International Journal of Applied Engineering Research ISSN 0973-4562 Volume 13, Number 10 (2018) pp. 7598-7603

Exploration of the Use of Solar Thermal Energy for Faecal Sludge Drying

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Abstract

Solar energy is gaining increased attention as a power source. This is due to the increasing cost of primary energy sources, depletion of unrenewable energy reservoirs, and an increase in environmental protection legislation.

Access to decent sanitation and clean water is a basic human right. In terms of sanitation, governments have moved towards the provision of centralised, semi-centralised and stand-alone sanitation systems. The use of ventilation improved pit (VIP) latrines results in the gradual filling of the toilets and generation of faecal sludge.

Current faecal sludge treatment methods include the use of drying beds, deep trench disposal, and the black soldier fly. Drying of faecal sludge results in the decrease of total volume of the sludge and assists in pasteurisation.

In this study a solar dryer was designed, constructed and tested for the drying of faecal sludge. An analysis of the solar irradiance was also carried out.

Keywords: Solar energy, Faecal sludge, Sanitation

INTRODUCTION

Access to water and sanitation is a basic human right. Ventilated improved pit (VIP) latrines are a basic form of sanitation system used in developing countries [1, 2]. At the gaining of democratic government in South Africa in 1994, over 50% of the total population lacked access to decent sanitation systems [3]. Since then there has been improvement in the provision of improved sanitation systems, with the eThekwini municipality having provided over 60 000 VIP latrines since 1999 [4].

Faecal sludge is the end product if on-site sanitation systems [5]. The treatment of faecal sludge is a critical part of the faecal sludge management chain. The removal of water from faecal sludge is an essential step, as it assists in the decrease of the mass and volume of the sludge, leading to a reduction in transport and handling costs [6]. In addition, there is a decrease in the concentration of pathogens due to the dual effects of heat and moisture reduction. The Latrine Dehydration Pasteurisation machine [7] can treat large amounts of sludge using thermal energy, but the operation costs are high due to the power requirements. Drying is a highly energy intensive process, with 40% of total industrial energy used for drying applications. Drying of faecal sludge is a critical step in the treatment of faecal sludge; the use of renewable energy offers an alternative to the conventional energy intensive process.

Solar thermal energy is a sustainable source of energy in developing countries that can lead to high drying performance at low operating costs. Solar drying is an attractive drying method providing a low temperature dehydration process which is useful for the dry product quality, is energy saving, and reduces the negative environmental impact. For this reason, drying beds have been built as greenhouses in order to profit from solar thermal energy [8, 9]. Their operation relies on two processes, drainage of leachate through the base, and drying from the surface [10].

This study was conducted to characterise the drying of faecal sludge based on solar energy and to evaluate the feasibility of application of solar energy on a large scale. Treatment of faecal sludge before reuse is a critical step in the prevention of complications in public health, environmental contamination and resource recovery. The research used faecal sludge sourced from pit emptying operations in eThekwini municipality in KwaZulu-Natal province, South Africa. Objectives of the study included the design of a solar drying rig for the experiments and evaluation of various drying conditions. Quantitative and qualitative analysis, including thermos-physical characterisation of VIP faecal sludge, was carried out.

DESIGN AND CONSTRUCTION

Solar Assessment

A solar resource assessment was carried out at the test site to determine the amount of solar energy that could be harnessed at the experimental site. A PV planner assessment using SolarGIS was carried out at the University of KwaZulu-Natal (UKZN), Durban. The results were used for thermodynamic calculations to validate the use of solar thermal energy for drying. The solar drying rig was installed on the roof of the Chemical Engineering building (latitude: 29°52'08.1" S; longitude: 30°58'46.6"E). The drying rig was aligned in an east-west axis in order to maximise the amount of solar irradiance received during the day, without requiring a tracking system.

The solar irradiance was determined from the data measured at the closest SAURAN station, situated on the roof of Desmond Clarence building (latitude: 29°52'15.5" S; longitude: 30°58'37.0"E) (housing the Department of Mechanical Engineering at the University of KwaZulu-Natal (UKZN). The measurement station was located about 350 m from the Chemical Engineering building roof (Figure 1). In order to verify the absence of local meteorological variations with respect to SAURAN station, the solar irradiance was measured on-site.

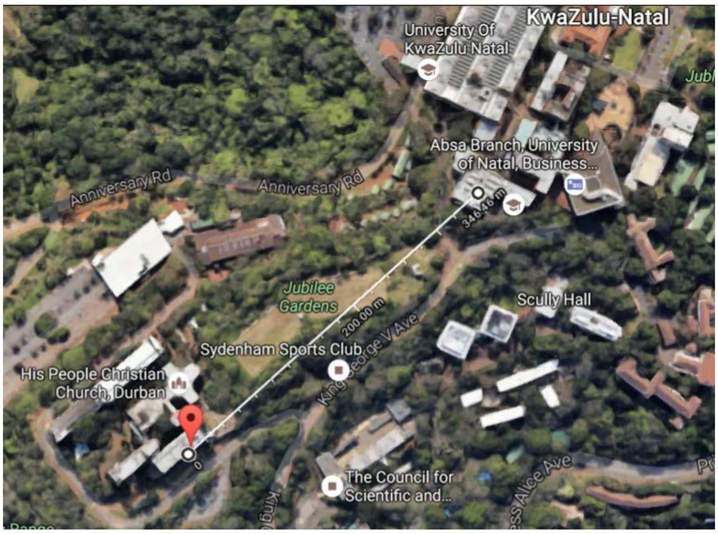

Figure 1. Distance between the SAURAN measurement station (on the left) and the experimental site (on the right), obtained from Google Maps ©

Solar Drying Rig

The sample was placed in a transparent cylinder which was exposed to direct solar radiation, and was linked to a balance so as to measure the loss of weight during the drying process. The drying kinetics were calculated from the weight loss measurements. Airflow which was pre-heated was induced into the drying chamber in order to remove the evaporated moisture and enhance the drying process. The humidity, temperature and flowrate of the air stream were measured at different points. The temperature of the sample was monitored.

An open air sun dried sample was placed next to the transparent solar drying box. The sample was exposed to direct solar radiation. Weighing occurred throughout the drying process to measure the moisture loss. The drying kinetics were calculated from the weight loss measurements.

The drying chamber was of a cylindrical shape in order to have aerodynamic conditions that are easy to characterise. The drying chamber was double walled with the vacuum air space between the two walls providing thermal insulation, in order to limit heat losses to the environment. The drying chamber had two ports to provide access to the drying zone: one port to introduce the support where the sample was placed, another to introduce thermocouples and humidity meters. The drying chamber was compact and mechanically stable. Figure 2 shows the full set-up of the experimental rig. Figure 3 shows the solar drying set-up.

Figure 2. Photograph of the solar drying rig

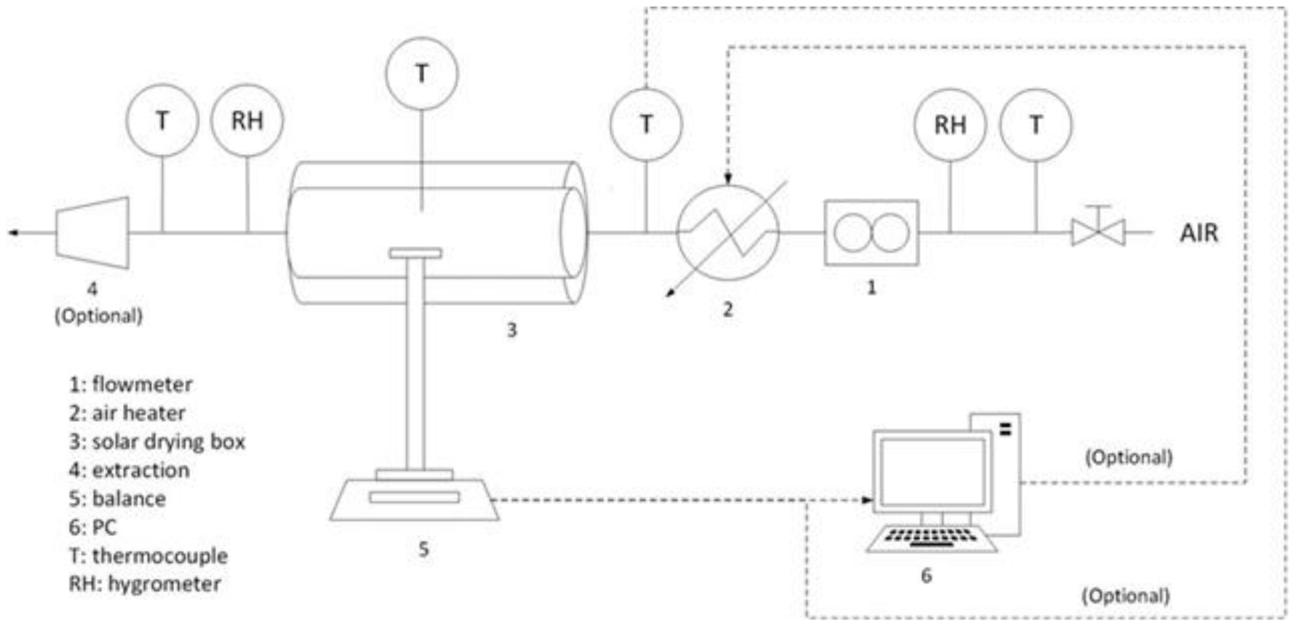

Figure 3. Solar drying setup

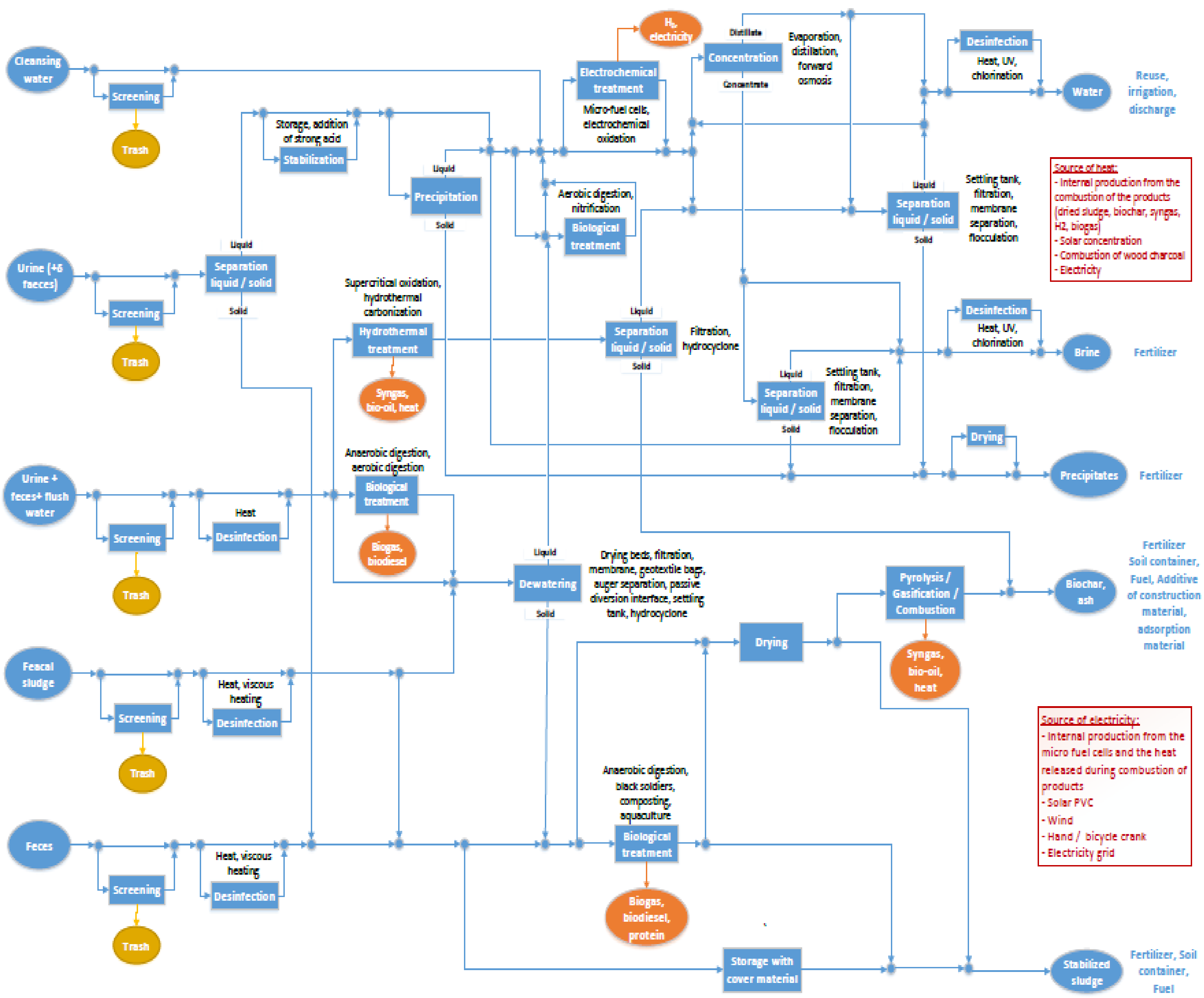

Figure 4: Importance of drying in waste management [11]

Solar Thermobalance

A solar thermobalance was built to measure the drying kinetics of faecal sludge. The drying took place inside a double wall vacuum tube made from an acrylic polymer (a high transmittance transparent material). The sample (faecal sludge from VIP latrines) was placed on a holder connected to a balance and a data logger. The loss of mass during drying was recorded. A temperature controlled compressed air stream passed through the tube in order to evaporate moisture and enhance drying kinetics. The flowrate was controlled by a valve. The rig instruments measured air humidity, flowrate, temperature and solar irradiance. Preliminary experiments included temperature measurements, flow characterisation and drying patterns.

Methodology

For preliminary experiments, synthetic sludge to characterise the sludge was utilised to test the apparatus. Faecal sludge sourced from pit emptying operations in the eThekwini municipality was used for the experiments.

After sampling, the faecal sludge was screened using different grid sizes to remove any unwanted material and grit such as plastics, inorganic matter and sanitary pads etc. The batch samples were collected from the same batch of faecal sludge, and, due to the low residence time, no premixing was required. Various intensity conditions for solar irradiance were experimented upon.

RESULTS AND DISCUSSION

According to the solar resource assessment carried out, the site receives approximately 1650 kW/h.m^2 of radiation (global horizontal irradiance). It also experiences a day length of between 10 hours and 14 hours from winter to summer. The site experiences a day length reduction of 2 hours due to shading and the layout of the land. Based on the energy results from the solar assessment, thermodynamic calculations were carried out on the moisture content removable from the sludge. The rate of moisture removal using the energy received at the site was 7.7 kg / day / m^2 in summer and 4.5 kg / day / m^2 in winter. This translates to a surface area of approximately 170 m^2 (half a soccer field centre circle) required to treat 1 tonne of faecal sludge per day to bring the moisture content from 80 % to 20 %.

Computational fluid dynamics (CFD) simulations using SolidWorks design software were carried out to optimise the design of the experimental rig. These included flow simulations to ensure flow convergence through the system through the alteration of input systems and orientations. Preliminary tests were carried out on the prototype to determine functionality, resulting in significant temperature rises in the prototype of on average 30 ºC above ambient conditions in the drying chamber. Outside wall temperatures were at ambient temperature and inner wall temperatures were at the temperature equal to the drying temperature, confirming the use of the vacuum as a good insulation method. A 48-hour vacuum test at 0.5 bar was carried out and the system held throughout that period. Flow tests resulted in a homogeneous flow through the system. Various thicknesses of synthetic faecal sludge were experimented upon. Figure 5 shows the results of these tests, demonstrating that solar thermal energy can be used for sludge drying.

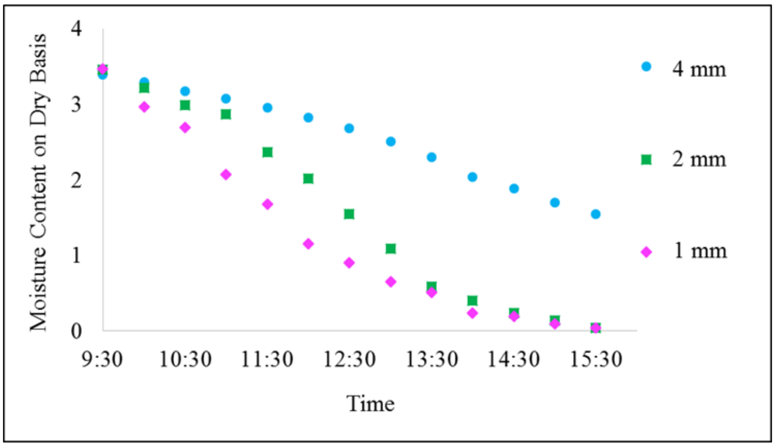

Figure 5. Drying curves of synthetic sludge

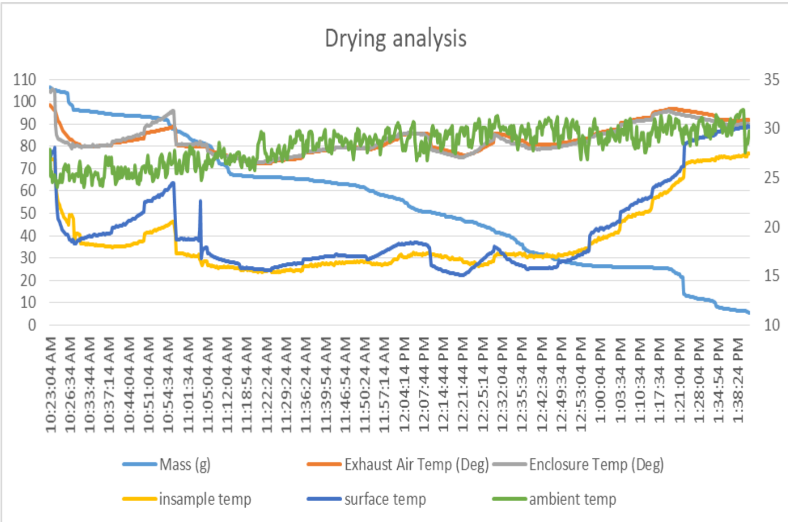

Figure 6a. Temperature and mass variations during experiment on a high irradiance sunny day.

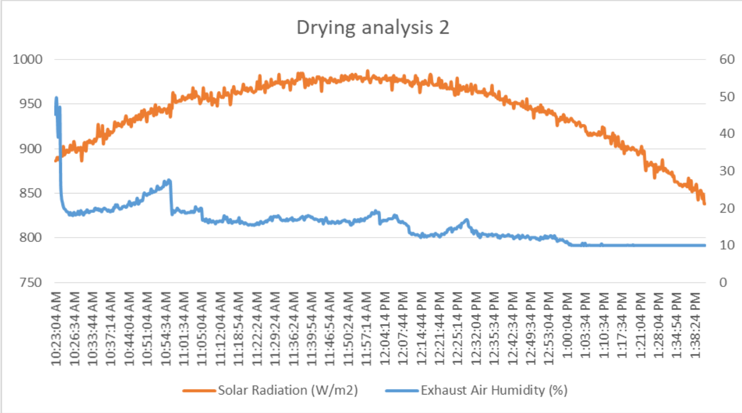

Figure 6b. Solar irradiance and humidity during experiment on a high irradiance sunny day.

Figures 6a and 6b show the variation of temperature, mass, humidity and irradiance on a 5mm thick layer sample. The variations indicate a decrease in mass of the sample with a temperature increase in the sample rising significantly towards the end of the drying curve. The same is noted for Figures 7a and 7b, although it was noted that the higher the solar irradiance the faster and shorter the drying time. The curves were a result of three averaged experiments in similar conditions to ensure result quality. In both sets of results, it was noted that for the duration of the experiments, the surface and internal temperature of the sample was significantly lower than the ambient temperature with the internal temperature being the lower of the two.

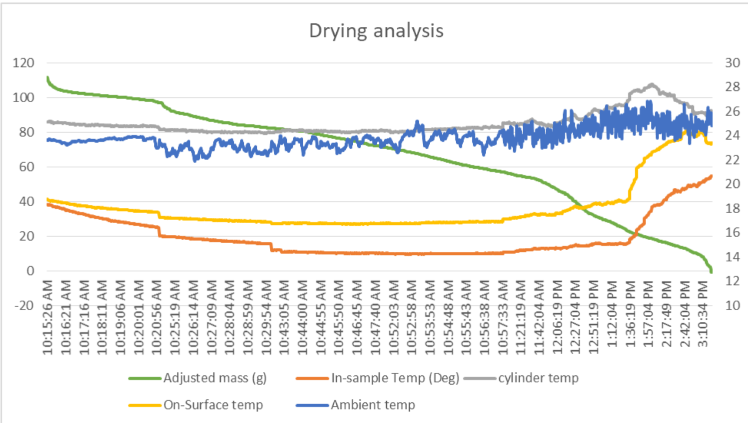

Figure 7a. Temperature and mass variations during experiment on a low irradiance sunny day.

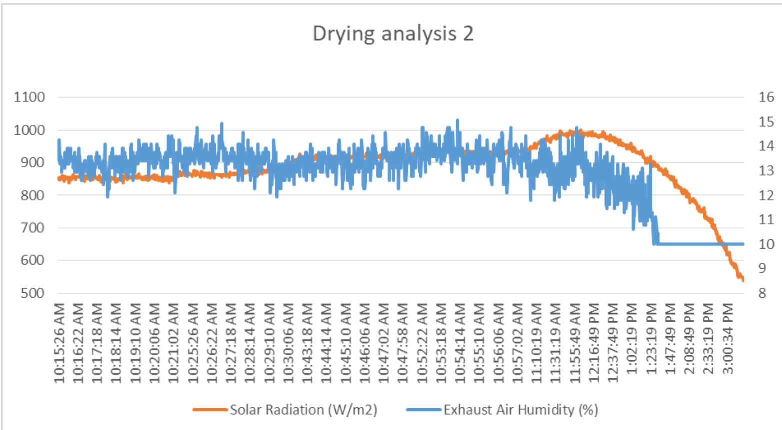

Figure 7b. Solar irradiance and humidity during experiment on a low irradiance sunny day.

The results showed that the higher drying rates due to higher temperatures resulted in development of a harder crust than lower drying rates with lower temperatures. However, the harder crust did not have a significant impact on drying time. Both drying cases resulted in moisture left in base of the sample resulting in the need for turning of the sample to ensure equivalent drying on both sides.

CONCLUSIONS

The preliminary stage of evaluations have proven the feasibility of the use of solar thermal energy for faecal sludge drying. At the time of the writing of the paper, experiments with faecal sludge had just commenced, but as noted solar irradiance received performs a critical role in the drying times of the samples.

Lab analysis tests were performed on the undried and dried samples. The tests were grouped into qualitative analysis, which looked into the physical quality of the dried sample, and quantitative analysis, which looked into the chemical quality of the tests. Qualitative analysis tests included tests on formation of cracks and crust during drying together with effect on odour and general nature of the sludge. Quantitative analysis tests included nutrient, calorific, thermal, moisture and ash content. Figure 4 shows the importance of drying and the re-use capacity of faecal sludge. Nutrient analysis, calorific value, thermal irradiance, ash and moisture content analysis tests will be carried out on the dried sample to evaluate the effect of drying on the re-use capacities as these are critical for re-use as a fertiliser, fuel or animal feed.

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