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ORIGINAL RESEARCH PAPER

Improvements to increase the efficiency of solar dryers for different waste sludge management

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ABSTRACT

BACKGROUND AND OBJECTIVES: In this study, an integrated phase change material drying system was designed to evaluate the efficiency of the system with the use of renewable solar energy for different types of sludge with different moisture content.
METHODS: This study was performed on the wastewater treatment plant sludge, paint, and marble sludge. By distributing the screws on the sludge tray, covering the system floor with a black trash bag, and mounting the reflector around the absorber tubes has increased the efficiency of the system.
FINDINGS: All the types of equipment used in the construction of the system are used as heat storage material and increase the internal air temperature, and the sludge temperature of the system. Temperature is transferred sequentially through air and objects. This research was conducted in winter by 1156 Wh/m^2 mean internal cumulative solar radiation. Due to the reduction of solar radiation, as the system was upgraded, more water was released from the sludge surfaces. By Scanning Electron Microscopy imaging, the porous surface was observed after sludge drying.
CONCLUSION: In this study, the waste sludge moisture decreased from 80% to 52.2% during three improvement stages. The paint sludge moisture content reduced from 56% to 25%, and marble sludge moisture in the final stage reached from 26% to 5.2%. The proposed solar dryer system is an economical way to reduce the sludge volume in the transportation process.

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INTRODUCTION

Renewable energy is one of the essential resources in energy supply and human development. Subsequently, the waste disposal process, especially sludge, has also become problematic. Solar radiation is a free energy source for various applications such as drying (Ali *et al.,* 2016). Traditional solar dryers, usually operated in the open air, which have been widely used in developing countries because of their simplicity and economic (Bolaji and Olalusi, 2008). Drying processes have previously required high energy costs (Di Fraia *et al.,* 2016), but recently it is known as an economical, convenient and slow process (Di Fraia *et al.,* 2018). Waste sludge, which is produced as a by-product of high-volume treatment plants. Liquid sludge from some industries is used as fertilizer on agricultural lands, but some types of sludge, such as pharmaceutical sludge, due to the specific content cannot be used as fertilizer, so it is dehydrated first. In some cases, it is possible to reuse the evaporated water (Mehrdadi *et al.,* 2007). Transporting sludge residues can cause problems due to high humidity and it has been suggested that solar dryers are an effective method to solve this problem (Świerczek *et al.,* 2018; Ying *et al*., 2012). Solar dryers are used for a variety of purposes including drying food and heating location (Bano *et al.,* 2015). The water in the sludge is classified as the type of free surface water and inner bound water (Wang *et al*., 2012). A large amount of sludge is produced daily by wastewater treatment plants (WWTPs.), which must be removed in a short time (Kacprzak *et al*., 2017), and if not disposed, it will cause environmental pollution (Wang *et al*., 2019; Wang *et al*., 2019; Wang *et al*., 2019; Archer *et al.,* 2017; *Manara and Zabaniotou, 2012*; Guo *et al.,* 2009). Solar dryers are investigated in both direct, indirect, and mixed-mode according to their performance and design (Simate, 2001). Integrated solar dryers are a good solution for continuous solar drying systems (Lakshmi *et al.,* 2018). Centrifuge, belt press, and drying bed are common techniques for sludge dewatering (Spinosa *et al.,* 2011). The efficiency of solar dryers depends on the type of absorber, area, wind speed, etc. The air is heated by absorbing solar radiation, and the drying chamber containing the sludge is exposed to hot air and direct radiation (Vlachos *et al.,* 2002). The efficiency of these systems can also be increased by extending the surface area of the absorber or by installing the fins (El-khawajah *et al.,* 2011). The solar collectors are beneficial for solar power source storage (Kamble *et al*., 2013), and can be a useful tool to save energy (Lakshmi *et al*., 2018), and minimize drying area. A systematic method for classifying solar dryers has also been developed, in two, general groups of active and passive solar dryers for two stages (constant phase) and (fall phase) (Udomkun *et al*., 2020). As the drying process progresses, the sludge becomes sticky and eventually turns into granules (Bennamoun *et al*., 2013). The drying rate depends on the mass and heat transfer from the interior sludge surface (Darvishi *et al.,* 2018). The reflector is sometimes used to improve the drying process and has been recognized as a suitable material, especially in the construction of a large-scale solar dryer (Kalbande *et al*., 2017). Heat transfer in solar dryers occurs through natural convection and conduction methods. The conventional drying process consumed more time and is in comparison with this designed solar drying system. Thermal energy is considered as latent heat (phase change), sensible heat, thermochemical, or combined heat (Khouya and Draoui, 2019). Phase change materials (PCM) such as paraffin results in the storage of reasonable heat to keep the temperature of the heated air at night or in hours when solar energy is not available (Bhardwaj *et al*., 2017; Al-Abidi *et al.,* 2012). In this system, the paraffin-wax phase change material was used to store solar energy, also the absorption of solar radiation increased through steps such as conduction method by spreading the screws on the tray and coating the system floor by the black bag and supplying the reflector. The solar dryer is set up in the city of Bursa on the campus of the Uludag University, and the study was performed in winter season. Every year, millions of tons of sludge waste are produced by various processes from different industries, and depending on its content, most of them are not allowed to be buried. A large amount of sludge water is evaporated by a solar dryer and its volume is significantly reduced. In this system, the drying efficiency of three sludge samples was investigated under different conditions and time intervals. This system facilitates the sludge transportation process, which is considered as an economical method. This study have been carried out in Bursa, Turkey in 2019.

MATERIALS AND METHODS

Sludge samples

The first sludge sample was from the Bursa wastewater treatment plant after mechanical treatment with 80% moisture. The second sample was paint sludge, which was from the painting section of the automobile factory and is dangerous according to EU (European Union) standards 080113 code, also is not permitted to be buried. The moisture content in the paint sludge was 56%. The third sample was marble sludge, which results from the cutting, and polishing of marble slabs. Marble sludge is not considered hazardous waste. The bulk of marble sludge is calcium and magnesium oxide and contains 26% moisture content. The specifications of all three types of sludge are shown in Table 1.

Experimental study

The dryer setup in this study was made of a triangular aluminum frame. The surface and sides of the system are covered with poly carbonate coating. System absorber was dark glass heat pipes evacuated tubes in which the copper pipes are embedded. Approximately 650 g of the copper pipes were filled with paraffin- wax phase change material that can absorb solar heat and stored during the night and in the absence of the sun. It prevents sudden temperature changes and causes more heat to enter the system. The generated heat by the paraffin-wax was transferred to the indoor air and the aluminum tray containing the sludge through convection, and finally to the sludge by the conductive method. Paraffin phase change material ensures that the dryers have enough heat to continue the drying process. Various sensors were used to different sections of the system to measure the temperature. Used sensors were (S3120, Comet, Czech Republic), a solar data logger (DT 185, CEM, India), (RX2100, HOBO onset data logger, USA), Thermal Camera (E5, FLIR, USA). A fan (120, Mutlusan, Turkey) and a pump (Vaillant VCK, UK) for regular air circulation were used. The installation of the fan resulted in a homogeneous distribution of air within the system, which accelerated the drying process. The sludge with 0.5 cm is loaded into the aluminum tray with

Table 1: Characteristics of three types of sludge

Sludge characteristics	Wastewater Treatment Plant Sludge	paint sludge	Marble Sludge
Total Solids (TS), %	20%	44%	74%
Magnesium oxide (MgO)			4,47%
pH	8.3		
Conductivity (µs/Cm)	267.83(µs/Cm)		
Lead (Pb)	31.77(mg/kg)	<0.05(mg/L)	
Calcium oxide (CaO)			49,07%
Zinc (Zn)	1212.04(mg/kg)	<0.1(mg/L)	
Aluminium (Al)	9005.25(mg/kg)		
Silicon dioxide(SiO_2)			1,69%
Arsenic (As)	11.47(mg/kg)	<0.05(mg/L)	
Mercury (Hg)	587.4(mg/kg)	<0.001(mg/L)	
Iron(III) oxide(Fe_2O_3)			0.21-1.3%
Chromium (Cr)	184.92(mg/kg)		
Selenium (SA) (mg/kg DS.)	2.34(mg/kg DS.)	<0.01(mg/L)	
Aluminum oxide(Al_2O_3)			1.04-1.3%
Iron (Fe)	8857(mg/kg)		
Nickel(Ni)	84.84632(mg/kg)	<0.05(mg/L)	
Sulphate (SO_4)	15209(mg/kg)	2.52±0.38 (mg/L)	
Carbon dioxide(CO_2)			38.60%
Dissolved organic		1430±28 (mg/L)	

a total area of 0.24 m^2. Fig. 1 shows the schematic diagram of the system.

Among the different methods, solar drying has more advantages than other methods, and in this study, during different stages, by improving the system, the priority of selecting this method is emphasized and with the development of science, the possibility of advancing this technique will continue. Drying technics are mentioned in Table 2.

Another important advantage of solar dryers is the inactivation of bacteria under solar radiation. In research conducted in previous months in the same system Wastewater treatment plant sludge under 2312 Wh/m^2 cumulative solar radiation, the amount of E-coli Microorganism is reduced from 5 logs CFU/gr to 3 logs CFU/gr.

RESULTS AND DISCUSSION

Solar dryers should work in both cloudy and sunny weather. Increasing the collector surface reduces drying time. The produced hot air provides conditions for moisture evaporation from the sludge

Fig. 1: Schematic diagram of solar drying system.

Table 2: Drying Techniques (Zhang *et al.,* 2014)

Drying techniques	Advantages	Disadvantages
Vacuum Drying	Method is suitable for sensitive material	Costly
Solar Drying	Low risk and maintenance cost Free energy High possibility of progress and development Simple installation Bacteria reduction	Long process It needs a wide space
Freeze Drying	Reduce surrounding pressure Operate under vacuum	Costly
Osmotic Dehydration	Energy consumption 'Short dying time	Not remove enough moisture
Oven Drying	Short dying time	Needs more energy
Drum Drying	Rapid and efficient	Costly
Spray Drying	Rapid and efficient	Costly

(Simate, 2001). The drying rate is achieved by removing moisture from the surface and inner part of the sludge (Can, 2000). Many strategies have been proposed in this study to improve and increase the efficiency of the dryer. By placing one kg of sludge into the dryer, the performance of the system was evaluated from 10 a.m. to 16 p.m. for 6 h. During three stages, the system was repeatedly modified to improve dryer performance. For all three sludge samples, one kg of sludge was spread on an aluminum tray and the internal temperature of the system was increased during direct sunlight and through heat stored in paraffin-wax. In the first stage, sludge drying efficiency increases by adding steel screws that were dispersed and standing on the sludge surfaces. The steel screws transfer heat directly to the sludge by a conductive method due to the heat received from the solar radiation, in addition, with increasing cracking on the sludge surfaces, the drying rate was increased. In the next stage, coating the dryer floor with a black trash bag actually enhanced the absorption of solar radiation directly into the system. In the third step, the use of aluminum foil as a reflector around the glass tubes causes solar radiation to hit the reflector and return to the collector and increase the absorption of solar radiation. The aluminum foil as a reflective material was used for increasing the absorption of sunlight (Wagner *et al*., 1984), also can be used as cheaper material easily around the glass tubes. Due to the concave shape of aluminum foil, the solar radiation was easily reflected in the black glass tubes for further absorption. These reflectors were connected to the dryer itself and reflect solar radiation to paraffin tubes, thereby the temperature of the paraffin increased. Drying speed was improved by system modification and sludge drying time was reduced. Fig. 2 shows the cracks created around the screws in three sludge samples.

In this study, the moisture content of all three sludge types at each stage in Eq. 1 is calculated.

$$\text{Moisture Content }\% = \frac{(M)-(D)}{(D)} \times 100 \qquad (1)$$

M = Wet sludge weight(g)
D = Dry sludge weight (g)

Increasing the drying performance in WWTPs. by applying Screws, black trash bag, and Reflector

In Fig. 3(a). is shown the weight of WWTPs. sample has reached from 1000 g to 800 g within 6 h by 1120 Wh/m^2 internal cumulative solar radiation. The mean temperature and humidity inside the system were 16.8˚C and 45.8%. In Fig. 3(b). by placing the steel screws on the surface of the waste sludge, the weight of the sludge has reached from 1000 g to 782 g, with 1120 Wh/m^2 internal cumulative solar radiation. In Fig. 3(c). in addition to the screws spreading, also the system floor was covered with black trash bag, and the sludge weight was reduced from 1000 g to754 g by receiving 1064 Wh/m^2 internal cumulative solar radiation. The average internal temperature and humidity of the system were 18.6˚C and 41.1%. In Fig. 3(d), the aluminum foil was used as a reflector along with the screws and black trash bag. At this stage, the weight of the sludge was changed from 1000 g to 722 g with 1046 Wh/m^2 internal cumulative solar

Wastewater Treatment Plant Sludge

Paint Sludge

Marble Sludge

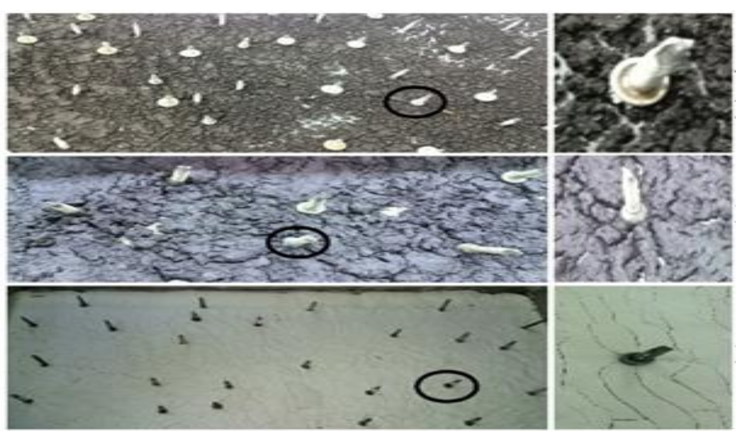


Fig. 2: Sludge morphology after solar drying by applying screws.

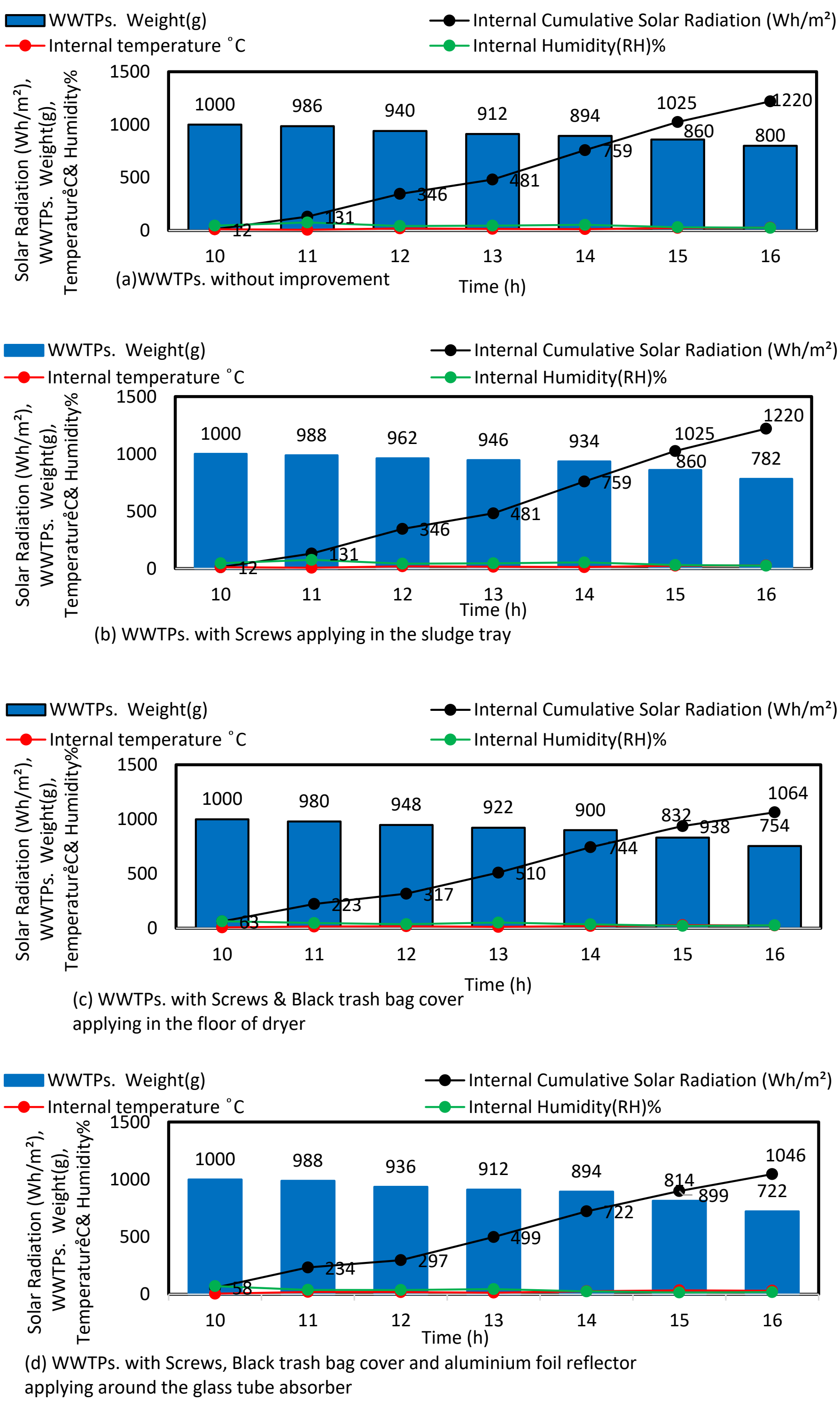


Fig. 3: WWTPs. drying performance by solar dryer; (a) WWTPs. without improvement; (b) WWTPs. with Screws applying in the sludge tray; (c) WWTPs. with Screws and Black trash bag cover applying in the floor of dryer; (d) WWTPs. with Screws, Black trash bag cover and aluminum foil reflector applying around the glass tube absorber.

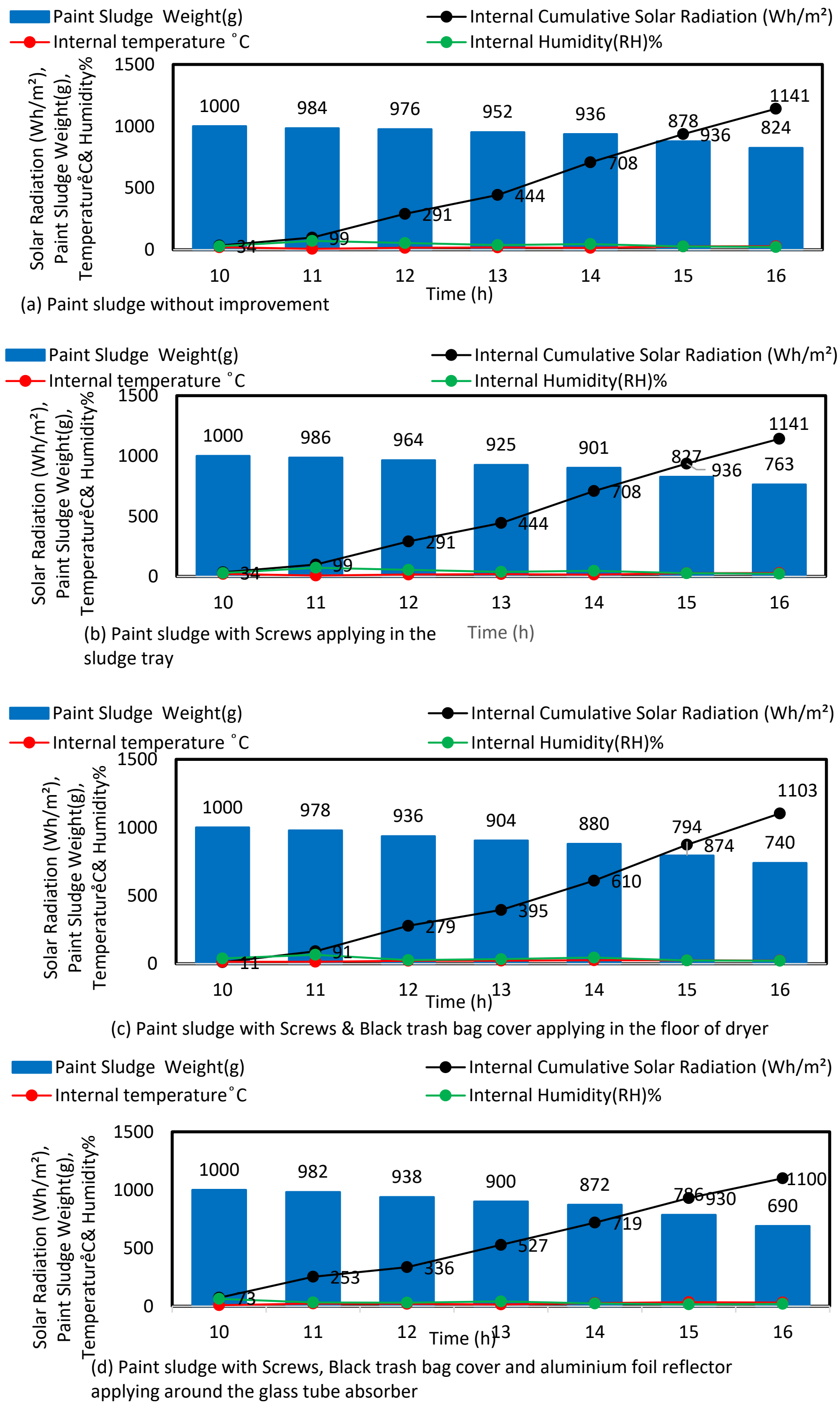


Fig. 4: Paint sludge drying performance by solar dryer; (a) Paint sludge without improvement; (b) Paint sludge with Screws applying in the sludge tray; (c) Paint sludge with Screws and Black trash bag cover applying in the floor of dryer; (d) Paint sludge with Screws, Black trash bag cover and aluminum foil reflector applying around the glass tube absorber.

radiation. Also, the average internal temperature and humidity of the dryer were 21.6˚C and 35.9%. In the Fig. 3, the sludge drying efficiency increases from 20% in Fig. 3(a) to 28% in the Fig. 3(d). At each stage, the sludge moisture reaches from 80% to 60%, 58.2%, 55.4% and 52.2%, respectively.

Increasing the drying performance in Paint Sludge by applying Screws, black trash bag, and Reflector

In Fig. 4(a), is shown the weight of the paint sludge sample has reached from 1000 to 824 g by providing 1141 Wh/m^2 internal cumulative solar radiation. The average temperature and humidity inside the system were 19˚C and 41%. In Fig. 4(b). by placing the steel screws, the weight of the sludge has reached from 1000 to 763 g with 1141 Wh/m^2 internal cumulative solar radiation. In Fig. 4(c), after covering the system floor with black trash bag, the sludge weight was reduced by receiving 1103 Wh/m^2 internal cumulative solar radiation from 1000 to 740 g. The average temperature and humidity of the internal system were 21˚C and 37%. In Fig. 4(d), by using the reflector, the weight of the sludge was changed from 1000 to 690 g with 1100 Wh/m^2 internal cumulative solar radiation. Also, the average internal temperature and humidity of the system were 23˚C and 32%. In the Fig. 4(a), the sludge drying efficiency increases from 18% to 31% in the Fig. 4(d). At each stage, the paint sludge moisture reduces from 56% to 38.4%, 32.3%, 30% and 25%, respectively.

Increasing the drying performance in Marble Sludge by applying Screws, black trash bag cover, and Reflector

In Fig. 5(a), the marble sludge weight sample has reduced from 1000 to 854 g with 1367 Wh/m^2 internal cumulative solar radiation. The average internal temperature and internal humidity were 25˚C and 45%. In Fig. 5(b), the sludge weight has reached by screws applying in the tray from 1000

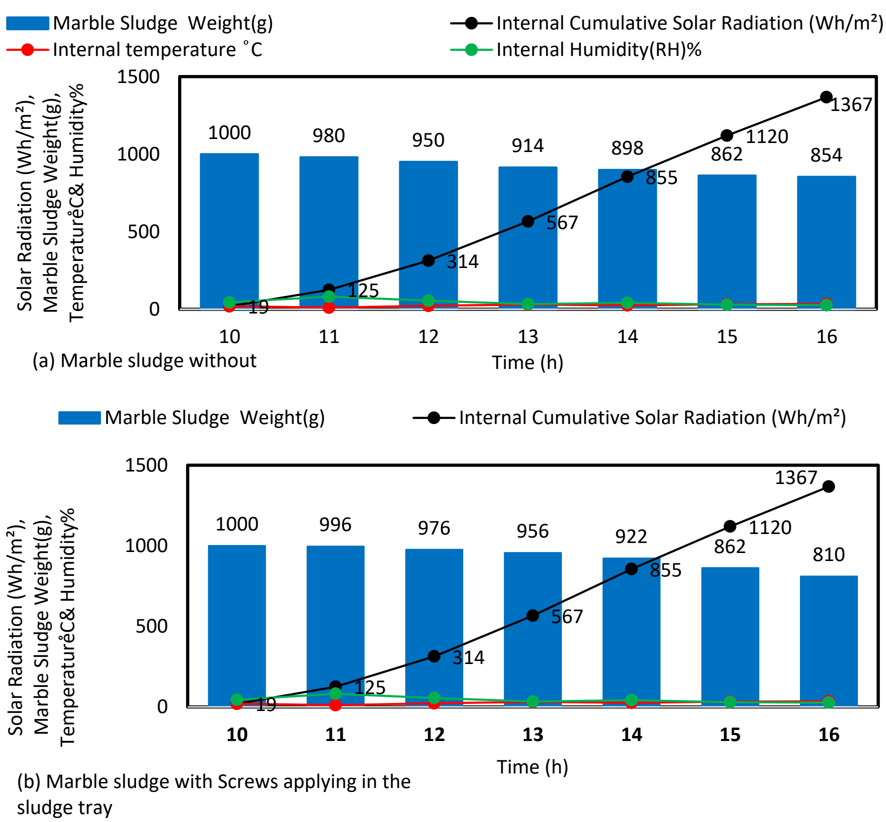
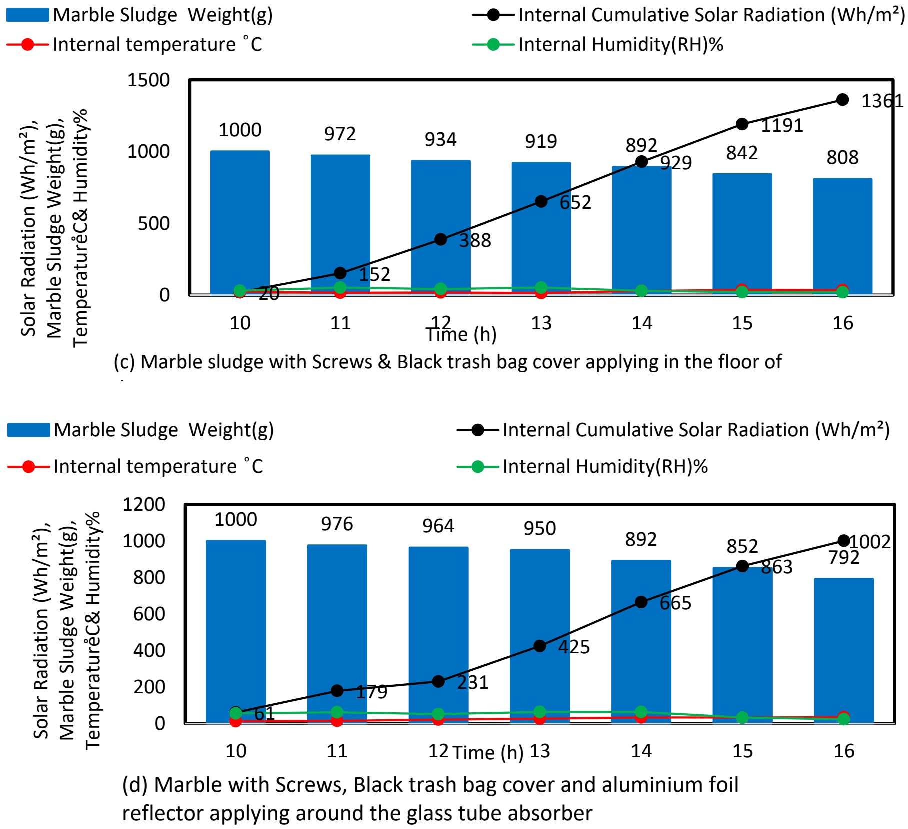


Fig. 5: The Marble sludge drying performance by solar dryer; (a) Marble sludge without improvement; (b) Marble sludge with Screws applying in the sludge tray



Continued Fig. 5: The Marble sludge drying performance by solar dryer; (c) Marble sludge with Screws & Black trash bag cover applying in the floor of dryer; (d) Marble with Screws, Black trash bag cover and aluminium foil reflector applying around the glass tube absorber.

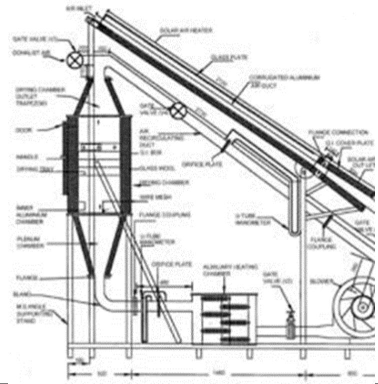
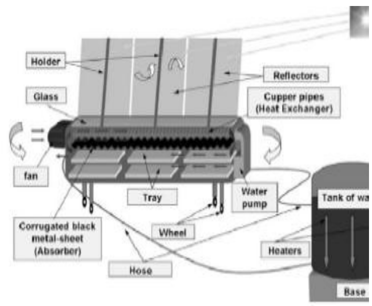
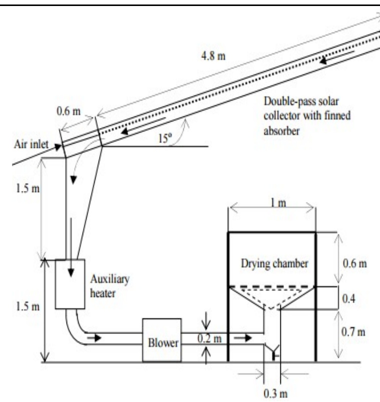
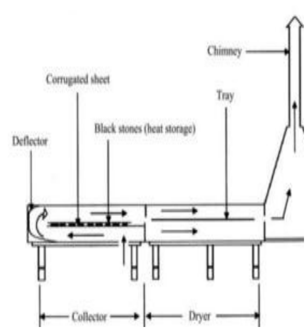
to 810 g with 1367 Wh/m^2 internal cumulative solar radiation. In Fig. 5(c), the system modified by black trash bag and the sludge weight was reduced from 1000 to 808 g by receiving 1361 Wh/m^2 internal cumulative solar radiation. The internal average temperature and humidity of the system were 25˚C and 35%. In Fig. 5(d). The sludge weight was changed from 1000 to 792 g with 1002 Wh/m^2 internal cumulative solar radiation. The average internal temperature and humidity were 26˚C and 50%. In Fig. 5(a), the sludge drying efficiency increases from 15% to 21% in Fig. 5(d). At each stage, the marble sludge moisture changes from 26% to 11.4%, 7%, 6.8%, and 5.2%, respectively.

The solar radiation intensity decreases during each step, but due to system upgrading, sludge drying efficiency increases. This study was conducted in winter, with 1156 Wh/m^2 mean solar radiation, which improved the sludge drying process from the first stage to third stage. Dryer efficiency increases with time and system quality increasing. This study was performed in a very short time when the solar radiation is very low. And the goal is just how to change the system improvement at each stage. In the drying systems that have been done in various studies in the previous articles, the improvement process has not been studied in steps and has been done for a longer period of time. Also, this study was performed only for one kilogram of sludge, which certainly has high efficiency in a larger volume of sludge will be more evident. Comparison of different solar dryer is shown in Table 3.

Heat transfer to sludge

Each material used in the system caused the system's internal temperature and sludge temperature to increase as a heat storage source, also Fig. 6 shows how the temperature rises sequentially. As the solar

Table 3: Comparison of different solar dryer

References	Moisture changes	Figure
(Sarsavadia, 2007) Onion slices	Moisture content reduces from 86% to 7% (wet basis).	
(Amer *et al.,* 2010) Banana slices	30 kg of banana slices in sunny day from moisture content of 82% to t 18% (wb).	
(Fudholi *et al.,* 2011) Marine products	Moisture reduced from 90% to 10 % in 15 h.	
(Berinyuy *et al.*, 2012) Sliced cabbage	Moisture content reduced from 95% to 9% in five days.	

Continued Table 3: Comparison of different solar dryer

References	Moisture changes	Figure
(Eke, 2014) Tomato, okra and carrot	For tomato, okra and carrot dryers achieved 54.55, 52.88 and 50.98 percent gain in drying time and 21.80%, 21.18% and 24.95% system drying efficiencies respectively.	
(Garanto, 2016) Sludge	Sludge is dried from 18 % DS to > 95% DS;	

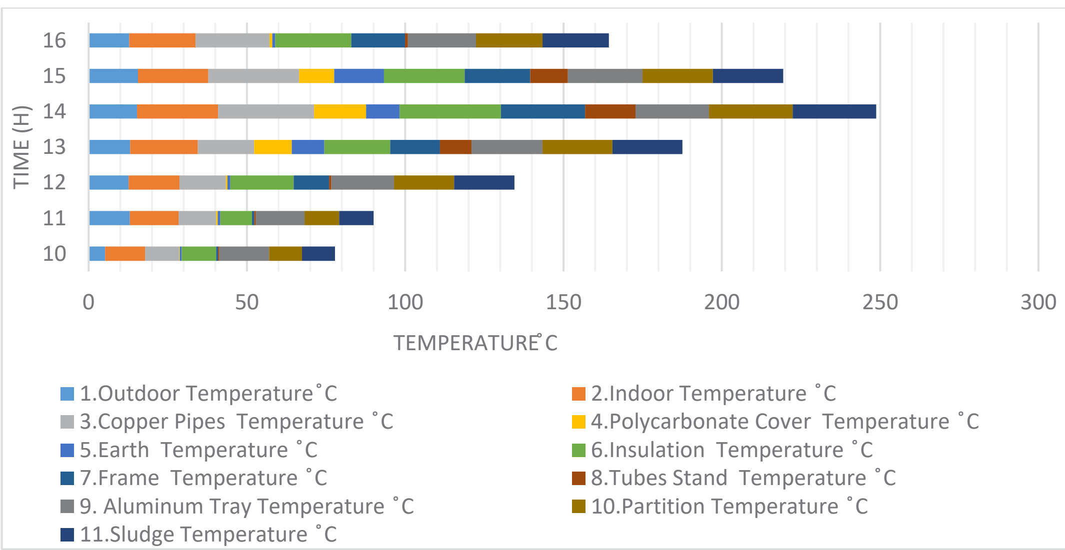


Fig. 6: Heat transfer in solar dryer system

radiation intensifies, all the components temperature inside and outside the system be increased, so the selection of equipment and the type of components are important. In Fig. 6, the temperature changes are shown from 10:00 a.m. to 16:00 p.m. and the highest change was at 14:00 p.m.

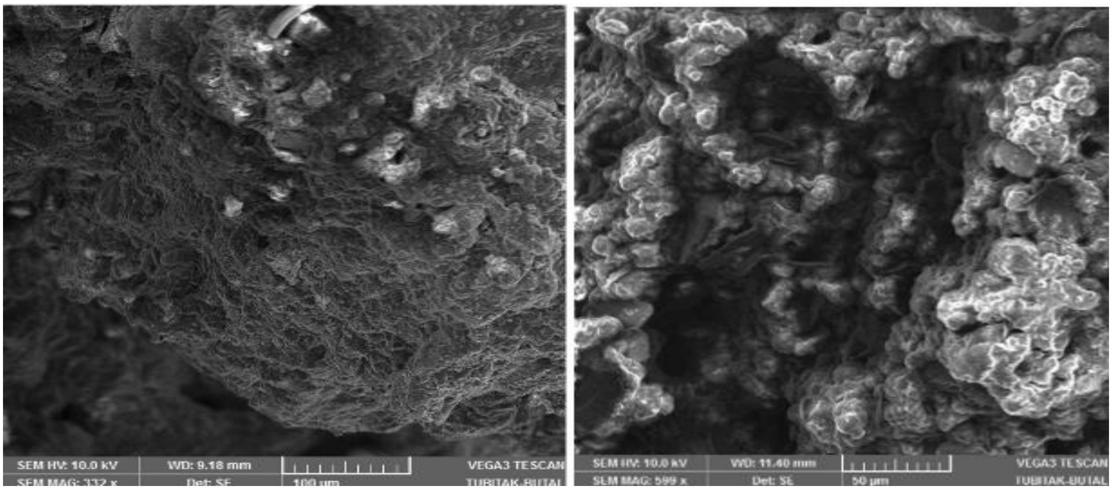


Fig. 7: SEM pictures from dried sludges: Left picture is WWTPs. with 11% Moisture and right picture is Paint sludge with 7% Moisture

SEM analysis

In this study, scanning electron microscopy (SEM) was imaged with a TESCAN VEGA3 SEM for WWTPs. with 11%, and paint sludge with 7% moisture content. As shown in Fig. 7, by increasing the temperature, the water particles rapidly detach from the sludge, resulting in pores and pipes of various dimensions on the sludge surface, which are more visible in the paint sludge. With this method, imaging the sludge morphology changes after drying were clearly visible. Wastewater sludge and paint sludge were imaged at 332 and 599 magnifications. The holes in the marble sludge does not form after drying and becomes a flat surface that is not visible by imaging.

CONCLUSION

In this study, the efficiency of a solar dryer designed for three different sludge types was investigated. During the drying process the system drying efficiency was improved from first step of spreading the screws in the tray to the third step of using the reflector in three sludge sample, with 1156 Wh/m^2 mean internal cumulative solar radiation in winter, which was more noticeable in the paint sludge due to the high amount of free water. The moisture content of WWTPs. reduced from 80% to 52.2% and paint sludge reduced from 56% to 25% and marble sludge moisture changed from 26% to 5.2%. At each stage, although the cumulative solar radiation be reduced, but due to system renewal, the sludge drying process was improved, which was more effective in the paint sludge and was clearly visible in SEM imaging. The equipment used in the construction of the dryer must have a high heat storage capacity as a heat source and have a positive effect on the drying process. In the first stage, the sludge absorbs heat through tray and screws by conductive method and increases the drying rate. In the second stage, the black coating of the dryer floor leads to absorb the solar radiation completely, and in the third stage, by installing the reflector, the sun lights returns to the glass tubes and the paraffin temperature increases. The heat of the paraffin transfers to copper pipes and it cause to increase the internal air temperature. In addition, four factors such as cumulative solar radiation, indoor temperature, indoor humidity and time play important role in the drying process. The importance of using this system is to reduce the volume of sludge that leads to a reduction in transporting costs, also it improves waste management and can be used in various industries. Investigating the progress of solar dryer technology is appropriate for future development. As a result of the research, the necessary conditions for drying three types of sludge in the winter season in the Bursa region were determined.

AUTHOR CONTRIBUTIONS

Z. Amin is the corresponding author and has performed all the experiments and literature review.

Professor N. Salihoğlu is the supervisor and has installed the system.

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CONFLICT OF INTEREST

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues including plagiarism, informed consent, misconduct, data fabrication and, or falsification, double publication and, or submission, and redundancy have been completely witnessed by the authors.

ABBREVIATIONS

a.m.	Ante meridiem
Eq.	Equation
°C	Degree Celsius
cm	Centimeter
%	Percentage
EU	European Union
g	Gram
h	Hour
kg	Kilograms
m^2	Square meter
PCM	Phase Change Material
p.m.	Post meridiem
RH	Relative humidity
SEM	Scanning Electron Microscopy
USA	United States of America
UK	United Kingdom
Wh/m^2	Watt-hour per square metre
WWTPs.	Wastewater Treatment Plant Sludge

REFERENCES

Amer, B.M.A.; Hossain, M.A.; Gottschalk, K., (2010). Design and performance evaluation of a new hybrid solar dryer for banana. Energy Convers. Manage., 51(4): 813-820 **(8 pages).**

Archer, E.; Petrie, B.; Kasprzyk-Hordern, B.; Wolfaardt, G.M., (2017). The fate of pharmaceuticals and personal care products (PPCPs), endocrine disrupting contaminants (EDCs), metabolites and illicit drugs in a WWTW and environmental waters. Chemosphere. 174: 437-446 **(10 pages).**

Ali, I.; Abdelkader, L.; El Houssayne, B.; Mohamed, K.; El Khadir, L., (2016). Solar convective drying in thin layers and modeling of municipal waste at three temperatures. Appl. Therm. Eng., 108: 41-47 **(7 pages).**

Al-Abidi, A.A.; Bin Mat, S.; Sopian, K.; Sulaiman, M.Y.; Lim, C.H.; Th, A., (2012). Review of thermal energy storage for air conditioning systems. Renewable Susta. Energy Rev., 16(8): 5802-5819 **(18 pages).**

ASTM., (1998). Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass, ASTM /D/2216-98, ASTM International **(4 pages).**

Bano, T.; Goyal, N.; Tayal, P. K., (2015). Innovative solar dryers for fruits, vegetables, herbs and an ayurvedic medicines drying. Int. J. Eng. Res. Gen. Res., 3(5): 883-888 **(6 pages).**

Berinyuy, J. E.; Tangka, J. K.; Weka Fotso, G. M., (2012). Enhancing natural convection solar drying of high moisture vegetables with heat storage. Agricultural Engineering International: CIGR J., 14(1): 141-148 **(8 pages).**

Bolaji, B.O.; Olalusi, A.P, (2008). Performance Evaluation of a Mixed-Mode Solar Dryer. AU J. Technol., 11(4): 225-231 **(7 pages).**

Bennamoun, L.; Arlabosse, P.; Léonard, A., (2013). Review on fundamental aspect of application of drying process to wastewater sludge. Renewable Sustainable Energy Rev., 28: 29-43 **(15 pages).**

Bhardwaj, A.K.; Chauhan, R.; Kumar, R.; Sethi, M.; Rana, A., (2017). Experimental investigation of an indirect solar dryer integrated with phase change material for drying valeriana jatamansi (medicinal herb): Case Study. Therm. Eng., 10: 302-314 **(13 pages).**

Can, A., (2000). Drying kinetics of pumpkin seeds. Int. J. Energy Res., 24: 965-975 **(11 pages).**

Di Fraia, S.; Massarotti, N.; Vanoli, L.; Costa, M., (2016). Thermo-economic analysis of a novel cogeneration system for sewage sludge treatment. Energy. 115(15): 1560-1571 **(12 pages).**

Di Fraia, S.; Massarotti, N.; Vanoli, L., (2018). A novel energy assessment of urban wastewater treatment plants. Energy Convers. Manage., 163: 304-313 **(10 pages).**

Darvishi, H.; Mohammadi, P.; Azadbakht, M.; Farhudi, Z., (2018). Effect of different drying conditions on the mass transfer characteristics of kiwi slices. J. Agric. Sci. Technol., 20: 249-264 **(16 pages).**

Eke, A. Ben., (2014). Investigation of low-cost solar collector for drying vegetables in rural areas. Agricultural Engineering International: CIGR J., 16(1):118-125**(8 pages).**

El-khawajah, M.F.; Aldabbagh, L. B.Y.; Egelioglu, F., (2011). The effect of using transverse fins on a double pass flow solar air heater using wire mesh as an absorber. Sol. Energy., 85(7): 1479-1487**(9 pages).**

Fudholi, A.; Otman, M.; Ruslan, M.; Yahya, M.; Zaharim, M.; Sopian, K., (2011). Technoeconomic analysis of solar drying system for seaweed. Proc. of the 7th IASME/WSEAS. International Conference on Energy, Environment, Ecosystems and Sustainable Development. Malaysia. p. 89-95 **(7 pages).**

Garanto, O., (2016). Solar sludge drying technology and dried sludge as renewable energy—closing the loop. J. Traffic Transp. Eng., 4: 221-229 **(9 pages).**

Guo, L.; Zhang, B.; Xiao, K.; Zhang, Q.; Zheng, M., (2009). Levels and distributions of polychlorinated biphenyls in sewage sludge of urban wastewater treatment plants. Res. J. Environ. Sci., 21(4): 468–473 **(6 pages).**

Kacprzak, M.; Neczaj, E.; Fijałkowski, K.; Grobelak, A.; Grosser, A.; Worwag, M.; Rorat, A.; rattebo, H.; Almås, Å.; Singh, B.R., (2017). Sewage sludge disposal strategies for sustainable development. Environ. Res., 156: 39-46 **(8 pages).**

Kalbande, S.R.; Jadhav, P.; Khambalkar, V.P.; Deshmukh, S., (2017). Design of Solar Dryer Assisted with Reflector for Drying of Medicinal Crops. Int. J. Curr. Microbiol. Appl. Sci., 6(2): 170-184 **(15 pages).**

Kamble, A.K.; Pardeshi, I.L.; Singh, P.L.; Ade, G.S., (2013). Drying of chili using solar cabinet dryer coupled with gravel bed heat storage system, Eur. Food Res. Technol., 1(2): 87–94 **(8 pages).**

Khouya, A.; Draoui, A.; (2019). Computational drying model for solar kiln with latent heat energy storage: case studies of thermal application. Renewable Energy, 130(42): 796-813 **(18 pages).**

Lakshmi, D.V.N.; Muthukumar, P.; Layek, A.; Nayak, P.K., (2018). Drying kinetics and quality analysis of black turmeric (Curcuma caesia) drying in a mixed mode forced convection solar dryer integrated with thermal energy storage. Renewable Energy, 120: 23-34 **(12 pages).**

Manara, P.; Zabaniotou, A., (2012). Towards sewage sludge-based biofuels via thermochemical conversion: a review. Renewable Sustainable Energy Rev., 16(5): 2566-2582 **(17 pages).**

Sarsavadia, P.N., (2007). Development of a solar-assisted dryer and evaluation of energy requirement for the drying of onion. Renewable Energy, 32(15):2529-2547 **(19 pages).**

Mehrdadi, N.; Joshi, S.G.; Nasrabadi, T.; Hoveidi, H., (2007). Application of solar energy for drying of sludge from pharmaceutical industrial waste water and probable reuse. Int. J. Environ. Res., 1(1): 42-48 **(7 pages).**

Simate, I.N., (2001). Simulation of the mixed-mode natural-convection solar drying of maize. Drying Technol., 19(6): 1137-1155 **(19 pages).**

Spinosa, L.; Ayol, A.; Baudez, J.-C.; Canziani, R.; Jenicek, P.; Leonard, A.; Rulkens, W.; Xu, G.; Van Dijk, L., (2011). Sustainable and Innovative Solutions for Sewage Sludge Management. Water, 3(2): 702-717 **(16 pages).**

Świerczek, L.; Cieślik, B.M.; Konieczka, P., (2018). The potential of raw sewage sludge in construction industry: a review. J. Cleaner Prod., 200: 342-356 **(15 pages).**

Udomkun, P.; Romuli, S.; Schock, S.; Mahayothee, B.; Sartas, M.; Wossen, T.; Njukwe, E.; Vanlauwe, B.; Müller, J., (2020). Review of solar dryers for agricultural products in Asia and Africa: An innovation landscape approach. J. Environ. Manage., 268(110730): 1-14 **(14 pages).**

Vlachos, N.A.; Karapantsios, T.D.; Balouktsis, A.I.; Chassapis, D., (2002). Design and testing of a new solar tray dryer. Drying Technol., 20(6): 1243-1271 **(29 pages).**

Wang, S.; Cui, Y.; Li, A.; Wang, D., (2019). W. Zhang, Z. Chen, Seasonal dynamics of bacterial communities associated with antibiotic removal and sludge stabilization in three different sludge treatment wetlands. J. Environ. Manage., 240: 231-237 **(7 pages).**

Wang, T.; Xue, Y.; Hao, R.; Hou, H.; Liu, J.; Li, J., (2019). Mechanism investigations into the effect of rice husk and wood sawdust conditioning on sewage sludge thermal drying. J. Environ. Manage., 239: 316-323 **(8 pages).**

Wang, P.; Mohammed, D.; Zhou, P.; Lou, Z.; Qian, P.; Zhou, Q., (2019). Roof solar drying processes for sewage sludge within sandwich-like chamber bed. Renewable Energy. 136: 1071-1081 **(11 pages).**

Wagner, C J.; Coleman, R.L.; Berry, R.E., (1984). Modular solar food dryers for farm use. Energy Agric., 3(c): 121-127 **(7 pages).**

Wang, W.; Li, A.; Zhang, X., (2012). DSC and SEM analysis on bound water characteristics in sewage sludge. Adv. Mater. Res., 347-353 **(7 pages).**

Ying, D.; Xu, X.; Li, K.; Wang, Y.; Jia, J., (2012). Design of a novel sequencing batch internal micro-electrolysis reactor for treating mature landfill leachate. Chem. Eng. Res. Des., 90(12): 2278-2286 **(9 pages).**

Zhang, X.; Rong, J.; Chen, H.; He, C.; Wang, Q., (2014). Current status and outlook in the application of microalgae in biodiesel production and environmental protection. Front. Energy Res., 2(32):1-15 **(15 pages).**

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