

Application of Greenhouse Technology for Solar Drying of Industrial Sludge- Preliminary Results

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Abstract

The application of solar drying of industrial sludge was conducted inside a greenhouse dryer at the University of Eldoret (UOE). Many industrial processes, such as food processing plants, discharge huge amount of wastewater that is usually treated before disposing. The Agrochemical and Food Company (ACFC Ltd), Muhoroni, discharges about 1.2 million litres daily from the production of industrial spirits through the fermentation of molasses. In this paper, preliminary results are presented on pilot drying experiments performed on liquid sludge discharged from the ACFC Ltd molasses processing plant. The liquid sludge was put on three rectangular containers to different depths and placed inside a greenhouse to dry until a constant mass of dry bio-solids were obtained. The masses and temperatures of the sludge in each container as well as the operating conditions (solar radiation and ambient temperature) were measured at equal time intervals of one hour during the day and recorded for use in the analysis. The results showed the moisture content of the samples to be 90.44%, 90.65% and 90.35% and the overall drying effectiveness of 0.54, 0.44 and 0.26 for the heights 2, 4 and 8 cm respectively. From these results, the most effective height for sludge drying under the prevailing climatic conditions of Eldoret is 2cm with an efficiency of 54%. However, the surface area needs to be increased in order to increase the yield per drying batch.

Key Words: Industrial Sludge, Greenhouse, Solar, Drying, Moisture

Introduction

Many industrial process plants discharge huge amounts of wastewater, which is usually treated before being discharged to hold-up lagoons. The Agro-Chemical and Food Company (ACFC Ltd) generates about 1.2 ML/day of effluents discharged through the fermentation of molasses at its plant in Muhoroni and represents a social and environmental problem of national scale. Disposal methods vary and include land disposal, incineration and re-use as a fertilizer. Analysis of the liquid sludge discharged from ACFC Ltd by the Department of Chemistry and Biochemistry, University of Eldoret, indicated that the wastewater has nutritional value that is beneficial for plant growth (Bore, 2009).

However, use of the wastewater in liquid form presents logistical challenges, especially in transportation to agriculturally potential areas far away from Muhoroni Township. In addition, the nutrients value in the liquid sludge is very dilute and requires huge quantities to be applied, which will exuberate further the cost of transportation. It has been suggested that dewatering of the liquid sludge provides an easier and cheaper method of disposing of industrial wastewater. The dry bio-solid products are easier to handle because they are compact and can be packaged in bags for ease of transportation and storage. In addition, the concentration of plants nutritional components in the dry bio-solid product is increased and the offensive odour is also eliminated.

Industrial processes produce wastewater continuously resulting in an ever increasing annual production of sludge all over the world with moisture content of over 90% (Chen *et al.*, 2006; Flaga, 2009). Several methods have been suggested for dewatering of wastewater but solar drying is usually considered the most appropriate because of its many advantages, including being a renewable energy source. Open-sun drying method is slow and prone to rain water wetting and a suitable solar technology need to be adopted. Solar dryers considerably reduce product drying time compared to open-sun drying and have been proved appropriate for drying fruits, vegetables and other crops (Santos *et al.*, 2005). In this paper, results of a study on the drying of wastewater discharge from ACFC Ltd are presented. The objective of the study was to investigate the use of greenhouse technology for solar drying of industrial sludge. The study focused mainly on the drying effectiveness and drying rate of the sludge discharge by the ACFC Ltd plant. The masses of the sludge in the two containers were measured at equal time intervals during the drying process and used to evaluate moisture content

profile. The drying results showed the moisture contents of the samples at the end of the drying duration.

Materials and Methods

Solar Sludge Drying

Solar drying process has been used widely for drying of industrial and agricultural products. Solar energy offers many advantages when used for drying and key among them is being a renewable source of energy. The solar energy is used to heat up the water, which in turn is evaporated from the product leaving it dried with little moisture content (Radaidah & Al-Zboon, 2011).

Many technologies have been used for sludge drying; these include mechanical drying, thermal drying and solar sludge drying (Salihoglu *et al.*, 2007). Among the existing solar technologies, greenhouse technology is the most appropriate method for solar sludge drying because it can be adapted to dry liquid products. The effectiveness of a solar dryer depends wholly on how much solar radiation the dryer can collect during the day (Mohsin *et al.*, 2011). The purpose of solar drying of the sludge is to reduce odour that results from chemical and biological reactions and volume reduction to ease storage, transportation and disposal processes (Ghaly & MacDonald, 2012). Research on thin layer drying of poultry manure and evaluation of the effects of drying with heated air on the chemical and biological properties of manure have concluded that the dried manure does not have an offensive odour and that temperature of between 40 to 60 °C is required to remove the odour.

Drying Analysis

The initial moisture content of liquid sludge can be determined using the convectional drying oven method. The procedure involves use of dried crucible whose mass is measured when empty. Liquid sludge of 5 g is poured on the dish and placed inside the drying oven and dried for 24 hours at a temperature of 110 °C. The initial moisture content (MC_i) can then be calculated from the following equation:

$$MC_i \quad (\%wb) = \left[\frac{M_w - M_d}{M_w} \right] \times 100\% \quad (1)$$

Where M_w is the mass of wet liquid sludge before drying and M_d is the mass of dry liquid sludge at the end of drying period.

The reduction in moisture content (MC_r) at every interval of one hour is calculated from the following equation:

$$MC_r \quad (\%wb) = \left[\frac{Mo(t) - Mf(t)}{Mo} \right] \times 100\% \quad (2)$$

Where $Mo(t)$ and $Mf(t)$ are the mass of the sample at the beginning and the end of the measurement intervals respectively. The masses were measured in grams, g. The value of MC_i is obtained from equation (1).

The rate of drying, D_r can be determined from the moisture removed at each interval by using the equation below:

$$D_r \text{ (g / hg)} = \left[\frac{Mo(t) - Mf(t)}{t_i} \right] \quad (3)$$

The equation (3) is usually presented in graphical form by plotting the drying rate D_r against time.

The drying effectiveness, D_e is defined as the time taken to remove one gram of moisture from the liquid sludge after a defined drying duration and is given by the following equation:

$$D_e \text{ (h / g)} = \frac{T_i}{M_R} \quad (4)$$

Where T_i is the drying duration in hours and M_R is the total moisture removed at the end of the drying duration. Equation (4) was used to calculate the drying effectiveness during the short time intervals and at the end of the overall drying period.

Experimental Set-up of the Solar Sludge Drying

Three rectangular plastic containers were used to simulate a drying bed and filled with liquid sludge to different depths and placed inside a greenhouse at the University of Eldoret. The drying trays had equal surface area of 254 cm². The liquid sludge was collected from the lagoons at the ACFC Ltd and transported to University of

Eldoret in containers. The moisture content (MC) of the liquid sludge is measured as 91.85% hence about 10% is solid only.

The liquid samples were poured into three trays at different heights of 2 cm, 4 cm and 8 cm and then placed inside the greenhouse next to each. The mass of each container was measured at equal time interval to determine the water lost in the drying process. The solar radiation and ambient temperature, both inside and outside the greenhouse, were also measured. All measurements were made in equal time intervals of one hour and recorded and used for analysis.

The samples were dried until dried solid sludge was obtained. The experiments were stopped once the masses in the container show constant value. The yield was recorded by weighing the dried sample. The initial moisture content (91.85%) was also determined using the drying oven method in order to be used for subsequent analysis.

The —drying time is the total time taken for the liquid sludge sample to reduce to the lowest possible amount of moisture content. The drying time is measured in both hours and days. The drying experiments were started from 6 a.m to 6 p.m and measurements were taken at equal time interval of one hour.

The temperatures of respective liquid sludge samples were measured using liquid thermometers which doubled up as stirrers. The ambient temperature and the solar radiation were also measured at the hourly intervals. The solar radiation was measured using a calibrated pyranometer. All the measurements were recorded and used for analysis.

Experimental analysis was done using Microsoft excel 2007 spreadsheet program. Graphical data on the results were then presented.

Results and Discussion

The experimental results showing the variation of moisture content with time of the liquid sludge at different depths of application is shown in Figures 1 and 2. The graphs show that the moisture content decreases exponentially with time. This is in agreement with the results reported for solar drying of grapes (Roberts *et al.*, 2007), cassava (Aliyu & Hamisu, 2009), fruits (Basri *et al.*, 2012), poultry manure (Ghaly & MacDonald, 2012) and apple slices (Rayaguru, 2012).

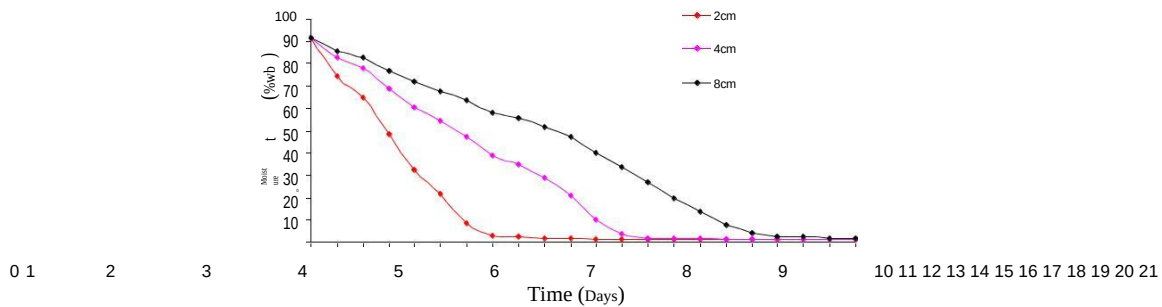


Figure 1. Moisture Content – Time Graph for the Entire Drying Period in Days for Respective Sample Heights

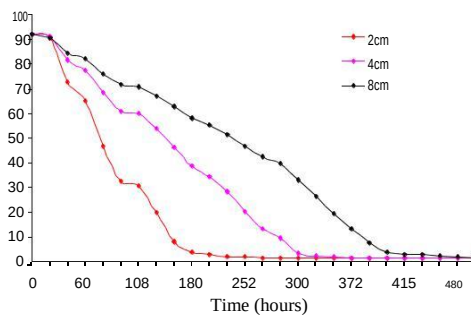


Figure 2. Moisture Content – Time Graph for the Entire Drying Period in Hours for Respective Sample Heights

The correlation equation between the decay of the sludge moisture content with time as obtained from figures 1 and 2 is of the following form:

$$Mc(t) = Mc(o)e^{-rt} \quad (5)$$

Table 1. Drying Results

Sample	MC (%wb)	M _R (g)	T (h)	r	D _e (h/g)
2 cm	91.85%	454g	245h	0.21	54%
4 cm	91.85%	950g	415h	0.17	44%
8 cm	91.85%	1854g	487h	0.11	26%

The drying time data was measured, recorded and presented as in Table 1 above. The moisture content, $MC(t)$ equation (5) was used to generate moisture decay constants, r . The results indicated that the sample depths affected evaporation of

moisture as a function of drying duration, T . As the drying duration and sample heights increased, the decay constant increased.

The 2 cm sample dried the fastest, then the 4 cm followed last by the 8 cm wet liquid sludge. The drying duration taken for every height showed that larger heights meant higher amounts of moisture in the wet liquid sludge and this emanated to longer drying time to remove the moisture.

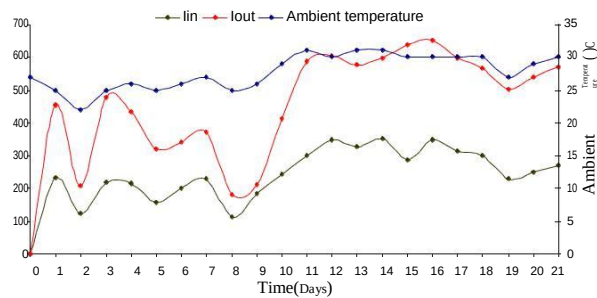


Figure 3. Radiation and Ambient Temperature Curves as a Function of Time in Days

The graphs in Figure 3 shows how the ambient temperature curves varied with solar radiation throughout the drying duration. The solar radiation affected greenhouse temperatures. An increase in solar radiation consequently increased the ambient temperature thus increasing sample temperatures. The greenhouse dryer enhanced the drying power of the sun as the air inside was heated sun and passed over to the wet liquid sludge. The heat acquired thereafter evaporated the moisture content present in the wet liquid sludge until its lowest value. At the moisture content lowest value, the sample was said to dry up. Moisture content removed is boosted by fact that water vapour is lighter than dry air, the warmer the air the more it can be removed by radiation.

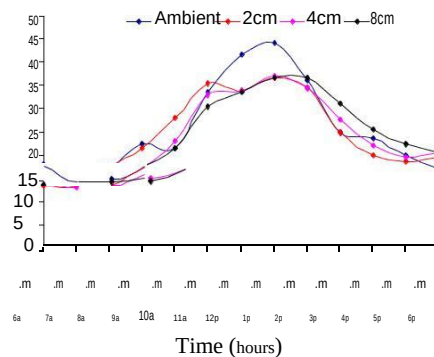


Figure 4. Temperature – Time Graph for a Randomly Chosen Day (Day 4) of the Drying Period

The temperature readings for day 4 are graphically represented in Figure 4. At the onset of solar radiation at 7 am, the sludge and ambient temperatures were 13.5, 13 and 14 °C for 2, 4 and 8 cm samples and 14.5 °C respectively. At 1p.m when ambient temperatures were at maximum, 44 °C, the respective sludge temperatures were 36.5, 37 and 36.5 °C and at sun set, 6 p.m, ambient temperatures dropped to 17 °C and sludge temperatures also dropped to 19.5, 20.5 and 20.5 °C for 2, 4 and 8 cm respectively. This meant that some heat is stored within the wet liquid sludge for drying to continue during night hours. It therefore explained the reduction of moisture during night hours.

The drying effectiveness was determined by the total drying period from equation (4) and presented in table (1).

$$D_e (2cm) = \frac{245}{454} \times 100 = 54\%$$

$$D_e (4cm) = \frac{415}{950} \times 100 = 44\%$$

$$D_e (8cm) = \frac{487}{1854} \times 100 = 26\%$$

The efficiency is a measure of how effectively the heat available in the greenhouse chamber is transferred into the wet liquid placed at varying heights in a given duration to eliminate an equivalent amount of moisture. The most effective and efficient height thus was one with the highest percentage, 54%, 2 cm.

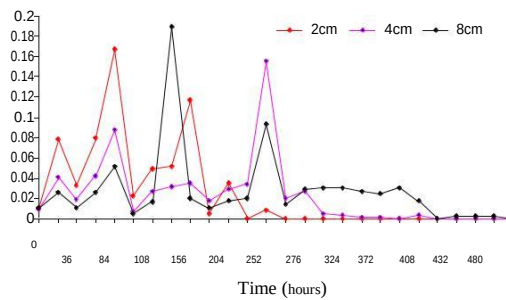


Figure 5. Drying Rate – Time Graph for the Entire Drying Period in Hours

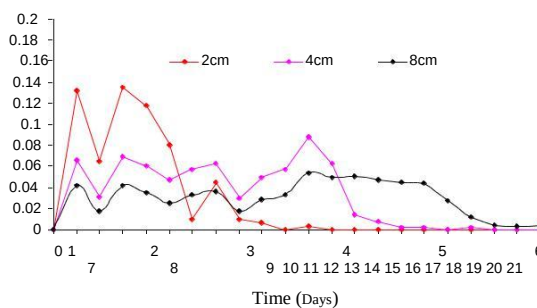


Figure 6. Drying Rate – Time Graph for the Entire Drying Period in Hours

The graphs in Figures 5 and 6 represent a three phase drying behaviour as depicted through at various stages of the entire drying period. The first phase is the increasing rate of moisture removal when moisture content in the wet liquid is highest, the second phase is the constant rate of moisture removal and the third phase is a falling drying rate of moisture removal. The moisture removal rate diminishes with time or as drying period comes to an end.

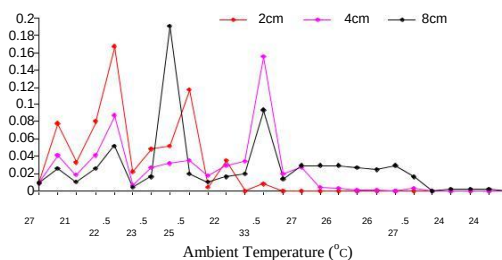


Figure 7. Drying Rate – Ambient Temperature Curves throughout the Drying Period

The graphs in figure 7 show interrelations of the drying rate and the greenhouse ambient temperature throughout the drying duration. At high ambient temperature, the drying rates of samples increases. This is not dependant on sample heights.

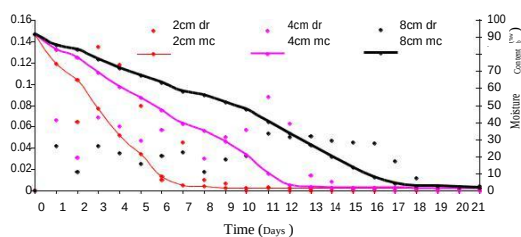


Figure 8. Drying Rate and Moisture Content Curves for Different Values of Temperature

The graphs in figure 8 show the general drying behaviour during the early stages of the drying period. The 2 cm sample drying rate is the highest followed by 4 cm then the 8 cm. The higher the moisture contents in the samples the higher the drying rate.

Conclusion

The experiments were run concurrently until a constant mass of dried bio-solids were obtained under the local climatic conditions of University of Eldoret. The preliminary results indicated moisture removal in the three trays (2, 4 and 8 cm) durations of 245, 415 and 487 hours, which translates to drying effectiveness of 0.54, 0.44 and 0.26 respectively. The final moisture contents of the samples in the respective trays were 90.44%, 90.65% and 90.35% and overall drying effectiveness of 0.54, 0.44 and 0.26. The results indicate that the most effective height for sludge drying to be 2 cm with an efficiency of 54%. Thus it is recommended that 2 cm depth be used but the surface area to be increased in order to increase the yield in each drying batch.

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