Dehydration Characteristics Of Sludge In A Solar Cabinet Dryer

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***Abstract*—The dehydration characteristics of sludge in a solar cabinet dryer were studied. This was with a view to exploring the application of solar energy to dry sludge. A model solar cabinet dryer was designed and constructed from locally available materials White corn processing sludge (eri) was obtained locally. Municipal solid waste (MSW)/farm yard manure (FYM) was also obtained and used. After determining the initial moisture content, two-hourly moisture content monitoring was done for each of three conditions – fully opened inlet vent, half opened inlet vent, and totally closed inlet vent. Daily variations in moisture contents of the eri and compost sludge were also monitored. Temperature inside and outside the solar dryer was also measured two-hourly from 9 a.m. to 5 p.m. daily. The optimum condition of the dryer was obtained when the inlet vent was half opened and the optimum temperature was 49°C. It was shown that for both eri and compost sludge, the residual moisture content inside the dryer, at the end of the drying period, was always lower than in the open air. The quality of the material was also preserved.**

***Keywords*—dryer, environment, solar cabinet, solar energy, waste management**

I. INTRODUCTION

Sludge refers to the residual, semi-solid material left from industrial wastewater, or sewage treatment processes. It can also refer to the settled suspension obtained from conventional drinking water treatment and numerous other industrial processes. The term is also sometimes used as a generic term for solids separated from suspension in a liquid; this 'soupy' material usually contains significant quantities of 'interstitial' water between the solid particles [1]. The solid constituents removed from wastewater treatment plants include screenings, gut, scum and sludge. The sludge resulting from wastewater treatment operation and processes is usually in the form of a liquid or semisolid liquid that typically contains 0.25 to 12 percent by weight, depending on the operation and processes used [2]. Of the constituents removed by treatment, sludge is by far the largest in volume (if dewatering process is not carried out in the treatment plant), and its processing and disposal is perhaps the most complex problem facing the engineer in the field of wastewater treatment. The problems of dealing with sludge are complex because: (i) it is composed largely of the substances responsible for the offensive character of untreated wastewater; (ii) the portion of sludge produced from biological treatment requiring disposal is composed of the organic matter contained in the wastewater but in another form, which can also decompose and become offensive; and (iii) only a small part of the sludge is solid matter. In the processing, disposal and reuse of sludge, moisture removal is one of the steps involved. Thickening (concentration), condition, dewatering, and drying are used primarily to remove moisture from sludge. According to Tchobanoglous *et al*. [2], sludge drying is a unit operation that involves reducing water content by vaporization of water to the air. The purpose of heat drying is to remove the moisture from the wet sludge so that it can be incinerated efficiently or processed into fertilizer. Drying is necessary in fertilizer manufacturing so as to prevent continued biological action.

The basic principle of operation in any solar drying process is based on the fact that water molecules change from liquid into vapour (Fig. 1). This requires energy, i.e. solar energy. The driving force is the difference between the partial vapour pressure inside the solids and the ambient air. In order to avoid equilibrium between the vapour pressure inside and outside the solids, the surrounding air is ventilated from the cell area. This is naturally helped by the fact that water vapour is lighter than the dry air. The warmer the air is the more water vapour can be transported. However, the partial vapour pressure in the air rises with the amount of moisture in the air. To assist the overall process in some colder climatic installations, where temperature or solar energy is not favourable year-round, additional heating systems can be installed for colder periods [3].

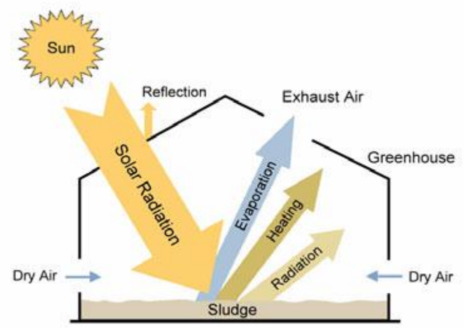

Fig. 1: Basic principle of solar dryer. Reference [3]

A past study [4] has concluded that the surrounding environmental conditions have the most influence on the evaporation rate, hence the performance of the solar dryer. These surrounding environment parameters are (1) outdoor solar radiation (2) outdoor air temperature, and (3) the ventilation flux. Precipitation also has a considerable effect on drying, especially if it occurs before cake cracking. Evaporation rate tends to reduce in overcast conditions because of low solar intensity. Wind has a beneficial effect as it increases the evaporation rate. The dry solids content of the feed solids is also of importance, but is less critical than the environmental conditions. Air-mixing (without ventilation) is an order of magnitude less effective than ventilation [4, 5].

Arinze and Kaul [6] agree that performance of solar dryer will generally be evaluated in terms of drying capacity, thermal efficiency and product uniformity. Sanni [7] found out that drying was faster inside the solar dryer, when he dried okro slices and yam chips. Makinde [8] also concluded that solar drying is a better method with regard to energy utilization and product quality.

Bolaji [9] reported that many researchers [10, 11] have in recent times designed and constructed dryers. Some of these dryers either use electricity or fossil fuel as source of energy. The ever-rising cost of electricity and fossil fuels have kept the operating cost of these dryers rising. Other researchers have worked on solar dryer and now different types of solar dryers are available [12, 13, 14, 15]. Most of these dryers are designed with circulating fan (powered by electricity) and moving parts, which required professional handlings. Since most of the farmers do not have formal education and are poor, it would be worthwhile for such solar dryers to be simple, affordable and maintenance-free.

Solar drying has become a more versatile process with the development of solids mixing equipment, emission control and additional heating systems in recent years [16]. Sludge drying is done by a number of means most of which are mechanical. The economics of other sources of energy has motivated scientists and engineers to take a second look at solar energy. Solar power equipment have the inherent advantage of being cheaper to construct, easier to maintain and less vulnerable to damages. Therefore, the objective of this study was to construct and evaluate the performance of a locally fabricated solar cabinet dryer for drying sludge.

II. MATERIALS AND METHODS

A. Design, Construction and Assemblage of Solar Dryer

The dryer cabinet (Fig. 2) was made of ¾ inch plywood, with a volume of approximately 0.2m^3. The top has a slant towards the front rear giving the cover an inclination of about 15^o. The inclination is to allow for air circulation as well as receive solar radiation. The transparent cover for collection of insolation is of glass with a total surface area of about 0.5m^2. The upper vent is 18.5cm x 10cm while the lower vent is 17cm x 14cm [8]. Drying tray (Fig. 3a) was placed between the lower and upper vents such that the rising hot air passes through the tray. The tray has spreading area of 0.31m^2 with wire mesh floor. The additional small trays were also made (Fig. 3b). Each of these trays has a spreading area of 0.09m^2 (30cm x 30cm) and serves as moulds for the materials to be dried. The interior of the dryer was painted black for maximum heat, that is, to enhance the trapping of the rays. The entire dryer system was supported and raised 20cm above the ground on a wooden frame. The height was considered adequate to allow for movement of air into and out of the cabinet.

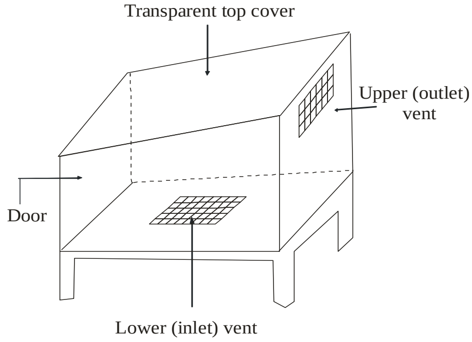

Fig. 2: Solar cabinet dryer

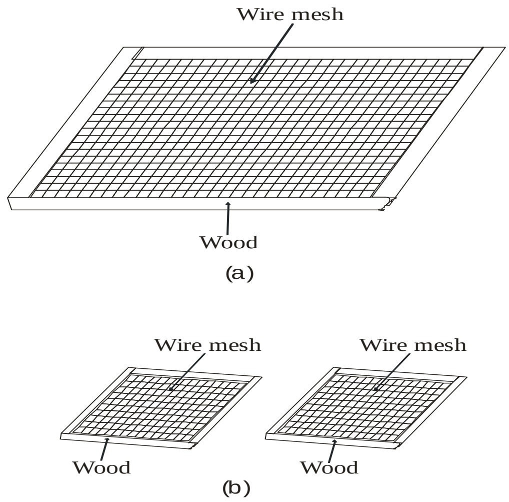

Fig. 3: Drying trays

B. Materials for Drying

Eri or Maize mash (waste obtained when ground soaked maize is sieved) was obtained from the production of *ogi* (maize mag). It was obtained locally and used for the experiment. The colour of the maize mash depends on the colour of the maize from which it was obtained. White maize mesh was used throughout. Municipal solid waste (MSW)/farmyard manure (FYM) was produced by aerobic composting method in an experimental work at the department of civil engineering, Obafemi Awolowo University (OAU), Ile-Ife, Nigeria. The mix ratio of the MSW:FYM used were those that gave the best compost. They were the 70:30 and the 60:40 mixes [17].

C. Experimental Procedure

The initial moisture contents of the materials were determined at the beginning of each test run. This was done by weighing about 35g of the material and putting it in the oven for about 24 hours. The final weight was then determined. The initial moisture content of the material was given as:

$$\frac{change\ in\ weight}{initial\ weight}\ x\ 100\%$$

The materials were then spread for drying. Each of the test runs of the experiment was carried out beside the control sample. The dryer samples were contained in the dryer chamber while the control samples were spread in the open air to dry. An optimal thickness of storage material of about 0.12m was found to be convenient for drying various agriculture products [18]. However, for this study, the samples were spread inside the moulds at an average thickness of depth of 1cm due to the nature and ease of handling of the materials. For the control, the mould was placed inside the open air i.e. on the ground. Samples were taken from the two experimental samples (i.e. dryer chamber and open air) at every two hours and the moisture content was determined using equation 1. The two-hourly residual moisture content was determined for three test runs, i.e. when the lower (inlet) vent was fully opened, when half closed, and when it was completely closed. The two-hourly residual moisture content was determined for only *eri*.

The above procedure was repeated, but for determination of daily residual moisture contents for both *eri* and compost at a condition of half closed inlet vent. As drying progressed, weights were obtained from the two representative samples i.e. dryer chambers and open air at the end of each day and the average moisture content of test material was determined using equation 1.

The temperature inside and outside the solar dryer was also measured every two hours from 900 hour (9 a.m.) to 1700 hour (5 p.m.) daily for each test run using mercury-in-glass laboratory thermometer. 9 a.m. to 5 p.m. each day was considered because the intensity of the solar radiation was greatest with that period of each day.

III. RESULTS AND DISCUSSION

Table I contains the results of two-hourly variations in moisture content for fully opened inlet vent. At the end of the drying day at 1700 hour the dryer sample was dried to about 44.44% and open sun sample was dried to 37.84%. Therefore, the efficiency of the dryer was 3.24% m.c./h and efficiency of the open sun was 4.62% m.c./h (m.c is moisture content; h is hour). It is thus shown that the percentage moisture content removed per hour is greater in the open sun than for the dryer when the inlet vent is fully opened. This could be due to inadequate or improper venting since the air within the solar dryer would soon become saturated at which point drying would cease or be exceedingly slow.

Table I: Two-hourly variation of moisture content of sampled test materials (for fully opened inlet vent)

Test Run	Moisture Content (%)					Efficiency (m.c/hr)
	Start (900hr)	1100hr	1300hr	1500hr	1700hr	
Dryer Sample	60.00	59.09	52.94	50.00	44.44	3.24
Open sun-dried sample		59.09	51.11	42.11	37.84	4.62

Table II shows the results of two-hourly variations in moisture content when the inlet vent was half opened. The dryer sample was dried to about 44.19% at the end of the drying day at 1700 hour. An increase in moisture content from 46.94% at 1500 hour to 51.25% at 1700 hour is observed for the open sun dried sample. This could be due to a reduction in air velocity outside the dryer. Efficiency of the dryer, for this condition, is 3.75% m.c/h, while that of open sun is 2.35% m.c/h. Thus the percentage moisture content removed per hour is greater for the dryer (with half opened inlet) than for the open sun.

The results of two-hourly variations in moisture content when the inlet vent was totally closed are shown in Table III. The dryer sample was dried to about 51.72%. Efficiency of the dryer was 2.64% m.c/h, and efficiency of open sun was 2.24% m.c/h. The percentage moisture content removed per hour in the dryer (with totally closed inlet vent) is slightly greater than for open sun. Tables IV and V show the results of daily variations in moisture content of both *eri* and compost sludge. For *eri* it took both the dryer and open sun dried samples three days of drying to reach a moisture content below 10%, with the dryer sample reaching the lower moisture content of 5.71%. For the compost sludge both dryer and open sun dried samples attained a moisture content less than 10% after only a day i.e. 24 hours of drying. For the 70:30 mix, the dryer sample reached a moisture content of 2.95% while the open sun dried sample reached a moisture content of 8.47%. And for the 60:40 mix, the dryer sample reached a moisture content of 3.08% while the open sun dried sample reached a moisture content of 5.98%.

Table II: Two-hourly variation in moisture content of sampled test materials (for half opened inlet vent)

Test Run	Moisture Content (%)					Efficiency (m.c/hr)
	Start (900hr)	1100hr	1300hr	1500hr	1700hr	
Dryer Sample	63.11	60.27	54.84	50.88	44.19	3.75
Open sun-dried sample		60.00	56.25	46.94	51.25	2.35

Table III: Two-hourly variation in moisture content of sampled test materials (for totally closed inlet vent)

Test Run	Moisture content (%)					Efficiency (m.c/hr)
	Start (900hr)	1100hr	1300hr	1500hr	1700hr	
Dryer sample	65.59	59.70	57.57	54.84	51.72	2.64
Open sun-dried sample		55.73	54.24	55.88	53.85	2.24

Table IV: Daily variations in moisture content of sampled test material (*eri*)

Test Run	Moisture content (%)			
	Start	Day 1	Day 2	Day 3
Dryer sample	62.86	50.00	28.57	5.71
Open sun-dried sample		52.86	34.29	7.14

Table VI presents the results of average two-hourly temperature readings obtained during the experiment. The average peak temperature readings in the dryer for the test runs were recorded around 1 p.m. i.e. 1300 hour. The peak ambient temperature readings were close to 33^{o}C. The temperature readings recorded for the dryer samples at the end of each drying day at 1700 hour showed increase of about 8^{o}C above ambient temperature readings. This provided some residual heat in the drying chamber and the removal of moisture from the samples continued during the early evening. The only exception is for the fully opened inlet, where the temperature reading at the end of the day is lower than the ambient temperature.

Figures 4 to 6 graphically illustrate the relationship between the temperature (inside the dryer) and loss in moisture content over the drying period for the various inlet vent conditions of the dryer. For the three conditions, graph of temperature has its steepest slope (positive) between 1100 hour and 1300 hour. This implies that the highest increase in temperature of the dryer is obtained between 1100 hour and 1300 hour when the inlet vent was fully opened, graph of moisture content (Fig. 4) has its steepest slope between 1100 hour and 1300 hour with the highest moisture loss of 6.15%. This means that for this condition, the highest drying rate was obtained when the temperature increased. The final residual moisture content was however about 74% of the initial moisture content.

Table V: Daily variations in moisture content of sampled test material (compost sludge)

Compost mix	Test run	Moisture content (%)	
		Start	Day 1
70:30	Dryer sample	27.15	2.95
	Open sun-dried sample		8.47
60:40	Dryer sample	28.41	3.08
	Open sun-dried sample		5.98

Table VI: Average temperature readings within and outside the dryer

		Temperature (^{o}C)				
		900hr	1100hr	1300hr	1500hr	1700hr
Fully opened inlet vent	Dryer	29.00	33.00	49.50	39.00	30.50
	Ambient	28.00	32.00	33.00	32.50	32.50
Half opened inlet vent	Dryer	30.50	31.50	49.00	46.50	37.00
	Ambient	29.00	32.50	32.50	32.50	30.00
Totally closed inlet vent	Dryer	29.50	37.50	51.00	49.50	38.50
	Ambient	28.00	29.50	32.50	31.00	30.50

When the inlet vent was half opened, graph of moisture content (Fig. 5) has its steepest slope between 1500 hour and 1700 hour with the highest moisture less of 6.69%. Although this does not correspond with the period of highest temperature increase, the final residual moisture content was about 70% of its initial value. This could be due to proper venting and air circulation inside the dryer. For the totally closed inlet vent, graph of moisture content (Fig. 6) has its steepest slope between 900 hour and

1300 hour with the highest moisture less of 5.89%. The final residual moisture content was about 79% of its initial value. This could be due to inadequate venting.

IV. CONCLUSION

Solar energy could be efficiently applied in drying sludge. For this particular dryer, the optimum condition was obtained when the inlet vent was half opened. The solar dried material was also found to be of better quality than the open air dried material. The dryer samples were protected against both dirt and dust as against the samples that were dried in the open air. The applicability of the solar dryer in drying sludge locally appears very promising as the dryer is simple in design, relatively cheap and requires no special technical skill to operate by the users. This work could also be repeated for coloured *eri*, to ascertain the possible effect of colour on the dehydration characteristics.

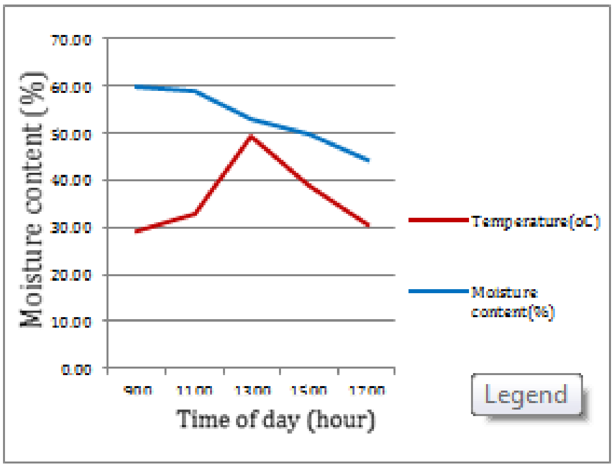

Fig. 4: Effect of temperature and air circulation on drying rate (fully opened inlet)

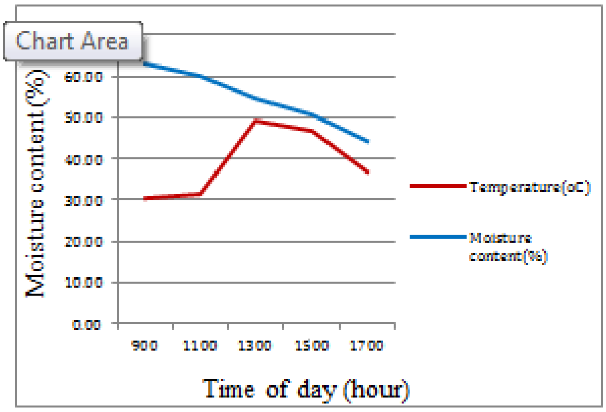

Fig. 5: Effect of temperature and air circulation on drying rate (half opened inlet)

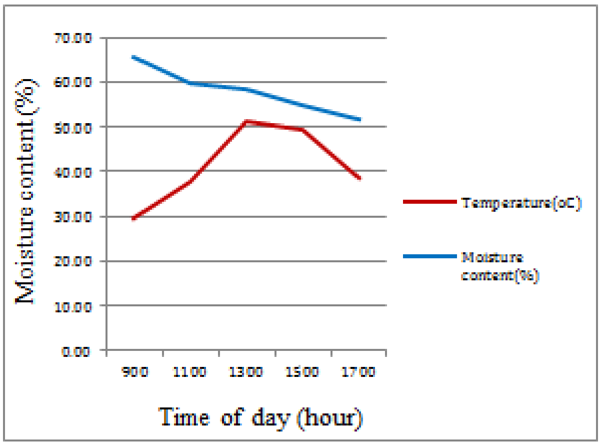

Fig. 6: Effect of temperature and air circulation on drying rate (totally closed inlet)

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