Hue University Journal of Science: Natural Science
Vol. 132, No. 1D, 79–86, 2023

pISSN 1859-1388
eISSN 2615-9678

Studies on semi-cylindrical solar tunnel dryer for drying wastewater sludge

Nguyen Xuan Loc [1]*, Do Thi My Phuong

[1] Department of Environmental Science, College of the Environment and Natural Resources, Can Tho University, Can Tho, Vietnam
[2] Department of Environmental Engineering, College of the Environment and Natural Resources, Can Tho University, Can Tho, Vietnam

* Correspondence to Nguyen Xuan Loc <nxloc@ctu.edu.vn>

(*Received: 04 November 2022; Revised: 09 January 2023; Accepted: 10 January 2023*)

Abstract. Drying plays an important process for wastewater sludge management, as it can minimise the volume of wastewater sludge before disposal, and consequently the cost of storage, handling and transport. In this study, the wastewater sludge was dried by using a solar tunnel greenhouse drying system. The performance of the dryer for drying wastewater sludge has been analyzed through no load and full load test. The three full load drying tests recorded that the temperature inside the tunnel dryer fluctuated around 55±5°C; while the no load drying test, the temperature of the drying tunnel maintained within 60±5°C; as compared to the ambient temperature of 30±5°C. The average moisture content of solar dried sludge decreased from 88.69 - 90.84% to 7.78 – 13.30% in the mixing conditions and 14.78 – 19.52% in the non-mixing conditions, in 5 days. The study suggests that the semi-cylindrical solar tunnel dryer of wastewater sludge has given satisfactory results within five days.

Keywords: wastewater sludge, solar, tunnel, drying system

1 Introduction

Water is an indispensable element for human life. In recent decades, the rise in global population and human activities lead to an increase in water consumption worldwide. It is predicted that the demand for water will increase by 2050 but the availability of water will be reduced; hence, demand for wastewater treatment plants will be increased [1]. Wastewater treatment plants produce treated wastewater that can be reused in agriculture and also as industrial processing water. Wastewater treatment by biological means in general, and by the activated sludge process in particular, has been widely adopted as the most effective technological method for treating wastewater. However, the application of this method in wastewater treatment plants results in significant production of biosolids (wastewater sludge). Wastewater sludge can be defined as the solid or semi-solid leftover after the treatment of wastewater [2]. It is considered as an undesirable by-product in wastewater treatment facilities. Wastewater sludge is a complicated and heterogeneous substrate containing organic and inorganic materials as well as microorganisms [3]. Wastewater sludge therefore requires special treatment and handling due to its significant volume, organic content, and pathogen load.

In other words, wastewater treatment plants can generate by-product wastewater sludge that could affect the environment in case of an inadequate management. Wastewater sludge treatment represents almost 50% of the whole cost dedicated wastewater treatment plants construction and operation [4].

Therefore, the biggest problem in wastewater treatment is wastewater sludge management. In general, there are few possibilities to manage it such as landfill, incineration or use it as a fertiliser in agriculture with limited amount. In fact, wastewater sludge landfilling is still a common practice in Vietnam and is presenting many environmental issues. Despite being the most environmentally friendly alternative for the final disposal of wastewater sludge, composting of wastewater sludge used in agricultural soils is still a controversial issue since it possibly contains pathogens, organic, and inorganic micropollutants that could affect the soil–plant system and then the food chain [3].

Within all the previous alternatives of wastewater sludge final disposal, drying is commonly used. Drying can reduce the water content below 10% dry solids leading to a decrease of waste mass and volume and in consequence the reduction of the cost storage, handling and transport [5]. The different ways of drying are natural drying, mechanical drying, thermal drying, and other hybrid drying installations. Solar drying, a process that operates under greenhouse plants, is widely used to accelerate the water evaporation rate exploiting the artificial greenhouse effect and avoiding the equilibrium of vapor pressure between wastewater sludge and air by controlled indoor air ventilation [6]. This process is more involved in wastewater sludge management fields when compared to other more expensive alternatives such as thermal drying that exhibits strong energy needs mostly provided by fossil fuels [7].

Energy sources are diverse in Vietnam, ranging from coal, oil, natural gas, hydropower, and renewable energy. Meanwhile, non-renewable energy sources such as coal, oil, and natural gas are increasingly scarce, hydroelectric energy resources are limited, causing humanity to face an energy crisis. With electricity demand projected to increase by eight percent annually until 2025, the government is moving forward to develop renewable energy sources to ensure energy security and addressing the growing power demand (Vietnam Briefing, 2020). The energy source (solar energy) - is a sustainable energy source, has a low environmental impact, and promotes energy independence that is receiving special attention today. In addition, stretching from latitude 23023' North to 8027' North, Vietnam is located in an area with relatively high solar radiation intensity [8]. Vietnam, therefore, is considered a nation with high solar potential, especially in the central and southern area of the country.

It is emphasized that solar air dryers have great potential for replacement of conventional scale drying of industrial and agricultural products [9]. Besides, affecting saving of fossil fuel, fuel wood, or electricity, solar drying may also be cost effective [10]. It was also confirmed that using solar drying plays an interesting role the moisture reduction of wastewater sludge [11]. Thus, it is necessary to research and improve the efficiency of drying wastewater sludge using solar devices and apply them in real wastewater treatment plants at low cost. The main objective of the current study is to report results from the experimental study on application of designed solar tunnel dryer for wastewater sludge drying.

2 Materials and methods

2.1 Wastewater sludge materials

Wastewater sludge from wastewater treatment plants in Tra Noc Industrial Zone of Can Tho city was used for the experimental study.

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2.2 Design of the solar tunnel dryer

In the study, a semi-cylindrical solar tunnel dryer was designed at experimental scale (length 2m, width 1m, and height 0.5m) for drying wastewater sludge at 40 percent moisture content to 10 percent moisture content. Low-cost materials possessing high rigidity, long life and superior thermal characteristics have been used for experiments. The metallic frame structure of the tunnel dryer has been covered with UV stabilized semi-transparent polyethylene sheet of 3 mm thickness. A gradient of approximately 5° has been provided along the length of the tunnel to induce natural convection airflow. Steel sheet floor plates have been painted black for better absorption of solar radiation.

Three cm thick insulating panel has been provided to reduce heat loss through the floor. It is based on the theoretical calculation for critical insulation thickness for this dryer. The structural components of solar tunnel drier include flat iron (20×3mm), floor, UV stabilized polyethylene film (3mm thick) and drying trays. The dimensions and other design parameters of the solar tunnel dryer are presented in Table 1. The schematic and practical illustration of the solar tunnel drier is given in Fig.1.

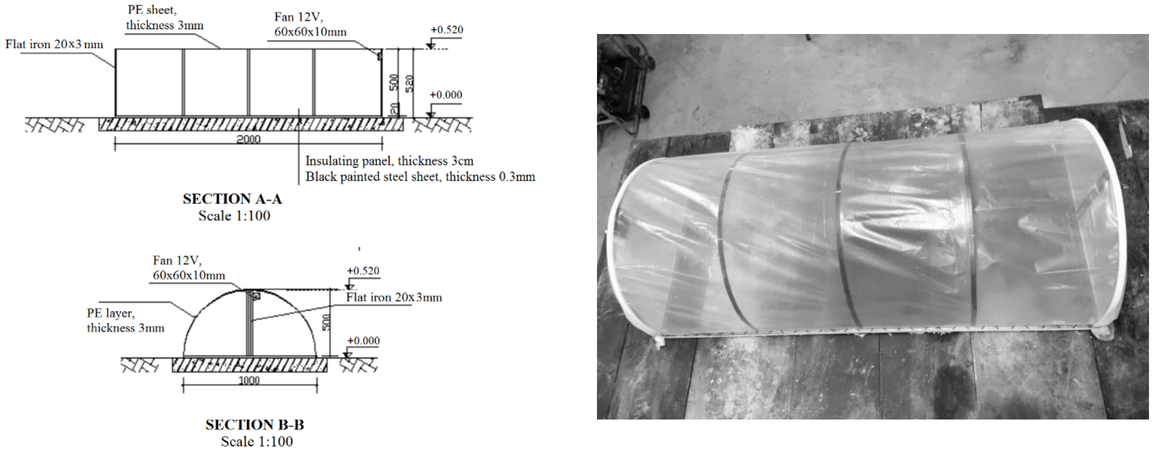

Fig. 1. A schematic diagram of solar tunnel dryer

2.3 Experimental set up

The performance of the tunnel dryer was evaluated by conducting tests at no-load and by loading with wastewater sludge, by measuring the following parameters: (a) radiation incident on the dryer, (b) air temperatures at various locations in the dryer and (c) Moisture content variation.

Each measurement was repeated 3 times and the average value of each measurement was taken.

Drying tests started at 9:00 hours and stopped at 15:00 hours in the month of April 2022. Under full load condition wastewater sludge was spread in 4 cm thick layer in trays. Total 8 trays of size 56 cm × 36 cm in the dryer. Each tray carries approximate 5 kg material.

A total of 4 testing periods, including 3 drying tests (Period 1, 2 and 3, loading with wastewater sludge) and 1 drying test (Period 4, no load testing), specifically as follows: Period 1 from April 5, 2022 to April 9, 2022; Period 2 from April 10, 2022 to April 14, 2022; Period 3 from April 15, 2022 to April 19, 2022; Period 4 from April 20, 2022 to April 24, 2022.

Table 1. Parameters analysed in this experiment

Parameter	Method	Technique
Temperature	One sensor was kept inside the solar tunnel dryer at the bottom point and one sensor was kept outside the solar tunnel dryer. All temperature data were recorded at an interval of an hour.	TAYLOR 1441E digital thermometer
Light intensity	A light meter was used to measure luminance flux per unit area, or the amount of visible light present at the dryer place.	Lutron light meter, model LX - 197
Moisture	The moisture content of the sludge was determined by the drying method. Samples of the sludge were taken and weighed. Then they were placed in moisture boxes that were placed in the oven at a temperature of 105 °C for 24 h. The samples were again weighed and the moisture content was determined on wet basis as the formula: M = 100 x (Wet Weight – Dry Weight)/Wet Weight	MELAG 405 oven

3 Results and Discussion

The performance of a dryer depends on the duration of drying and the quality of the end product, besides factors such as collector performance and drying temperature.

3.1 Variation of temperature and light intensity

Elaborate testing of the solar tunnel dryer was carried out under no load and full load conditions during April 2022 for drying wastewater sludge at the laboratory level. The performance of solar tunnel dryer is discussed under the following subheadings: (i) full load testing of solar tunnel dryer and (ii) no load testing of solar tunnel dryer.

Full load testing of solar tunnel dryer

Full load testing of solar tunnel dryer was done for evaluating the performance in actual loaded condition. Wastewater sludge with approximately 90% initial moisture content was taken for study and loaded in the trays of solar tunnel dryer. Wastewater sludge was spread a thin layer of approximately 6 cm thickness in trays of 56 × 36 cm size. Eight trays were loaded onto the tunnel dryer in the three periods 1, 2 and 3.

The testing on full load was done for consecutive 15 days the month of April 2022, respectively. As shown in Figs. 2-4 that maximum temperature inside the solar tunnel dryer fluctuated between 12:00 – 13:00 hours. More the, highest temperature was 59.8 °C at 13:00 hrs (period 1), 60.4 °C at 12:00 hrs (period 2), and 60 °C at 12:00 hrs (period 3), against the maximum ambient temperature of 33.04 °C 13:00 hrs (period 1), 33.12 °C at 12:00 hrs (period 2), and 32.22 °C at 12:00 hrs (period 3). Whereas, the minimum temperature inside the solar tunnel dryer was 51, 48.6 and 43.6 °C at 9:00 hrs in periods 1, 2 and 3, respectively, in the month of April against the minimum ambient temperature of 30.24, 30.38 and 29.22 °C in periods 1, 2 and 3, respectively.

Hue University Journal of Science: Natural Science
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eISSN 2615-9678

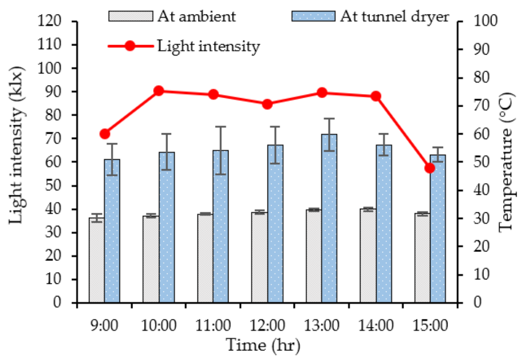

Fig. 2. Light intensity and temperature variations with time at full load in the period 1 (05/04 – 09/04)

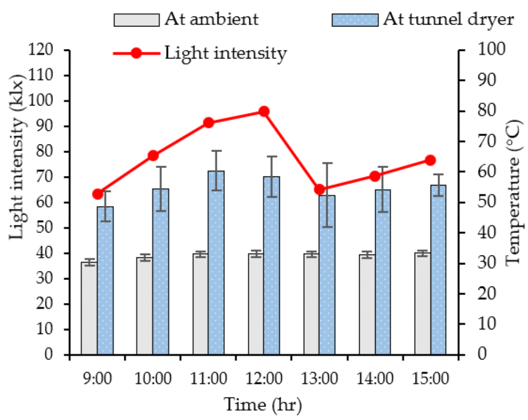

Fig. 3. Light intensity and temperature variations with time at full load in the period 2 (10/04 – 14/04)

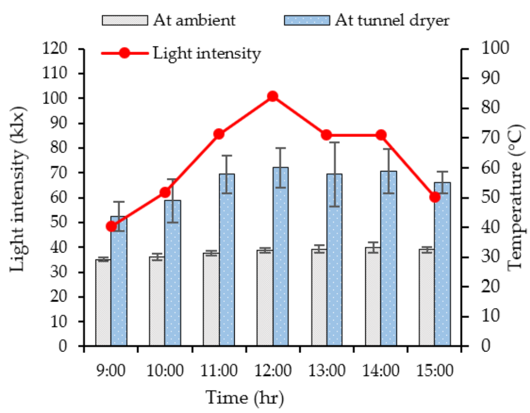

Fig. 4. Light intensity and temperature variations with time at full load in the period 3 (15/04 – 19/04)

It was also observed that the maximum ambient light intensity in this month was 89.66 klx at 13:00 hrs (period 1), 95.78 klx and 100.76 klx at 12:00 hrs (period 2 and 3). Correspondingly, the temperature inside the tunnel dryer and at ambient was maximized the time where the ambient light intensity was highest. There is a positive correlation (with R^2 = 0.956) between temperature and light intensity under experimental conditions (Fig. 5).

No load testing of solar tunnel dryer

During no load testing, the solar tunnel dryer was empty, i.e., no wastewater sludge was placed in the solar tunnel dryer for drying. The testing on load was done for consecutive 5 days, in period 4, from 20th to 24th of April. As shown in Fig. 6 it was observed that the maximum temperature attended inside the tunnel was 69.40 °C at 12:00 hrs while the minimum inside temperature was 48.40 °C at 9:00 hrs in the month of April.

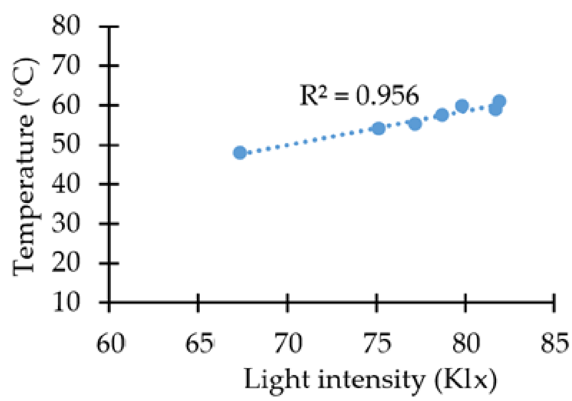

Fig. 5. Correlation between temperature and light intensity

DOI: 10.26459/hueunijns.v132i1D.6989

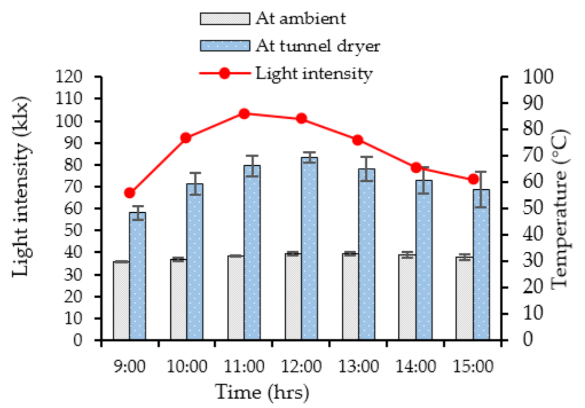

Fig. 6. Light intensity and temperature variations with time at no load in the period 4 (20/04 – 24/04)

Corresponding, the maximum ambient temperature was 33 °C at 12:00 hrs while minimum ambient temperature was 29.86 °C at 9:00 hrs. It was also observed that the maximum and minimum solar insulation in this month was 103.64 klx at 11:00 hrs and 67.08 klx at 9:00 hrs, respectively.

3.2 Variation of moisture content

The variation of moisture content in periods 1, 2 and 3 is shown in Fig. 7-9, respectively. The two drying conditions were conducted, including (i) the sludge was mixed manually once per day; (ii) the sludge was not mixed. It can be seen that the tunnel drying system removes higher water content in the sludge than the open sun drying during 5 days of testing. In which, the first period from 5th to 9th of April (Fig. 7), that moisture content was reduced from 90.84 percent to 14.57% and 19.52%, respectively, in the mixing and non-mixing conditions, respectively; Meanwhile, open sun drying with mixing and non-mixing conditions achieved the moisture content of 54.21% and 66.04%, respectively.

In the second period from 10th to 14th of April (Fig. 8), the initial wastewater sludge had a moisture content of 89.05%, after the drying process, the remaining moisture content was 13.30% and 15.53%, respectively, in the drying tunnel with mixing and without mixing; Compared with open sun drying, the moisture content was 42.25% and 54.97% under mixing and non-mixing conditions, respectively.

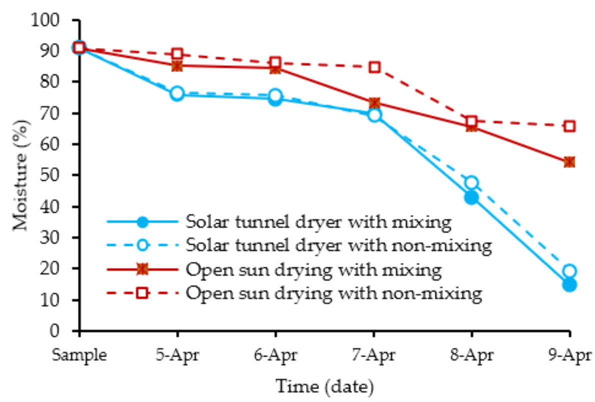

Fig. 7. Moisture reduction in period 1 (05/04 – 09/04)

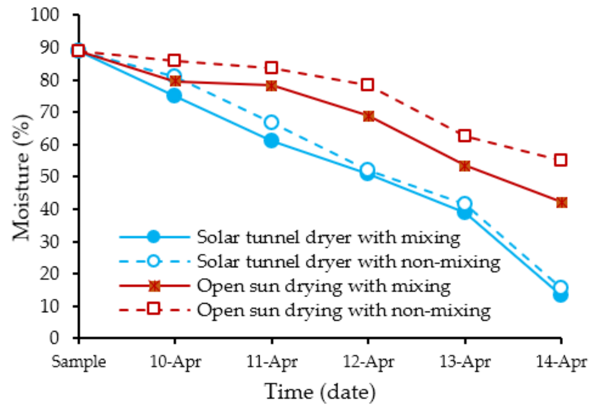

Fig. 8. Moisture reduction in period 2 (10/04 – 14/04)

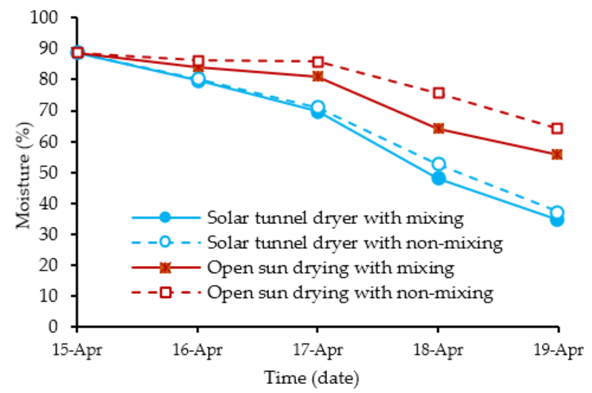

Fig. 9. Moisture reduction in period 3 (15/04 – 19/04)

pISSN 1859-1388
eISSN 2615-9678

In the third period from 15th to 19th of April (Fig. 9), the initial moisture content of the sludge was 88.69%, after the drying process, the remaining moisture was 7.78% and 14.78%, respectively, in the drying tunnel with mixing and non-mixing; Compared with open sun drying with mixing and non-mixing conditions, the moisture content was 40.68% and 50.67%, respectively.

The results obtained in this study was consistent with Mathioudakis et al. [11]. The authors proposed drying wastewater sludge using a pilot-scale solar drying plant of approximate 2.5 m^3. Approximately, 8 kg of dewatered sludge were placed into crates forming a depth between 20 and 25 cm. The sludge was mixed manually once per day. The results show that the moisture content of wastewater sludge has decreased from 85% to 6% wet basis within 7–12 days in summer and to 10% as final moisture content within 9–33 days in autumn [11].

Through the three trial drying periods, it was concluded that the reduction in moisture content of wastewater sludge dried in solar tunnel dryer was found to be superior than sludge dried in the open sun environment.

4 Conclusion

When using solar tunnel dryer to dry wastewater sludge, both the temperature and intensity of light could affect the drying process. In addition, temperature inside the tunnel dryer showed a positive correlation with light intensity. The greater the temperature is, the faster the drying inside tunnel dryer is heated, and the faster the drying efficiency is. Both light intensity and temperature changed rapidly during the day. Temperature inside the solar tunnel dryer was higher than outside by 20 – 28 °C during sunshine hours. The moisture content of wastewater sludge loaded in the dryer during 5 days of testing was reduced from an initial value of 88.69 - 90.84% to around 7.78 – 13.30% in mixing condition, and around 14.78 – 19.52% in non-mixing condition, which is approximately three times lower than the moisture content of the sludge under open sun drying. In conclusion, the performance of studied solar tunnel dryer was quite satisfactory in terms of reducing the mass and the volume of the wastewater sludge within 5 days.

Acknowledgement

The authors gratefully acknowledge Huynh Thanh Thao and Nguyen Thi Kim Xuyen, for their assistance with the experiment.

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