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ASSESSMENT OF WASTE SLUDGE CHANGES DURING SOLAR DRYING

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Abstract

This research presents the efficiency of an air-based solar drying system for providing comprehensive information on optimal management of the wastewater treatment plant sludge (WWTPs) by using renewable energy. The solar drying method was appropriate for utilizing facilities to remove ammonia and able to inactivate environmentally stable *Escherichia coli* (*E. coli*) microorganisms which were dropped at 2 logs CFU/gr. The thermal efficiency of the dryer was recognized under the realistic circumstance in summer when the outdoor peak solar radiation was 934 Wh/m^2, also, maximum and minimum indoor temperature varied between 62°C to 14°C. The main point of this research was to consider that 2312 Wh/m^2 internal cumulative solar radiation, 32˚C average internal temperature, and 58% average internal moisture were the leading factors to remove 1kg sludge moisture from 80% to below 10%. This study provides conditions for sludge drying by constructing a special design system for transferring intense hot air from tubes to the system and controlling internal temperature and humidity.

Keywords: cumulative solar radiation, optimal management, renewable energy, solar drying system

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1. Introduction

In recent years, extensive research has been conducted on the benefits of renewable resources. Sunlight is a clean source of energy, but only a small part of this energy is used by humans (Aboltins and Palabinskis, 2011). A lot of studies have been done on sludge drying (Di Fraia et al., 2018). The proper use of solar energy should be carefully monitored to improve efficiency and minimize the processing time of the drying system (Ameri et al., 2018). The drying operation is widely used to decrease sludge moisture and reduce waste management investment, but the lack of knowledge in this field increases the antimicrobial stability of sludge (World Health Organization, 2019). Chamber of Environmental Engineers in Turkey reported about 2,300,105 tons of sludge as a certain by-product from WWTP produced annually (UCTEA, 2018). According to Bennamoun et al. (2013a) and Tunçal and Uslu (2014) researches, the dewatering process can be done in three ways: convection, conductive, and solar drying. Solar drying systems is recognized as direct, indirect, and mixed-mode forms (Kumar et al., 2016; Tomar et al., 2017). The thermal efficiency increases by embedding the fins into the air passage of the dryer (Garg et al., 1989). It has been notified that dual-pass solar air heater performance is usually 10 to 15% higher than a single pass (Alam and Kim, 2017). Fins, baffles, and expanded surfaces are usually used to increase the heat transfer rate (Alta et al., 2010). The efficiency of the solar drying system can be affected by several parameters such as absorption type, collector dimensions, number of tubes, wind speed, and materials used within the system. According to the dryer chamber model, the performance of the system is optimized and leads to increased product quality and reduced cost and time (Husham Abdulmalek et al., 2018). The WWTPs include heavy metals, organic compounds, bacteria, viruses, drugs, and hormones

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that make difficulties in disposal management (Seggiani et al., 2012). An important drawback in the drying process is the sticky phase of the sludge, which reduces the drying performance. During the night and in winter, due to low temperatures and different weather conditions, a low drying rate should be considered. Experimental results obtained by Adekunle Komolafe et al. (2018) showed that the air temperature of the dryer system in different places was much higher than the ambient temperature during the day between 9:00 - 18:00, also the maximum dryer chamber temperature ranged from 54°C to 70.8°C. The advantages and disadvantages of the solar drying method are assessed by energy consumption and drying rates. In a study of Belloulid et al. (2019), the concentration of dry solids in wastewater sludge using solar drying pans (DP), reached 80% during 32 hours in summer and 57 hours in winter. The use of solar energy for sewage sludge dewatering is studied in recent modern works by Roux et al. (2010) and Seginer and Bux (2006). The solar drying system is usually used for low and medium heat (Karaca et al., 2019), also this system requires wide space for installation with high direct sunlight. The integration of solar drying with a conventional drying method causes to increase the drying system performance (Pirasteh et al., 2014).

Solar drying is a sustainable method for transferring heat to sludge (Salihoglu et al., 2007) and it doesn't have a systemized shape for drying kinetics (Bennamoun et al., 2013b). Sewage sludge threatens environmental health by producing significant amounts of biogenic nitrogen (Grönman et al., 2016). So many solutions have been proposed for nitrogen recovery (Havukainen et al., 2016). In this study, *E. coli* microorganisms and nitrogen content changes have been measured before and after sludge drying. Moynihan et al. (2015) observed that *E. coli* bacteria content depends on pH, humidity, and retention time. Using a closed solar dryer can reduce the time up to 65% when compared with the open solar drying system (Sacilik, 2007). According to a study of Đurđević et al. (2019), sludge drying requires a lot of energy, which can be significantly reduced by using solar energy. The solar dryer is a user-friendly and a non-polluting system providing low maintenance cost.

In this study about 1kg wastewater treatment plant sludge was loaded in a developed solar dryer, and the drying rate, *E. coli* inactivation and nitrogen reduction were assessed as an energy-saving method. The solar dryer apparatus was mounted at the campus of Uludag University, Bursa, Turkey situated at 40°N, 29°E. This proposed small-scale solar drying system can be easily expanded according to the increasing amount of sludge. In this study, by improving drying conditions and providing facilities with less energy and time, the efficiency of the drying system was increased.

2. Material and methods

2.1. Sludge samples

Bursa West WWTP is located in the North West of Turkey with 400 tons/day total capacity for the treatment of domestic wastewater. The sludge sample used in this study was obtained from the mechanical dewatering stage with 20% dry solids. Some of the sludge properties before the drying process received from the Bursa Water and Sewerage Administration (BUSKI) are mentioned in Table 1.

2.2. Experimental study and procedure

The experimental system consists of five glass heat pipes evacuated tubes and a solar collector as the main elements. The glass pipes length were 1.80 m and are made of transparent Borosilicate glass with copper sheet coverage. The main body of the drying system was made of 190x110x220 cm aluminium box profile and can be constructed easily. The top and sides of the apparatus were covered with a 10 mm multiwall rainbow polycarbonate sheet. To measure the sludge and system internal/external temperature and moisture, HOBO data logger and Comet thermocouple sensors were used, also they had been set per 15 minutes as interval time. The below and the backside of the system were insulated with 4 cm Polyurethane. A pump and a fan were used to increase the heat transfer rate. An internal ventilation system with 120m^3/h airflow was installed on the roof to circulate hot air into the system and the stainless steel Vaillant VCK FAN Motor for providing the required pressure was mounted.

In each loading, the sludge was spread on an aluminium tray of 0.24 m^2 area and 0.5 cm depth. The collector was aligned to the south, and it was established with a 30° horizontal slope. The solar radiation measurement was performed between sunrise and sunset by using a pyranometer.

In the mixed-mode solar drying system, solar radiation is transferred to the system directly and indirectly from glass tubes. The evaporated water content during the drying process was estimated based on the weight difference each day. Weighing of the sludge sample was carried out using an electronic balance (1 kg capacity with 0.5 gr resolution). The amount of initial and final moisture in the sludge was analyzed by a Sartorius moisture analyser and drying oven at 105°C to a constant mass according to ASTM D2216 – 19 standard methods.

Other equipment used during the study were Kjeldahl Distillation Unit (TKN test), Autoclave, and Incubator device for *E. coli* M.O. determination. The influence of parallel fins for hot air movement and the effects of mass flow on the thermal performance of the system were reviewed.

Table 1. Characteristics of the WWTP sludge

Total Solids (TS), %	20%
PH	8.3
Conductivity (µs/Cm)	267.83
Sulphate (SO_4) mg/kg	15209
Silver (Ag) mg/kg	2.34
Aluminium (Al) mg/kg	9005.25
Arsenic (As) mg/kg	11.47
Cadmium (Cd) mg/kg	1.41
Chromium (Cr) mg/kg	184.92
Copper (Cu) mg/kg	142.60
Iron (Fe) mg/kg	8857

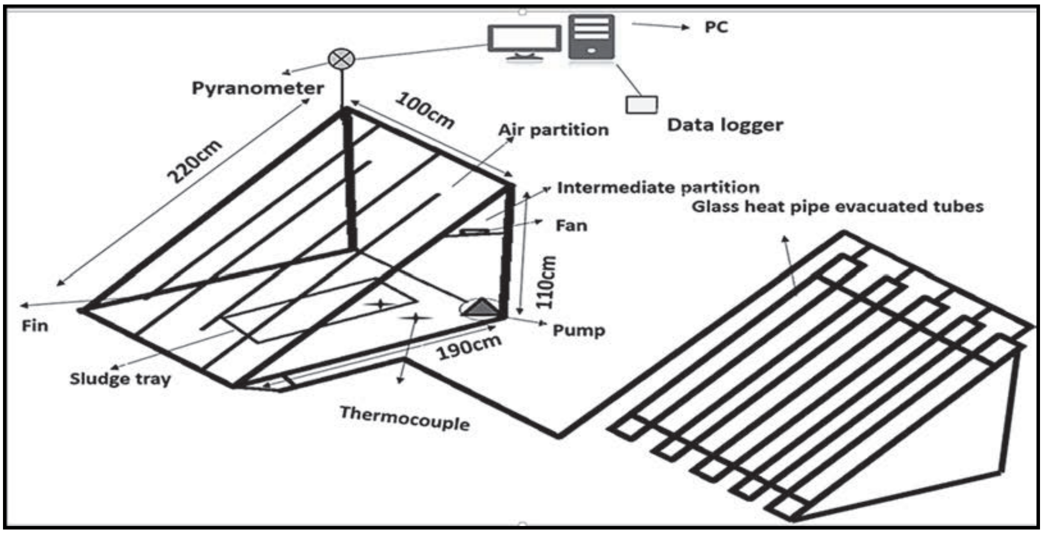


Fig. 1. Configuration of Solar Dryer

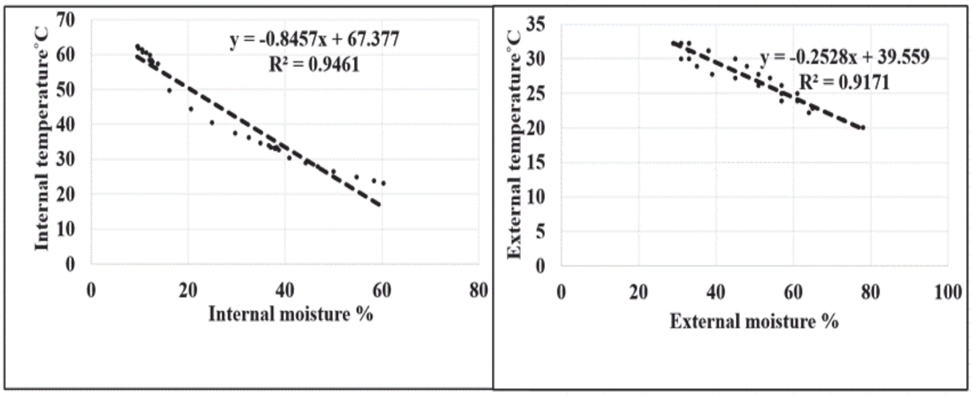
The cylindrical glass pipes were connected in series outside the system as the absorber. In this comprehensive study, one kilogram of wastewater sludge was loaded into the system, and the moisture content, Total Kjeldahl Nitrogen and sludge *E. coli* changes were measured after drying. In Fig. 1a schematic model of a designed system is described

2.3. Logical relationship between temperature and moisture during sludge drying process

The outer water layer in the sludge is free water, and during drying, the bound water comes out from the inner layer (Deng et al., 2009; Ferrasse et al., 2002). During the drying period, the shape of the sludge changes from the sticky phase to the granular phase. The bound water as deep moisture of sludge removes hardly because of water connection by capillary forces. Increasing the temperature in the system causes a decrease in relative humidity. Humidity capture capacity of air depends on the temperature. In Fig. 2, the inverse relationship between the internal and external temperature and moisture is considered. The internal temperature and moisture were ranged between (14-62)˚C and (10-99)%.

Also the external temperature and moisture were ranged between (13-32)˚C and (29-100)%. Moisture falls when the temperature rises. As can be seen, there is a huge difference between the internal and external temperature of the system, meaning that moisture and temperature changes the system efficiency. There were about 2 to 35 degrees of differences between indoor and outdoor temperatures, and the most variation was between 09:00 am to 15:00 pm. Indoor moisture follows a similar seasonal pattern, but outdoor moisture fluctuates with no consistent pattern. The relative humidity of the indoor air is determined by the indoor air temperature. Reducing airflow and air exchange rates increases the relative humidity. The system must provide adequate ventilation to control relative humidity and temperature.

Variable changes are explained using regression analysis in a linear model. R-square is a good criterion for comparing linear models and it always is between 0% and 100%. High R-squares are a good model for the results data. The correlation between indoor and outdoor temperature and moisture was weak and suggests that outdoor parameters cannot be considered as proper indicators for the drying process.



(a) (b)

Fig. 2. (a) Linear equation between internal temperature and moisture
(b) Linear equation between External temperature and moisture

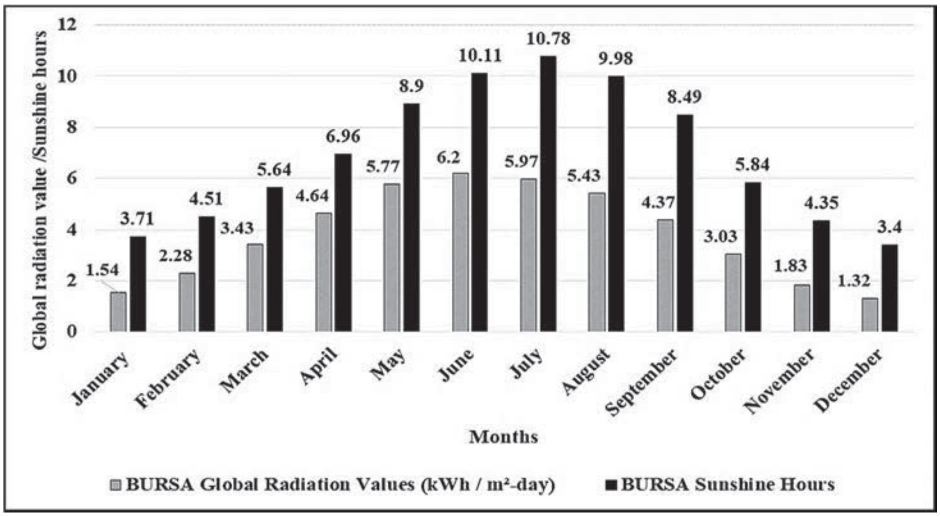


Fig. 3. Bursa Monthly average radiation

3. Results and discussion

3.1. Mathematical analysis of the drying process

In this study, the sludge moisture is determined by the following equation, which is related to the weight of evaporated water (Eq. 1) (ASTM, 1998):

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

where: M –Weight of moist sludge; D – Weight of dry sludge.

The initial and final moisture content changed from 80% to below 10% and it was observed after the first day for 1 kg sludge. The moisture content defined the rate of drying and it is reviewed by Shanmugam and Natarajan (2007). The activity of the collector is determined by the amount of beneficial energy gained from the sun. In this system, 1/3 of the solar radiation passes through the permeable cover of the collector. The solar radiation is partly reflected, absorbed, and transmitted from multiwall polycarbonate cover.

The multiwall polycarbonate layer is used in this system, providing high thermal insulation. The heat loss ratio was calculated from the cover of this system. The following equation is used to calculate heat losses for a simple greenhouse as our system. There is a logical relation between heat loss and solar radiation. In Eq. (2), Q_c represents the heat loss of a similar greenhouse (Márquez et al., 2017).

$$Qc = U \text{x} A \text{x } \Delta\text{T} \qquad \ldots\ldots(2)$$

where: U = Heat transfer Coefficient (W/ [m^2 x ˚C]); A=Exposed surface area (m^2); ΔT= Temperature differential between the inside temperature and outside temperature ˚C.

The amount of heat loss was increased with increasing radiation and temperature. Heat loss for single layer polycarbonate at 32˚C internal average temperature was approximately 50W. Below and behind, the system was insulated with polyurethane walls. Due to the low thermal conductivity of the insulation material, the heat loss can be ignored.

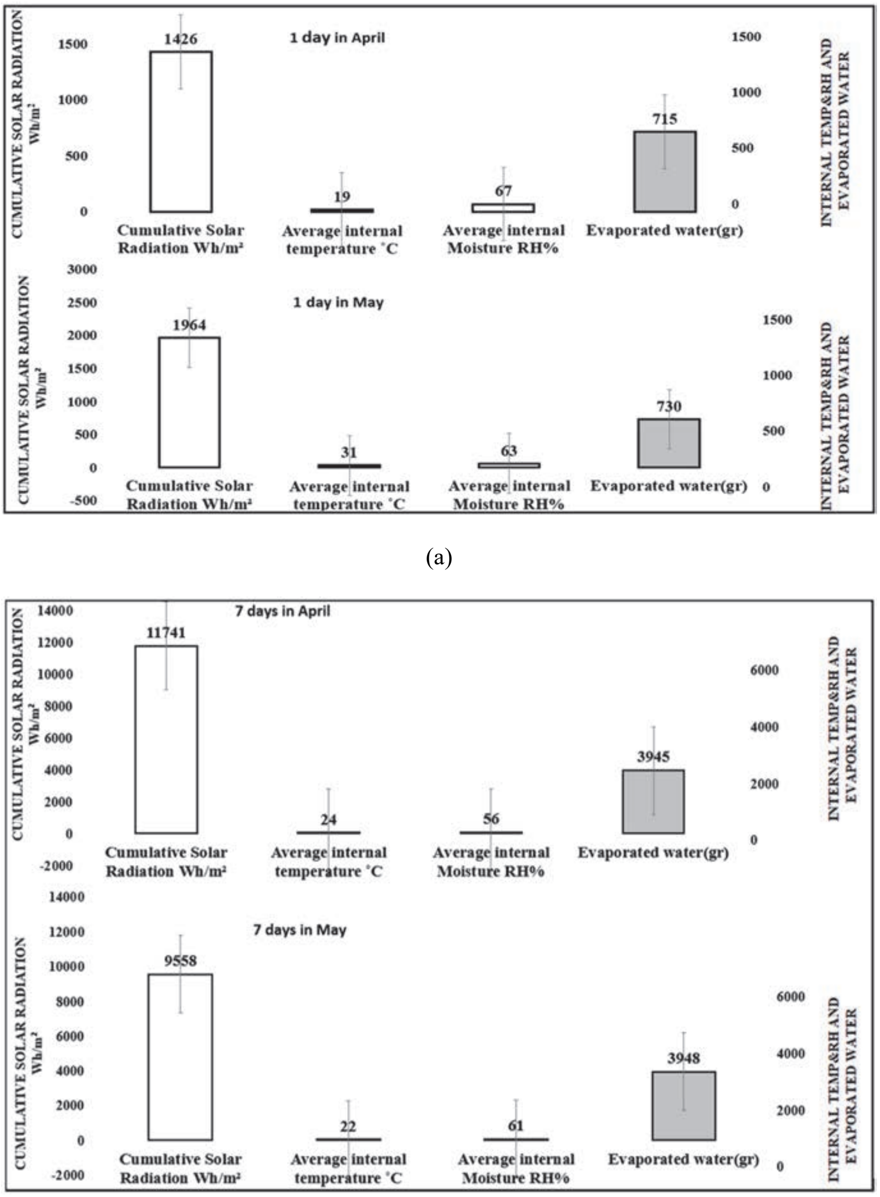
3.2. The required energy for the drying process

The solar radiation in Bursa has been measured for a year. July is the sunniest, and December has the lowest sunshine. Maximum Peak sun hours (PSH) are reported by Solar Energy Potential Atlas in Fig. 3 (GEPA, 2019). As can be seen in Fig. 4, the drying process has been investigated for different periods with varying sludge volume. The strongest relation in solar drying was between cumulative solar radiation and evaporated water and was shown for two months in April and May.

In the warm seasons, depending on the amount of solar radiation received, the moisture content of 1 kg of sludge is reduced to less than 10% in about 1 day. Under the same conditions, 5 kg of sludge with higher thickness was dried in the same area for less than 1 week, but after the sludge has completely dried, the moisture content has started to increase again, because over the drying threshold the sludge began to absorb moisture from the environment. The three essential parameters in the drying process were the cumulative solar radiation, internal temperature, and moisture of the drying system.

The amount of water evaporation was also increased with increasing solar radiation and temperature. By examining Fig. 4 graphs, we actually determine the dependence and the correlation between the parameters.

In Fig. 5 the water evaporation process is investigated daily for 5 kg of sludge. From the first day to the third day the evaporated water was increased by increasing temperature and cumulative radiation consecutively.



(a)

(b)

Fig. 4. Evaporated water content in different drying period in April and May by common greenhouse without glass heat pipe evacuated tubes (1 kg in one day(a) and 5 kg in one week (b))

The sharp increase in water evaporation was observed from the third day to the fourth day, in fact, the water trapped in the sludge finds a way out by breaking the sludge bonds. In Fig. 6, is shown the amount of evaporated water from sludge substrates in July. In fact, for 1 kg sludge drying with 0.5 cm thickness by providing 2312 Wh/m^2 internal cumulative solar radiation, 32˚C internal average temperature, and 58% internal average moisture cause to 749 gr water evaporate during a day. So, if all the parameters are kept in the same range, by spreading 1602 gr sludge, 1000gr water will easily vaporize. Also, the amount of energy consumed by the pump and fan was 1.1 kWh per day.

3.3. E- coli M.O. changes in sludge under solar radiation

Exposure of microorganisms to sunlight causes direct and indirect damage. In a study provided by Gontijo et al. (2018), thermal energy from the solar radiation reduced microorganisms in the sludge. Temperature and solar radiation effect the microorganism's survival in the sludge. EPA (2006) method was used for the quantification of *E. coli.* The time-temperature parameter is the main factor for bacterial inactivation in heating applications (Singh et al., 2011). *E. coli* grows over a period of 48 ± 3 hours in the incubator at 35°C ± 0.5°C.

During the drying process *E. coli* was chosen as a variable indicator microorganism in this research because it is naturally present in raw wastewater sludge concentrations and a significant decrease was measured after solarisation. The *E. coli* inactivation under solar radiation has investigated, and the average value for each operational condition is shown in Fig. 7. The bacterial reduction was determined approximately at 2 log CFU/g after 24 hours at 32˚C average and 62˚C maximum internal temperature. Wastewater sludge concentration has been classified as a pollutant in two levels of Class A and Class B according to pathogen density.

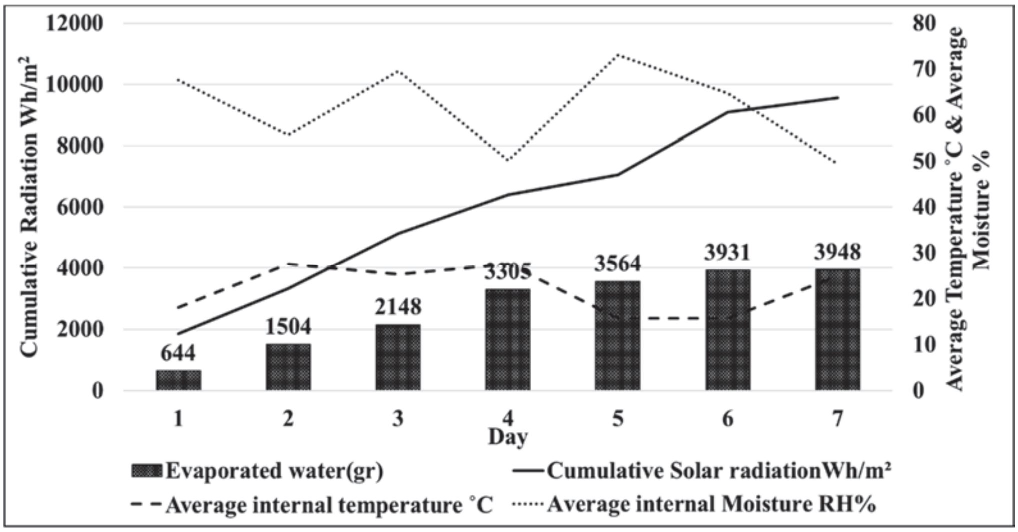


Fig. 5. The daily amount of water evaporated from 5 kg of sludge for one week in May without glass heat pipe evacuated tubes

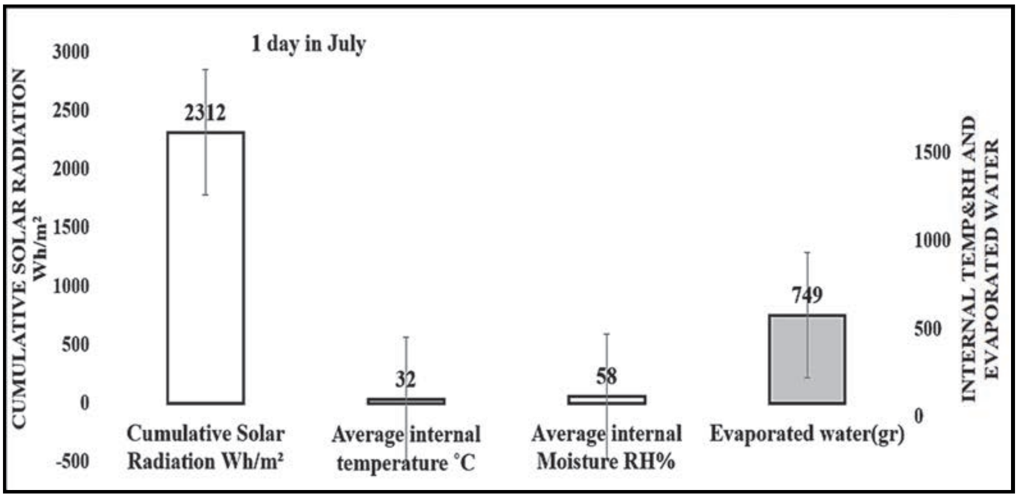


Fig. 6. The Evaporated water content from sludge during one day in July by solar dryer with glass heat pipe evacuated tubes

According to part 503 EPA, there is a restriction on the use of high-quality sewage sludge. As European sanitary standards, *Escherichia coli* concentrations in west WWTPs are relevant to Class B. Within the sludge drying system, a great pathogen reduction was achieved in closed- loop system (Salihoglu et al., 2007).

After sludge solarisation, pathogens were reduced to low levels that are not created a specific threat to environmental health. To achieve the EPA Class A pathogen qualification, the internal cumulative solar radiation must be more than >2312Wh/m^2 with 34˚C sludge temperature for 2 log CFU/gr reduction after one day. In the study of sludge drying system, the level of the pathogens falls to below class B but does not reach under the class A (USEPA, 1993).

After the drop of *E. coli* about 2 logs CFU/gr this value remained constant and as time progressed, no change was found. The results of the *E. coli* inactivation test are shown in Fig. 7. According to previous studies, *E. coli* is more susceptible to high-temperature inactivation during solarisation (Watcharasukarn et al., 2009). So there was a positive correlation between the M.O. decreasing, time and internal cumulative solar radiation for municipal sewage sludge.

3.4. Ammonia release during solar radiation

Total Kjeldahl nitrogen is determined as the total of free ammonia and organic nitrogen combination as (4500-N) standard method. During the WWTPs drying, nitrogen is released in laboratory experiments and the nitrogen content is found by calculating total nitrogen, soluble nitrogen, ionized ammonia and non-ionized ammonia (NH_3). NH_3 was titrated by sulfuric acid volumetric solution (Bremner and Mulvane, 1982). The titration step should be done after the distillation was completed and boric acid was referred to as a receiver during distillation. Optionally, Milner and Zahner (1960) proposed titration with a sulfuric acid solution.

The amount of ammonia was calculated by the milliliter of sulfuric acid used in the titration. However, the highest amount of nitrogen is included as organic nitrogen, which is adhered to the cell structure. Sewage sludge drying process related to the nitrogen content release in various forms. After the first day of sludge drying, the ammonia content changed from 9000mg/kg TS to 6800 mg/kg. According to Horttanainen et al. (2017) researches, the most significant part of the total nitrogen in the sewage sludge includes 81% organic nitrogen, 19% soluble nitrogen with 12% NH^{4+} and 7% NH_3, NOx. It was considered, that there was an obvious relationship between the temperature and ammonia release into a gas form during the drying process.

3.5. Evaluation drying system by Correlation Test

The sufficiency of the solar dryer system is tested by Pearson correlation test. This is a well-known method for analysing data when the different varieties are compared with each other and its presence is measured by the p-value. There is a significant relationship between internal temperature, moisture, and solar radiation. In the Pearson test (r) value range is from (-1, +1). -1 means a negative linear relationship between factors, 0 means no linear relationship and +1 indicates a positive relationship between variables. Hypotheses are as following:

H0: There is no correlation between internal temperature, moisture and solar radiation ($r = 0$);

H1: There is a correlation between internal temperature, moisture and solar radiation ($r \neq 0$).

The circles on the plot are scattered closely as a straight line, so there is a linear relationship between these three variables two by two. The scatterplot mention that as the solar radiation score increases the temperature increases so the Pearson correlation coefficient to be positive. A negative correlation is the moisture content with temperature and solar radiation: as the moisture increases the amount of temperature and solar radiation decreases. Most of the points scattered within an ellipse along with the linear model.

As it can be seen in Table 3, the correlation coefficient (R) is determined as a large coefficient and the p-value is less than 0.0001 (Table 2), so H0 is rejected in favour of H1. The relationship between parameters is indicated by the shape of confidence ellipse, respectively. Fig. 8 showed that there is a correlation between internal solar radiation, internal temperature, and internal moisture. There is a negative correlation with moisture, and a negative slope is clearly detectable. The largest R is related to the relationship between internal temperature and radiation.

4. Conclusions

The efficiency of the system was examined based on the heat dissipation at various points. By circulating the extracted heat from the glass tubes to the system, the performance of the solar dryer was increased. The solar drying system was able to maintain indoor temperatures without the need for extra heating. The goal of this research was to investigate the effect of solar radiation in various sludge concentrations on ammonia release and *E. coli* bacteria inactivation. Also, this solar dryer is a prototype of a real enterprise.

The offered system has advantages to convective dryers because it can probably be combined with incineration plants with low time and energy consumption.

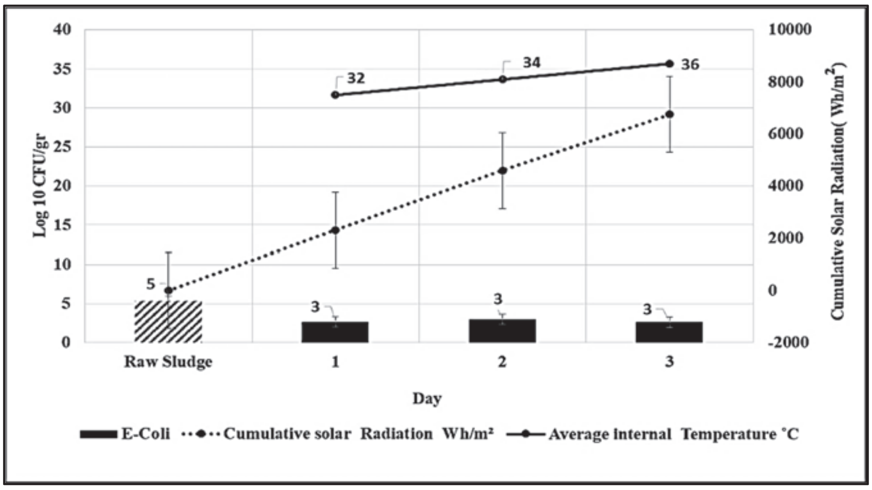


Fig. 7. *E. coli* changes after sludge solar drying in the first week

Table 2. P-values (Pearson): internal temperature, internal moisture and internal solar radiation

Variables	*Internal temp of system (˚C)*	*Internal RH of system (%)*	*Internal Radiation (W/m²)*
Internal temp of system (˚C)	0	< 0.0001	< 0.0001
Internal RH of system (%)	< 0.0001	0	< 0.0001
Internal Radiation (W/m²)	< 0.0001	< 0.0001	0

Table 3. Coefficients of determination (Pearson): internal temperature, internal moisture and internal solar radiation

Variables	*Internal temp of system (˚C)*	*Internal RH of system (%)*	*Internal Radiation (W/m²)*
Internal temp of system (˚C)	1	0.897	0.844
Internal RH of system (%)	0.897	1	0.667
Internal Radiation (W/m²)	0.844	0.667	1

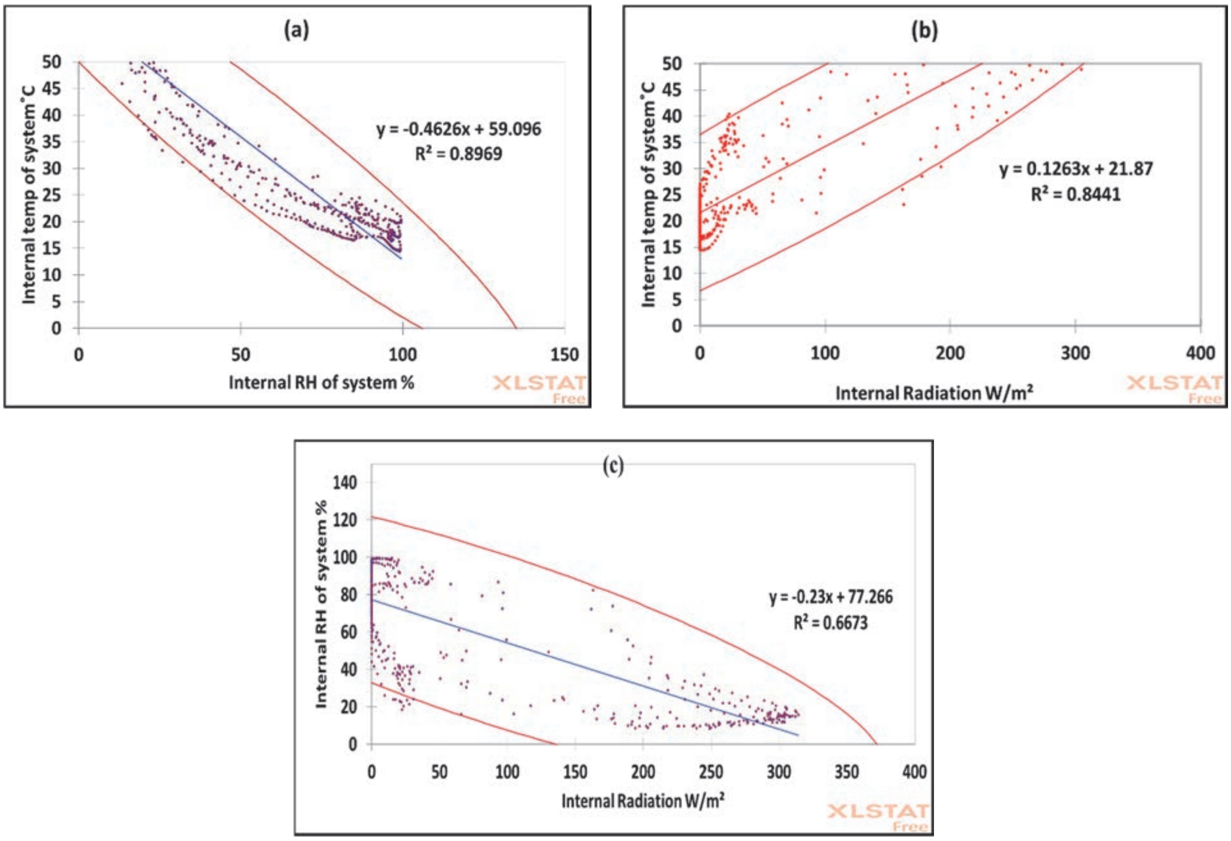


Fig. 8. Pearson correlation test between internal radiation, internal temperature and internal moisture in (a, b and c)

Consequently, by providing the suitable conditions and adjusting these three parameters such as cumulative internal solar radiation, internal temperature and internal moisture the sludge can be dried completely. The sludge bed material was also an important factor. The sludge was examined within the system for several consecutive days during the drying process. One day was sufficient time to complete drying of 1kg sludge and it was observed that microorganisms were inactivated about 2 log CFU/g and ammonium was released in the system under sunlight.

In this system, by providing 2312 Wh/m^2 cumulative internal solar radiation, 32°C average temperature, and 58% average moisture, the sludge moisture content reached below 10% in July. One of the most important aspects of this project was to reduce the moisture of high-volume sludge waste produced by using solar energy. The sludge transportation and disposal costs are reduced and make it a harmless substance. In the near future, this system by integrating with new technologies will enable to expand in various sectors. Also, by using different phase change materials, it will be possible to store more heat.

References

Aboltins A., Palabinskis J., (2011), *Investigations of Heating Process and Absorber Materials in Air Heating Collector*, Proc. World Renewable Energy Congress, vol. Solar thermal application (STH), Linköping, Sweden, May 8-31, 3991-3998.

Adekunle Komolafe C., Adekojo Waheed M., (2018), Design and fabrication of a forced convection solar dryer integrated with heat storage materials, *Annales de Chimie Science Des Matériaux*, **42**, 23-39.

Alam T., Kim M.H., (2017), Performance improvement of double-pass solar air heater – A state of art of review, *Renewable and Sustainable Energy Reviews*, **79**, 779-793.

Alta D., Bilgili E., Ertekin C., Yaldiz O., (2010), Experimental investigation of three different solar air heaters: Energy and exergy analyses, *Applied Energy*, **87**, 2953-2973.

Ameri B., Hanini S., Benhamou A., Chibane D., (2018), Comparative approach to the performance of direct and indirect solar drying of sludge from sewage plants, experimental and theoretical evaluation, *Solar Energy*, **159**, 722-732.

ASTM, (1998), Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass, ASTM /D/2216-98, ASTM International, On line at: https://www.astm.org/DATABASE.CART/HISTORICAL/D2216-98.htm.

Belloulid M.O., Hamdi H., Mandi L., Ouazzani N., (2019), Solar drying of wastewater sludge: a case study in Marrakesh, Morocco, *Environmental Technology (United Kingdom)*, **40**, 1316-1322.

Bennamoun L., Kahlerras L., Michel F., Courard L., Salmon T., Fraikin L., Belhamri A., Léonard A., (2013a), Determination of moisture diffusivity during drying of mortar cement: experimental and modeling study, *International Journal of Energy Engineering*, **3**, 1-6.

Bennamoun L., Arlabosse P., Léonard A., (2013b), Review on fundamental aspect of application of drying process to wastewater sludge, *Renewable and Sustainable Energy Reviews*, **28**, 29-43.

Bremner J.M., Mulvaney C.S., (1982), *Nitrogen-total*, In: *Page AL, Miller RH, Methods of soil analysis. Part 2, Chemical and Microbiological Properties*, American Society of Agronomy, Keeney D.R. (Eds.), Soil Science Society of America, Madison, Wisconsin, 595-624.

Deng W.Y., Yan J.H., Li X.D., Wang F., Lu S.Y., Chi Y., Cen K.F., (2009), Measurement and simulation of the contact drying of sewage sludge in a Nara-type paddle dryer, *Chemical Engineering Science*, **64**, 5117-5124.

Di Fraia S., Massarotti N., Vanoli L., (2018), A novel energy assessment of urban wastewater treatment plants, *Energy Conversion and Management*, **163**, 304-313.

Đurđević D., Blecich P., Jurić Ž., (2019), Energy recovery from sewage sludge: The case study of Croatia, *Energies*, **12**, 2-19.

EPA, (2006), EPA Method 1681 fecal coliforms in sewage sludge (biosolids) by multipletube fermentation using A-1 medium, EPA-821-R-06-013, U.S. Environmental Protection Agency, Washington, D.C., On line at: https://www.epa.gov/sites/production/files/2015 08/documents/method_1681_2006.pdf.

Ferrasse J.H., Arlabosse P., Lecomte D., (2002), Heat, momentum, and mass transfer measurements in indirect agitated sludge dryer, *Drying Technology*, **20**, 749-769.

Garg H.P., Datta G., Bhargava A.K., (1989), Performance studies on a finned-air heater, *Solar Energy*, **14**, 87-92.

GEPA, (2019), *Solar Energy Potential Atlas*, Directorate General of Energy Affairs, On line at: http://www.yegm.gov.tr/MyCalculator/pages/16.aspx.

Gontijo J.C., Wagner L G., Souza M.E. de., Possetti G.R.C., (2018), Sanitation and drying of sewage sludge on radiant floors using solar energy and biogas: comparison between different thicknesses of deposited mass, *Brazilian Archives of Biology and Technology*, **61**, 1-7.

Grönman K., Ypyä J., Virtanen Y., Kurppa S., Soukka R., Seuri P., Finér A., Linnanen L., (2016), Nutrient footprint as a tool to evaluate the nutrient balance of a food chain, *Journal of Cleaner Production*, **112**, 2429-2440.

Havukainen J., Nguyen M.T., Hermann L., Horttanainen M., Mikkilä M., Deviatkin I., Linnanen L., (2016), Potential of phosphorus recovery from sewage sludge and manure ash by thermochemical treatment, *Waste Management*, **49**, 221-229.

Horttanainen M., Deviatkin I., Havukainen J., (2017), Nitrogen release from mechanically dewatered sewage sludge during thermal drying and potential for recovery, *Journal of Cleaner Production*, **142**, 1819-1826.

Husham Abdulmalek S., Khalaji Assadi M., Al-Kayiem H.H., Gitan A.A., (2018), A comparative analysis on the uniformity enhancement methods of solar thermal drying, *Energy*, **148**, 1103-1115.

Karaca G., Dolgun E.C., Koşan M., Aktaş M., (2019), Photovoltaic-thermal solar energy system design for dairy industry, *Journal of Energy Systems*, **3**, 86-95.

Kumar M., Sansaniwal S.K., Khatak P., (2016), Progress in solar dryers for drying various commodities, *Renewable and Sustainable Energy Reviews*, **55**, 346-360.

Márquez J.M.A., Bohórquez M.Á.M., Melgar S.G., (2017), A new metre for cheap, quick, reliable and simple thermal transmittance (U-Value) measurements in buildings, *Sensors*, **17**, 1-18.

Milner O.I., Zahner R.J., (1960), Titration of traces of ammonia after Kjeldahl distillation, *Analytical Chemistry*, **32**, 294-294.

Moynihan E.L., Richards K.G., Brennan F.P., Tyrrel S.F., Ritz K., (2015), Enteropathogen survival in soil from different land-uses is predominantly regulated by microbial community composition, *Applied Soil Ecology*, **89**, 76-84.

Pirasteh G., Saidur R., Rahman S.M.A., Rahim N.A., (2014), A review on development of solar drying applications, *Renewable and Sustainable Energy Reviews*, **31**, 133-148.

Roux N., Jung D., Pannejon J., Lemoine C., (2010), Modelling of the solar sludge drying process SoliaTM, *Computer Aided Chemical Engineering*, **28**, 715-720.

Sacilik K., (2007), Effect of drying methods on thin-layer drying characteristics of hull-less seed pumpkin (*Cucurbita pepo* L.*)*, *Journal of Food Engineering*, **79**, 23-30.

Salihoglu N.K., Pinarli V., Salihoglu G., (2007), Solar drying in sludge management in Turkey, *Renewable Energy*, **32**, 1661-1675.

Seggiani M., Puccini M., Raggio G., Vitolo S., (2012), Effect of sewage sludge content on gas quality and solid residues produced by cogasification in an updraft gasifier, *Waste Management*, **32**, 1826-1834.

Seginer I., Bux M., (2006), Modeling solar drying rate of wastewater sludge, *Drying Technology*, **24**, 1353-1363.

Shanmugam V., Natarajan E., (2007), Experimental study of regenerative desiccant integrated solar dryer with and without reflective mirror, *Applied Thermal Engineering*, **27**, 1543-1551.

Singh S., Chander S., Saini J.S., (2011), Heat transfer and friction factor of discrete V-down rib roughened solar air heater ducts, *Journal of Renewable and Sustainable Energy*, **36,** 5053-5064.

Tomar V., Tiwari G.N., Norton B., (2017), Solar dryers for tropical food preservation: Thermophysics of crops, systems and components, *Solar Energy*, **154**, 2-13.

Tunçal T., Uslu O., (2014), A review of dehydration of various industrial sludges, *Drying Technology*, **14**, 1642-1654.

UCTEA, (2018), World Environment Day Turkey Report, On line at: http://www.cmo.org.tr/resimler/ekler/0d4a5b926c005a6_ek.pdf.

USEPA, (1993), Standards for the Use or Disposal of Sewage Sludge; Final Rules. Federal Register, 58, 9248-9415, Office of Science & Technology, Washington, D.C, On line at: https://www.epa.gov/sites/production/files/2015-10/documents/58_fr_9248_-_9404_standards_for_the_disposal_of_sewage_sludge_final_reduced.pdf.

Watcharasukarn M., Kaparaju P., Steyer J.P., Krogfelt K.A., Angelidaki I., (2009), Screening *Escherichia coli*, *Enterococcus faecalis*, and *Clostridium perfringens* as indicator organisms in evaluating pathogen-reducing capacity in biogas plants, *Microbial Ecology*, **58**, 221-230.

WHO, (2019), Water sanitation hygiene, On line at: https://www.who.int/water_sanitation_health/sanitation-waste/wastewater/en/.