2004

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Ali Mohammad Gharaibeh
University of Wollongong, ag16@uow.edu.au

Muttucumaru Sivakumar
University of Wollongong, siva@uow.edu.au

Hagare Dharmappa
University of Western Sydney

Publication Details

Gharaibeh, A., Sivakumar, M. & Hagare, D. (2004). Drying of water treatment plant residuals. In M. Mowlaei, A. Rose & J. Lamborn (Eds.), Environmental Sustainability through Multidisciplinary Integration (pp. 164-172). Australia: Environmental Engineering Research Event.

DRYING OF WATER TREATMENT PLANT RESIDUALS

A. GHARAIBEH, M. SIVAKUMAR AND H. DHARMAPPA

Sustainable Earth Research Center (SERC), School of Civil, Mining and Environmental Engineering, University of Wollongong, Wollongong, NSW 2522

SUMMARY: Drying of ferric chloride water treatment plant residuals have been studied in two experimental sand drying beds. One bed was open and the other was covered with glass to study respectively the open bed drying of residuals under normal weather conditions and passive solar energy drying. The covered bed was fabricated, with a view, to simulate the solar distillation stills. A weather station was used to monitor the dynamic weather conditions in order to study their effect on the drying process. Solids content, drainage water volumes and distillate from the covered bed were measured on a daily basis. The aim of the study was to accelerate the drying process of residuals using passive solar energy drying technique. The study showed that the residuals dry faster in the open bed. The passive solar bed design was altered several times during the study in order to improve the bed performance. However no significant improvements were found in the performance. A reduction of 33% in drying time was achieved when the solar drying bed was provided with a fan heater. The operating conditions of both beds and their effect on the drying process are studied to understand the operation of sand drying process.

1. INTRODUCTION

In a previous study (Gharaibeh et al. 2001) meteorological parameters such as wind speed, humidity, solar radiation, rainfall and ambient temperature were found to have significant impact on the performance of the sand drying beds. The weather conditions and their effect on the drying process were studied.

Solar drying is a technology suitable for producing dry material of certain water content at an economical price. The potential is to dry water treatment plant residuals to a manageable level keeping in mind other environmental issues. The boundary conditions of a solar drying design are mainly the quantity of residuals produced, the local meteorological conditions and the other available sources of energy. The advantages of accelerated residuals drying processes are reduction of time for final reuse or disposal and hence reduction in the land area used for drying.

Unexpected wet days contribute to extensive delays in the drying process. From an economical and handling point of view, it is important to dry the residuals to 30%-45% solids content before final disposal or reuse. In order to achieve this task, the drying technique should be modified to accelerate the drying process as a long-term solution for this problem.

A solar drying process can be designed in a similar way as that of solar distillation still. A passive solar still collects heat without assistance from other solar collectors or mechanical device. However, active solar stills are incorporated with mechanical devices such as fans or pumps and/or other types of solar collectors. The use of solar distillation units as shown in Figure 1 can serve two purposes, the first is drying of the residuals effectively and quickly, and the second is the utilisation of the evaporated and then condensed water back into the system without any losses of the water.

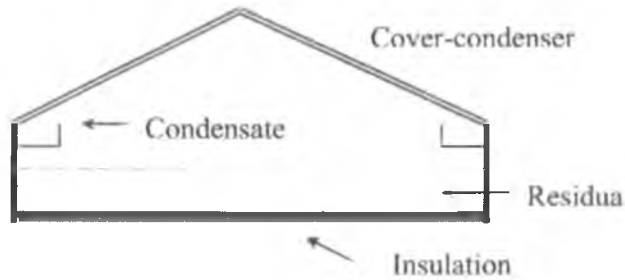


Figure 1. Schematic cross section of a bay of a basin-type solar still (Adapted from Duffie and Beckman, 1991).

Solar distillation is a technique where fresh water can be extracted from sea or saline water by the use of a shallow black basin to absorb solar radiation; water vaporises from the saline water, condenses on the underside of a sloped transparent cover, runs into troughs where it can be collected (Duffie & Beckman, 1991).

The solar distillation technique can be modified to suit the conventional sand drying beds when the application depth is shallow. The transparent cover can be constructed on top of the bed having widths of one to two metres as a corrugated cover; the sloped cover has less solar radiation reflectance than the flat cover. The troughs can be constructed underneath the end of each sloped transparent cover and can be supported from the bottom with light reliable supports. The troughs can be interconnected with a common header where water can be recycled again in the filtration process or supplied to customers. The covers can be supported by frames and should be removable to allow easy access in order to remove the dried residuals by low ground pressure equipment. The glass cover plate should have a high transmittance for solar radiation and should not deteriorate with time. Water-white glass, which has an iron content of about 0.01% and a transmittance of 92%, would be perfect for this purpose (Duffie & Beckman, 1991).

2. SOLAR DRYING TECHNOLOGIES OF RESIDUALS

In the past, limited attempts have been undertaken to dry sewage residuals using solar drying technologies. Experiments were conducted by El-Ariny and Miller (1984), using solar heated residuals drying beds and compared with a normal drying bed. A greenhouse type experimental bed with a sloping roof was constructed and the bed enclosure was covered with translucent acrylite sheets. These sheets were clear and colourless with light transmission capacity of 92 percent. The bed was equipped with five air outlet louvers opposite to the hot air inlet nozzles. Hot air was forced through an array of 16 flat-plate air-type solar collectors and into the drying bed. In this experiment, it was found that a reduction of 50% in the drying period was needed to obtain solids concentration of 30% and a reduction of 60% in the drying period to reach 60% solids content. For the sewage residuals, El-Ariny and Miller (1984) found that the odour disappeared after few days in the solar drying beds; this implies that heat destroys the microorganisms and/or volatilises the odour in these residuals.

Another experimental study was conducted by Hossam et al (1990) to use solar air heated drying beds and compare them with conventional sand drying beds. The climatic conditions in Alexandria (Egypt), where the experiment was conducted, were generally favourable for dewatering sewage residuals on sand drying beds except when there was heavy rainfall during the wet season, which prolonged the drying time. However, it was concluded that solar heated drying beds save about 35% of the conventional drying bed area. Solar air heated drying beds cut the drying time from 18 days to 8 days, and were especially effective during the wet season (50% average reduction in drying time).

Luboschik (1999) developed a sewage residuals solar drying process in Germany. This process was a greenhouse type solar drying bed equipped with an air exhaust duct. Air in the duct was exhausted by gravitational circulation and to accelerate transport of moist air, ventilators were actuated when required. In this drying process, drying time was dependent on the initial moisture content and the natural solar radiation. No details were given about the drying time and conditions of the study.

In the previous studies, experiments were performed on sewage residuals and there were no studies reported on solar drying of water treatment plant residuals. Most of the studies were carried out in hot climates, except for Luboschik (1999), which are not comparable with Wollongong climatic conditions.

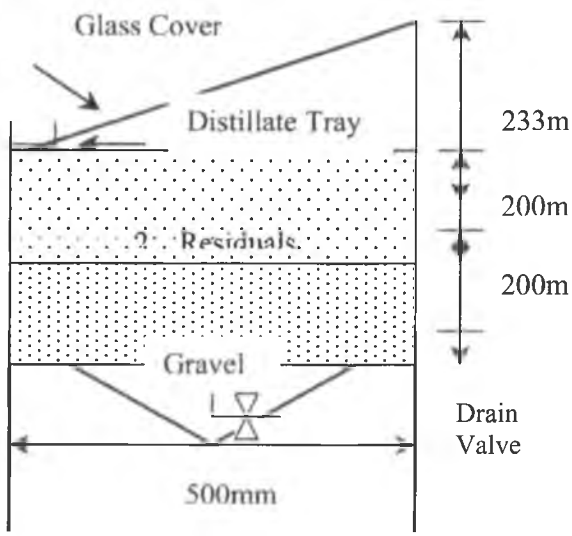


Figure 2. Cross-sectional area of the solar drying bed.

3. EXPERIMENTAL STUDY

3.1 Apparatus

A comparative study of a solar drying bed (Figure 2) and a normal (open) drying bed was conducted from July 1999 until May 2001. Both drying beds were identical; the only difference was the glass cover. The dimensions were 500 mm wide, 500 mm long, 400 mm high (triangular shape of the bed is not included) from all three sides and 633 mm high from the rear side; the tilt angle of the cover was 25^0 with respect to the horizontal. Under the glass cover, and from all sides, a distillate trough was fitted and condensed water was collected via a drainage tube at the front left hand side of the trough into a small plastic container. Another plastic container was used for the collection of the drained water from the lower end of the triangular bottom section. Large gravel was placed at the bottom triangular section for drainage and supporting the sand area, the sand was placed on the top 200 mm section of both beds, which were separated by a Geotextile mat. The upper 200 mm section is left for the residuals applications. Both beds were thermally insulated with polystyrene foam. The following parameters of the covered bed were regularly monitored: the cover temperature (inside), the residuals surface temperature, and the mass change of the drained and distillate water with respect to time. The open bed was monitored the same way but without surface temperature monitoring for the first five experiments (Series I) and it was monitored for the following experiments.

3.2 Weather Station

A weather station was used to monitor the meteorological parameters: ambient temperature, wind speed, solar radiation, relative humidity and rainfall. Relative humidity, wind speed and solar radiation were measured on an hourly basis. Ambient temperature, residuals surface temperature and rainfall was measured on a 6-minute basis. These parameters were stored in a data logger; the data can be downloaded via a laptop computer with special software compatible with MS Excel. The data logger is powered by a built-in chargeable battery, which is charged by a solar panel mounted on a 5 m mast on top of the weather station.

3.3 Experimental Procedure

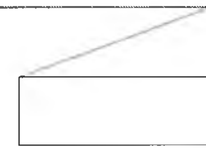
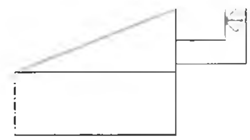
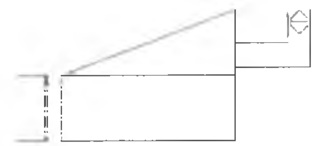
Daily samples were taken from both beds to check the solids content using a moisture analyser. In each bed, samples were taken from five different locations and were mixed together, then two measurements were performed for each sample and an average reading was taken. The moisture analyser dried the samples at 105 ^{0}C until no moisture was left and it automatically calculated the initial and final weights and gave the reading in percentage as solids content. The analyser was calibrated every month; the accuracy of the analyser scale was $\pm$ 0.001 g.

Three series of experiments were conducted in order to improve the drying time in the experimental solar bed by changing the bed design as given in Table 1. In series I experiments the solar bed was completely sealed and the evaporated water was condensed and collected under the glass cover via the condensate tray. In Series II, the bed was equipped with a ventilator at the back section and five holes at the front (each 25 mm in diameter). In Series III, hot air was forced through the holes into the cavity of the bed using a fan heater (900 Watts).

4. RESULTS AND DISCUSSION

4.1 The solar bed in Series I was meant to act as a greenhouse heat trap. As a result, high temperatures were achieved for residuals in the solar drying bed (see Figure 3). On the other hand, the drying time of the normal bed was faster than the passive solar bed as shown in experiment 8 (see Figure 4) because the moisture in the cavity has nowhere to escape.

Table 1 Summary of experiments and their modifications

Series	Experiment Number	Experiments Conditions	Sketch
I	4, 5, 6, 7 and 8	Bed completely sealed	
II	12, 13, 17, 18 and 19	Five holes (each 25 mm in diameter) in front section of the bed and a wind driven ventilator at the back section	
III	14	Conditions as above in II in addition to a fan heater fitted at the front where hot air flows into the cavity through the holes	

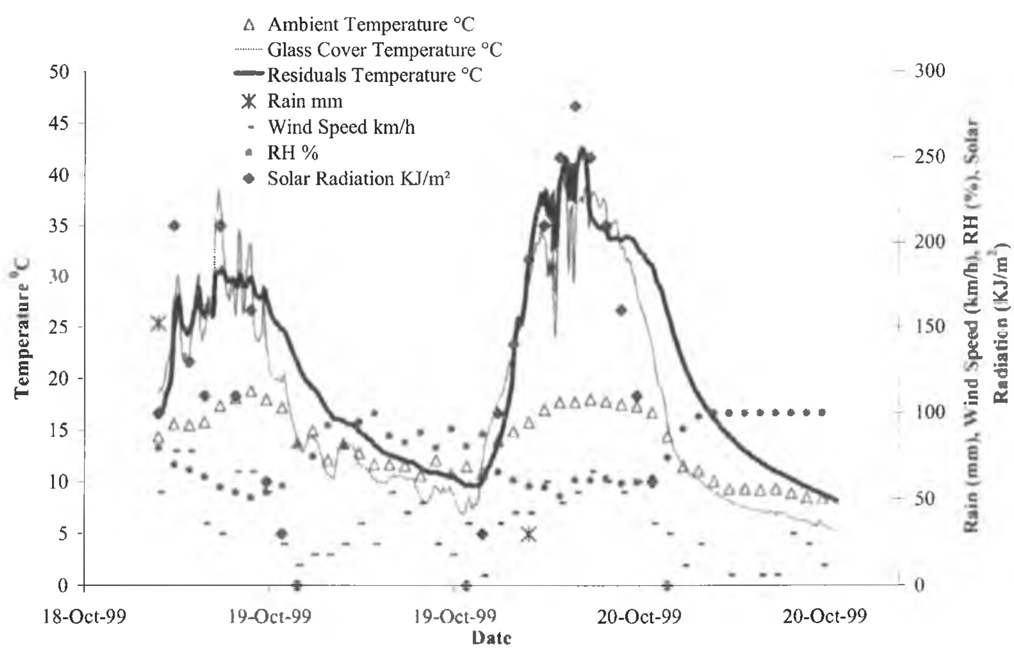


Figure 3. Variations of weather conditions as recorded by the weather station, (experiment 8)

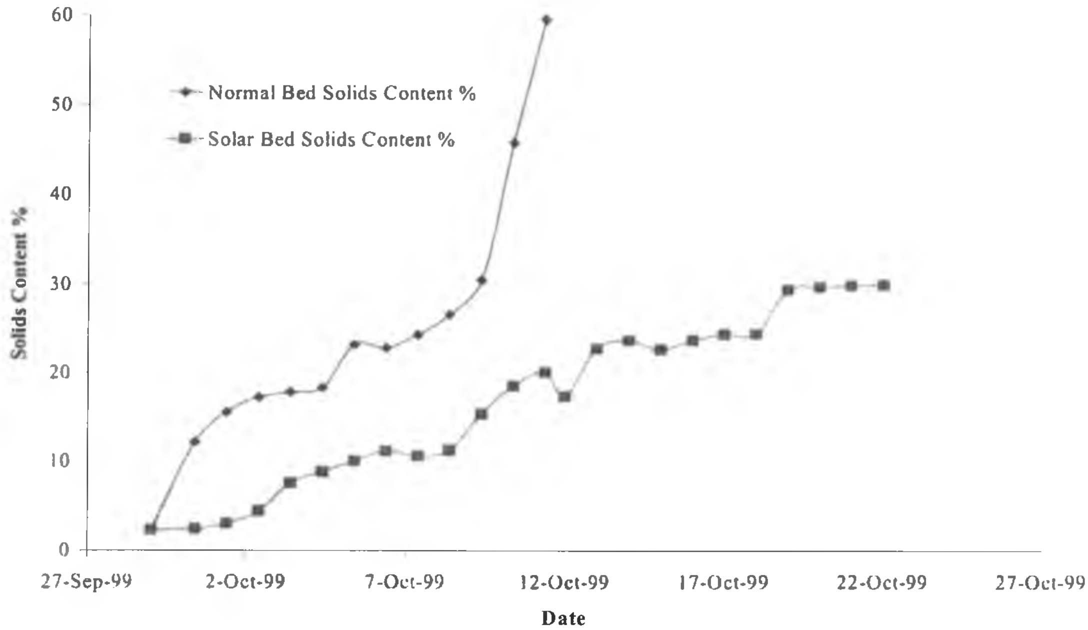


Figure 4. Drying time for open and passive solar beds (experiment 8)

Table 2 Volume of drained and distillate water and solids content for experiment 8

Date	Time	Volume of Distillate for Solar Bed (mL)	Volume of Underdrained Water for Solar Bed (mL)	Volume of Underdrained Water for Normal Bed (mL)	Solar Bed Solids Content (%)	Normal Bed Solids Content (%)
29/09/1999	14:00				2	2
30/09/1999	08:00	85	21500	30000	2	12
05/10/1999	07:50	260	10000	3500	10	23
06/10/1999	07:55	63	250	20	11	23
07/10/1999	07:45	111	1300	15	13	24
11/10/1999	08:00	1010	100		20	60
12/10/1999	07:55	264	60		21	
13/10/1999	07:40	145	50		23	
14/10/1999	07:45	76	50		24	
15/10/1999	07:55	51	40		24	
18/10/1999	07:55	419			24	
19/10/1999	07:55	248			24	
20/10/1999	07:50	145			29	
21/10/1999	07:50	314			30	
22/10/1999	07:55	310			30	
25/10/1999	07:55	325			30	
26/10/1999	08:00	38			31	

Table 3 – Performance of the solar and normal drying beds

Exp. No.	Series	Depth Applied (mm)	Normal Bed Solids Content (%)		Solar Bed Solids Content (%)		Drying Time (Days)		Average Solids Content (%/Day)	
			Applied	Removed	Applied	Removed	Normal	Solar	Normal	Solar
4	I	50	1.6	83	1.6	20	16	25	5	0.7
5	I	50	1.7	89	1.7	20	11	11	8	1.7
6	I	200	3.2	23	3.2	17	14	14	1.4	1
7	I	200	1.2	91	1.2	26	10	18	9	1.4
8	I	200	2.4	60	2.4	31	13	28	4.4	1
12	II	200	1.6	53	1.6	35	35	35	1.5	1
13	II	200	3.5	65	3.5	37	22	41	2.8	0.8
14	III	200	1.5	54	1.5	49	27	18	2	2.7
17	II	Multiple (5x50 mm)	1.4	58	1.4	51	33	40	1.7	1.2
18	II	Multiple (3x100 mm)	1.5	56	1.5	52	21	38	2.6	1.3
19	II	Multiple (5x50 mm)	1.7	58	1.7	52	35	36	1.6	1.4

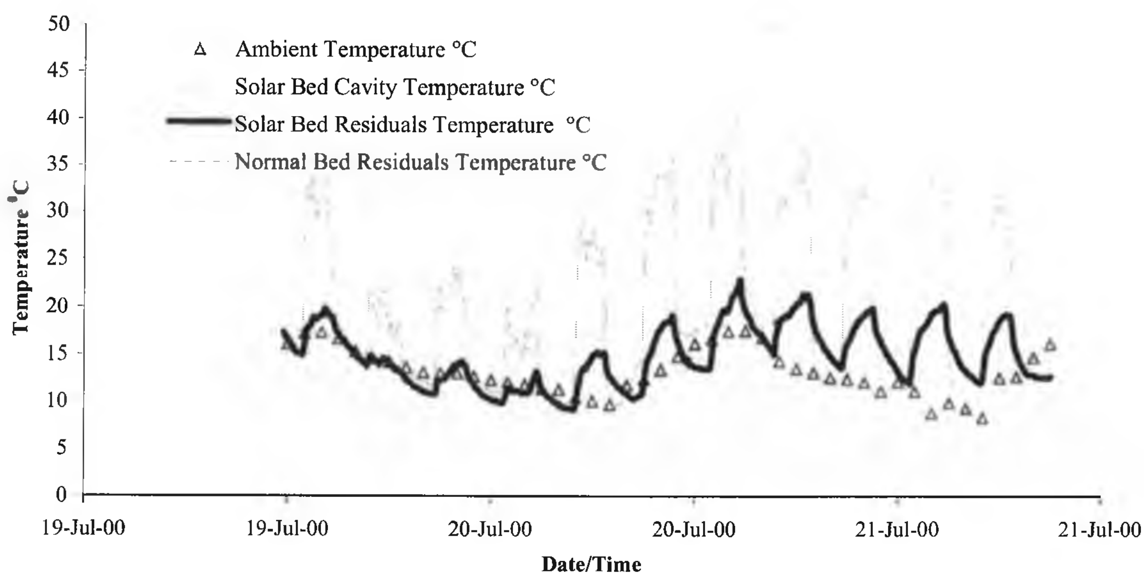


Figure 5. The effect of heated air on the temperatures of active solar bed cavity and residuals for experiment 14

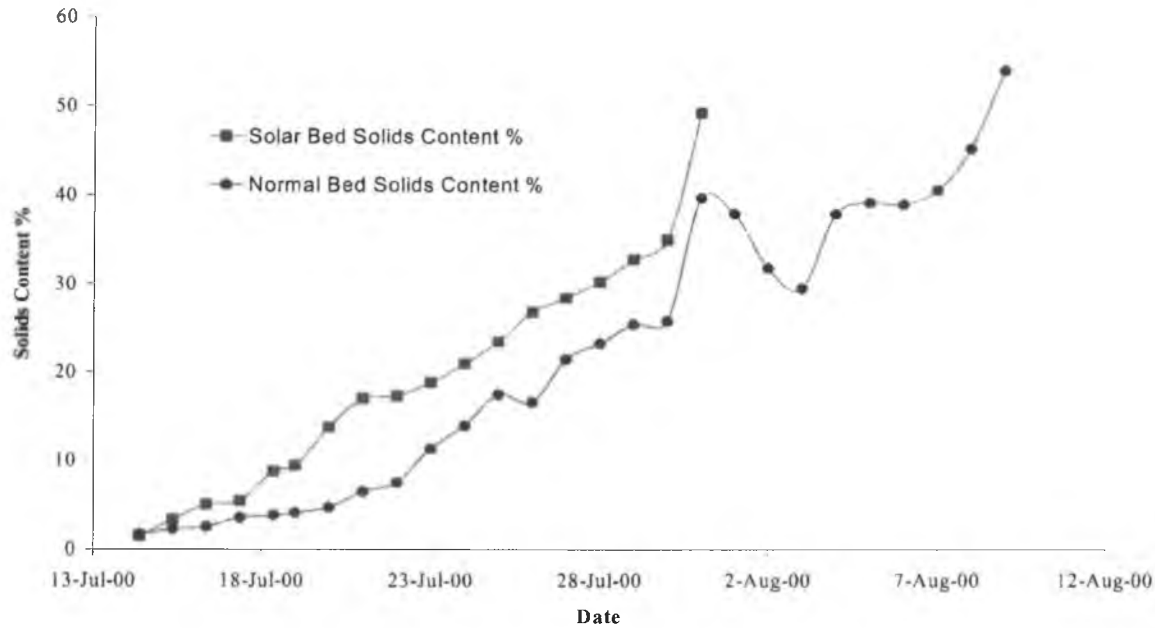


Figure 6. Drying time of open and active solar beds (experiment 14)

Water drainage was observed to be slower in the solar bed that prolonged the drying time (see Table 2). The average solids content per day of the normal bed in Series I experiments was much higher, which means that the drying rate was much faster as shown in Table 3. The drying rates varied from one experiment to another according to variations in weather conditions (see Figure 3), the application thickness and the initial solids content.

Series II experiments were performed by removing the saturated air inside the cavity of the bed by using a roof ventilator (no electrical energy was used) in order to draw air through the holes located at the front side of the bed. Table 3 shows that the drying rate improved in series II experiments, however it was still less than the normal bed. A possible reason may be that the roof ventilator was not effective in removing the humid air from the cavity of the passive solar bed when the wind speed was low or stagnant.

In experiment 14 (Series III), the solar bed was provided with a fan heater blowing air from the front holes of the bed and air exits from the back via the ventilator. A timer was used to run the fan heater for two hours and to stop for two hours. The variations in temperature inside the solar bed cavity can be seen in Figure 5 as a result of the fan heater operation. The residuals temperature of the solar bed was higher than the normal bed (see Figure 5). The forced hot air over the residuals surface supplied heat to evaporate and remove the moisture from the cavity of the bed. The moisture holding capability of air increases by elevated temperatures.

A reduction in drying time from 27 days to 18 days (33%) to reach 50% solids content has been achieved in this study using the fan heater in the solar bed (see Table 3 and Figure 6). Hossam et al (1990) achieved 50% reduction in drying time with the solar air heated drying beds compared to the conventional beds. This could be attributed to the differences in characteristics between sewage and water treatment plant residuals and the weather conditions. The modifications made in the solar bed show that it is important to improve both the heating and mechanical ventilation capabilities of the bed. Heating without ventilation does not improve the drying process since the saturated air is not capable of holding more moisture.

5. CONCLUSION

This study was an attempt to use the passive solar drying technology to be utilised in the drying of water treatment plant residuals. It was found that there was no significant advantage with the passive solar drying bed. Although very high temperatures of the residuals were achieved in the set-up of the passive solar bed, drying time could not be enhanced compared to the conventional sand drying bed. It appeared that removing the humid air from the cavity of the solar bed was a very important factor for enhancing the drying process. It has been found that active solar drying can reduce the drying time by 33%, which is similar to the findings of previous studies on sewage residuals. Further experimental and theoretical works are to be carried out to understand both passive and active solar drying of water treatment plant residuals.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the support received by the Sustainable Earth Research Centre (SERC) of the University of Wollongong to undertake this project.

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