted in moisture under these conditions, leading to a fast crust formation that slowed the migration of the moisture from the core to the surface and consequently caused a decrease of the overall drying rate.

Based on the drying rate figures found in this work, the area to reduce the moisture content of one tonne of sludge from 80 to 20% (similar to the LaDePa process in Durban, South Africa) will be 1700 m^2 in the less favourable case (drying rate of 0.4 kg/h/m^2). This represents an acceptable area footprint, as it is equal the 1/5 of the area of a soccer field. In order to increase the performance and subsequnetly decrease the area footprint, the solar drier should be designed so as to avoid crust formation.

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