EXPERIMENTAL STUDIES ON DEWATERING OF TANNERY SLUDGE USING LAB SCALE SOLAR DRYER

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Article History: Received: 04.05.2023 **Revised:** 14.06.2023 **Accepted:** 08.07.2023

Abstract

The treatment of tannery wastewater in the Common Effluent Treatment Plants (CETPs), Effluent Treatment Plants (ETPs) and Pre-treatment plants in individual tanneries, generates significant volume of tannery sludge in the present time. The sludge is generated by the primary treatment as chemical sludge and secondary treatment as bio-sludge. Due to the presence of chromium, the chemical sludge produced by the primary treatment must be disposed of in a secure landfill system. As a result, when the sludge is sent to the landfill system, the moisture content must be decreased to the extent possible in a sustainable way for reducing the disposal cost. A lab scale solar dryer has been fabricated and experiments were carried out for the reduction of moisture content. The chemical and bio-sludge from CETP treating the tannery wastewater was collected for the study. Sludge dewatering has been studied and samples were kept inside and outside solar dryer to compare the performances. From the results, it was found that the bio-sludge kept inside solar dryer showed better performance comparing with the chemical sludge. It is also noticed that the bio-sludge having slightly higher drying rate than chemical sludge as the bio-sludge is rich in organic and porous which circulate the generated heat inside the sun dryer over the surface of the sludge particles, reducing their moisture content.

Keywords: Solar dryer, tannery sludge, CETP, dewatering

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DOI: 10.31838/ecb/2023.12.6.161

1. Introduction

In recent years, an extensive research has been conducted on the benefits of renewable energy resources. Sunlight is a clean source of energy, but only a small part of this energy is used by humans [1–3]. The sun is the largest available carbon-free energy resource for human being. Many investigations have been conducted to learn how to harvest and apply solar energy as a primary source of energy [4, 5]. Governments and industries all around the world are contemplating different ways to prevent and reduce greenhouse gas emissions in their activities and operations. Therefore, many sustainable renewable energy systems are installed and used to replace fossil fuels. In these methods, solar energy has been in focus because it is the most promising energy source and has many advantages compared with other kinds of renewable energy sources. Solar energy causes no or little negative effect on the environment and hence, it is considered as one of the main energy sources now and in the future, it’s use is expected to increase manifold. Solar drying is particularly applicable in countries located on the sunny belt of the Earth, i.e., in regions where the sun radiation is high and the duration of sunshine is long [6]. The first use of solar energy for drying purposes dated back to 8000 B.C.; the first solar drying equipment was found in south of France. However, the conventional drying industry started around the 18th century [7]. A lot of studies have been done on sludge drying [5]. The proper use of solar energy should be carefully monitored to improve efficiency and minimize the processing time of the drying system [7]. 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). Solar drying systems is recognized as direct, indirect, and mixed mode forms [8]. The thermal efficiency has been significantly increased by embedding the fins into the air passage of the dryer [9]. The efficiency of the solar drying system can be varied 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 [10].

The solar drying system is usually used for low and medium heat [10], 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 [11, 12].

Drying is defined as the process of removing the moisture from a product and can be implemented in two stages. In the first stage, the moisture inside the product is brought to the surface and dried in air at a constant rate as water vapor. The second stage involves a slow drying rate, and its process is related to the properties of the material to be dried [13, 14]. Drying of different materials, namely, gases, liquids, or solids, can be accomplished by different methods. Solar drying in agriculture, especially in the rural areas in developing countries, is not an option but a necessity because most of these areas do not have access to grid-connected electricity and cannot afford fuel for heaters to provide warm air for drying crops. In such areas, drying methods that employ heaters and fans are not appropriate because of high-energy consumption. Energy consumption is one of the most important considerations in the drying systems [15]. Energy consumption always depends on the type of products to be dried. The use of conventional dryers results in high energy consumption and monetary burden. One disadvantage of solar drying is that solar energy, when used as the only source of energy for drying, is not always available.

Thus, hybrid solar dryers, wherein solar energy is combined with other sources of energy, such as fossil fuel, biomass solid fuel, and electrical energy, are used as an alternative solar energy source to address the above-mentioned disadvantage. Drying can be performed using chemical desiccants, by chemical decomposition of the moisture in the stuff, or by freezing using liquids and solids. It can also be performed mechanically by compression, gravity, or centrifugal forces. Preliminary, physicochemical, and biological treatment are all included in the wastewater treatment plants. Primary and secondary sludge from the physical-chemical and biological treatments are combined, dewatered using mechanical centrifugation, and dried in a composting facility [16]. The remaining sludge is subsequently dumped in a landfill. Without being composted, the filtered materials and the sand that is collected throughout the process are sent to the landfill [17, 18]. In leather processing, Basic chromium sulphate (BCS), a trivalent chromium salt [19], is used in leather tanning process which has the significant impact on the environment if it is not properly treated and managed. During treatment of tannery wastewater using physico-chemical treatment, chromium present in the wastewater is precipitated along with other suspended solids in primary sludge. Hence the sludge is considered as hazardous wastes which need to be disposed in hazardous waste landfill or any other safe methods directed by the regulatory authorities. The transport, treatment and disposal cost of this hazardous waste is based on weight basis and hence the moisture content in the sludge plays significant role in arriving at cost of disposal cost. Hence, in this current research, an innovative solar dryer has been designed, fabricated and experimented for the removal of moisture content in the tannery chemical sludge and bio-sludge.

2. Materials and Methods

2.1 Lab Scale Solar drying setup

The lab scale solar drying system of size 4 x 1.5 m is fabricated with metal tubes as structural material. A 6.0 mm thick double wall transparent polycarbonate sheet had been used as the transparent material. The floor is painted black on the surface and is insulated at the bottom using an insulated sheet. The insulted sheet acts as resistant material by avoiding the heat dissipation and the black colour absorb the heat and release in the later stage. The solar dryer has four sensors to measure the temperature and humidity at different locations. The atmosphere's temperature and humidity were measured using a weather meter. The atmospheric solar radiation data is obtained from the weather using pyranometer (Kipp and Zonen model).

In order to eliminate the water vapour that is produced during the process of sludge drying, an exhaust arrangement was also added which would speed up the drying process. The detailed specification of the transparent sheet used for the study is given in table below.

Table 1: Specifications of Polycarbonate Sheet

Parameters	Values
Sheet Width	1220 mm
Weight (Kg/m^2)	1.3
Light Transmission	Clear – 80%
Heat Transfer Co-Efficient (U Value)	3.5 W/m^2 ^{o}K
Thermal Expansion	0.65 mm/m ^{o}C
Possible Heat and Moisture Expansion	3 mm/m
Maximum service temperature	120 ^{o}C
Structure	Multi Wall

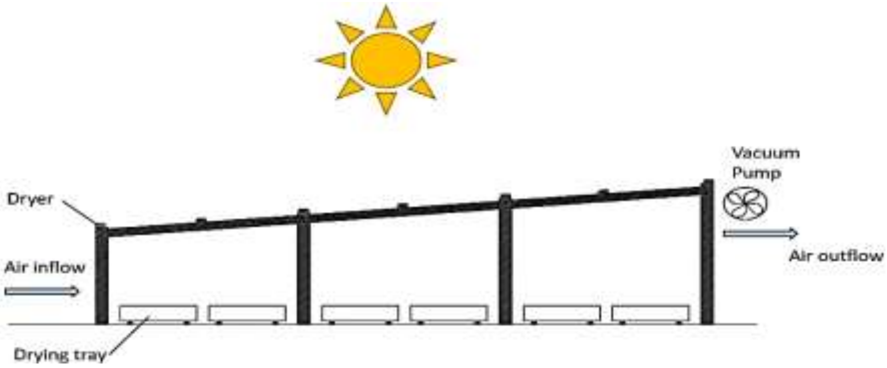

Fig 1. Layout of the Solar dryer

2.2 Drying Trays and filtering media:
The experiment was carried out using a 225 (L) x 225 (W) x 340 (H) mm aluminium tin. The tin is filled to a depth of 50 mm with sand, 50mm depth of 20 mm gravel and 100mm depth of 75 mm gravel, respectively. These packed materials act as sludge filtering media. The sludge layer is kept for a depth of 150 mm above the filtering media in the aluminum tin.

2.3 Tannery Sludge:
The chemical sludge generated from the primary treatment of the common effluent treatment plant treating tannery waste water in Chennai was used in this study. Similarly, the excess bio-sludge was collected from the aeration tank of the same treatment facility. Currently, the tannery sludges are disposed in the secure landfill system or sent to cement industries for co-processing as per the directions of the regulatory authorities.

Fig 2. Experimental set-up of

2.4 Moisture analysis method
The moisture is measured using the moisture analyser – Radwag Mac 110. The results are also confirmed analyzing using AAPHA standards.

3. Results and Discussion

3.1 Variation of temperature and humidity with time in solar dryer

During the study period, the solar dryer's daily ambient temperature in a typical day was recorded in the range of 28 to 34°C outside solar dryer whereas the temperature inside the solar dryer ranged from 30 to 58°C, making it clearly evident that the highest temperature of 58°C has been achieved. It was found that the average daily solar radiation (intensity) during the study period was about 340 W/m^2. The weather factors, such as sun radiation intensity, air temperature, and relative humidity, play a major role in drying process of tannery sludge used in the study and these data were collected over a drying period. Fig 3 and 4 shows the profile of temperature and humidity data for a typical day.

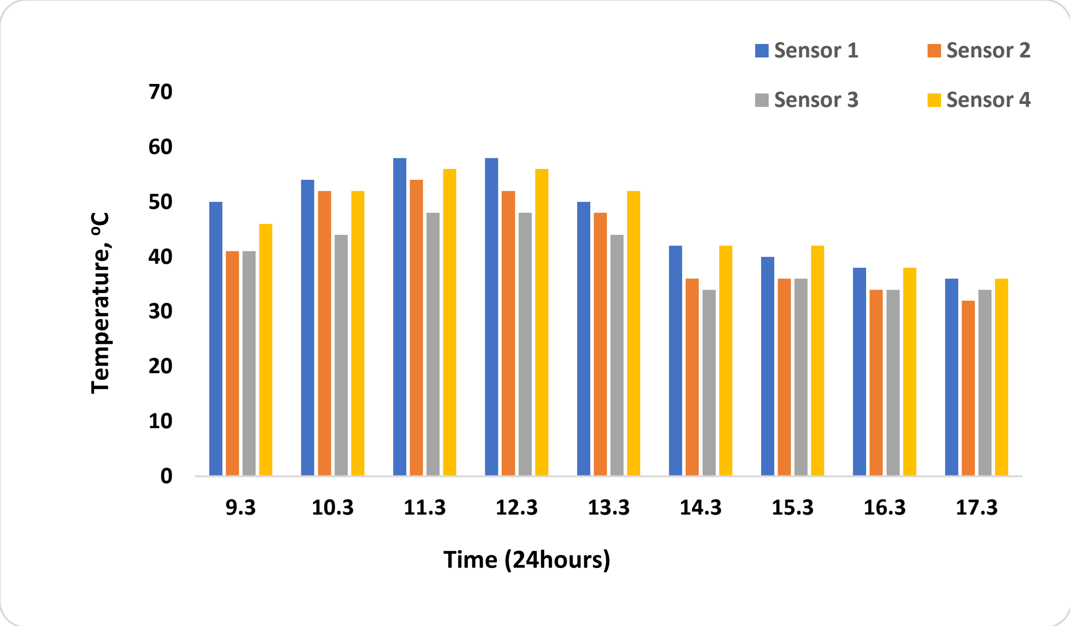

Fig 3. Temperature profile with time in solar dryer

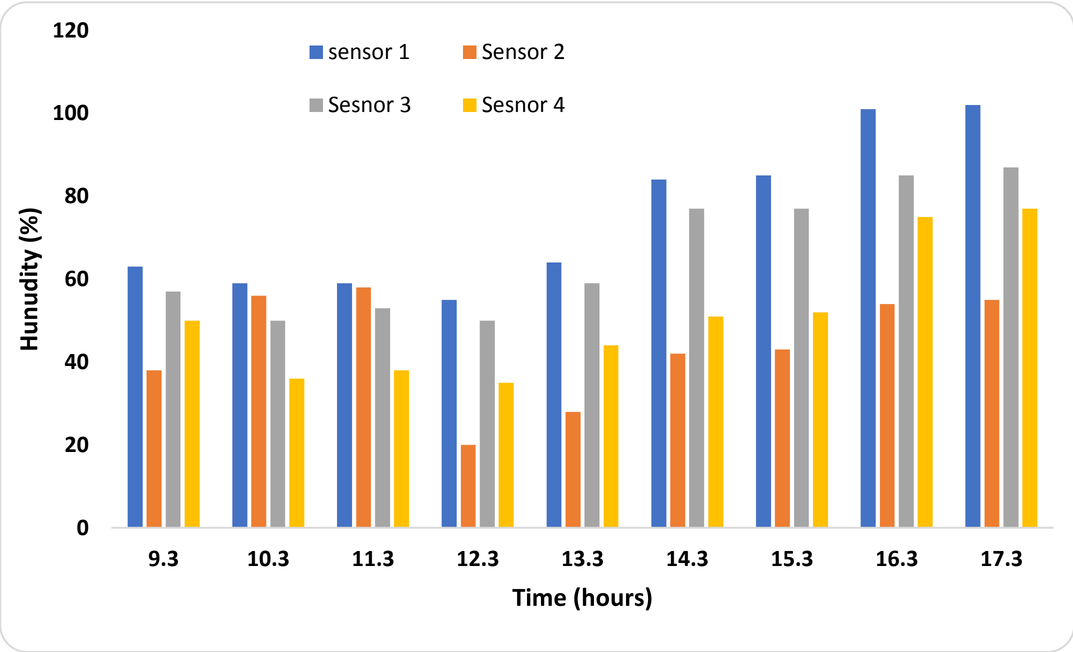

Fig 4. Humidity profile with time in solar dryer

3.2 Tannery sludge drying in solar dryer

Sludge samples were collected from the drying tins every day and moisture content of samples were determined. Fig.5 illustrates the solar drying data over a period of 18-day experimental investigation conducted with chemical sludge. From the Fig.5, it clear that the sludge samples kept within the solar dryer showed effective for removal of moisture when compared to the sludge kept outside the solar dryer. Moisture removal rate in the sludge sample kept inside the solar dryer showed 32.3% higher than the sludge sample kept outside for chemical sludge.

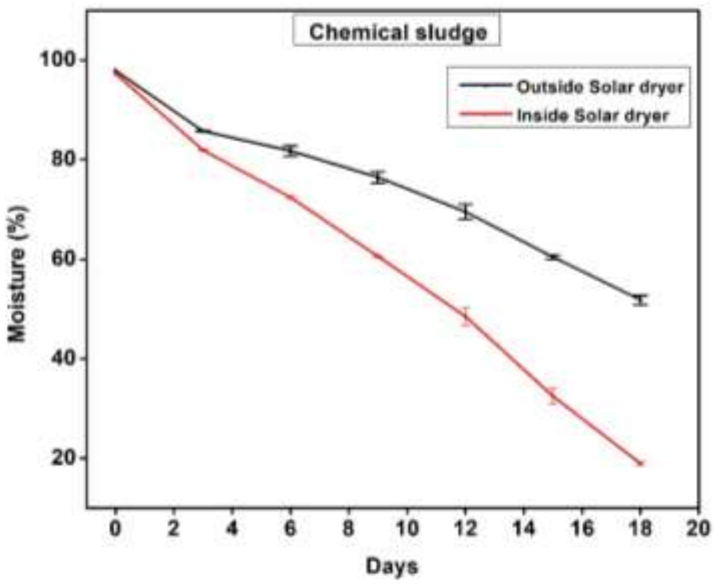

Fig 5. Reduction of moisture content with time for chemical sludge

Similarly, the bio-sludge generated during the secondary treatment is also needs to be dried before disposing it to the landfill system. Moisture removal rate in the sludge sample kept inside the solar dryer showed 36.6% higher than the sludge sample kept outside for bio-sludge. The tannery bio-sludge drying results are shown in Fig. 6.

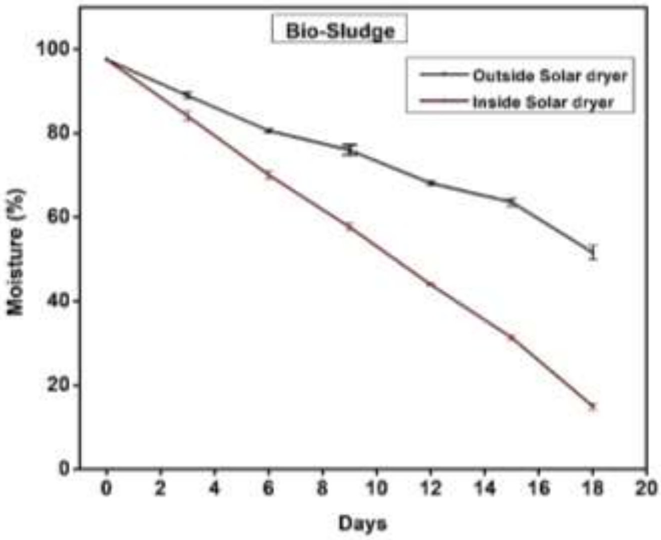

Fig 6. Reduction of moisture content with time for bio-sludge

Air within the solar dryer is mixed by forced draught fans and circulated by exhaust fans, the drying rate is also increased where the ventilation is significantly more effective (per unit of air output) than air mixing. It is also observed that the bio-sludge has higher drying rate comparing with the chemical sludge which is due to the presence of organic content in the bio-sludge [20]. The moisture distribution and removal follows the order: Free moisture that can be eliminated by gravitational settling through the filter media kept inside the tin but is not bonded to the sludge particles, surface moisture that is adhered to the surface particles and maintained there by adsorption, interstitial moisture that can be extracted mechanically using strong forces from the dewatered cake's capillaries or trapped inside solid flocs and moisture that is chemically and intracellularly bonded [21].

In the experiment, it is observed that once the sludge begins to dry, tiny cracks are gradually appeared on the surface which become larger as the drying progresses, this period of time appears as an approximately constant speed [22–24]. When the surface of the sludge is still wet, the cracks can appear in places with defects on the surface or low local moisture content because of having fast water loss in these two places, which cause local shrinkage of the sludge surface to produce cracks. The cracks cause the sludge to crack at the sludge cracks and in the vicinity of the cracks and the water to evaporate faster, and so the cracks become larger. However, the increase of the cracks has almost negligible effect on the drying rate of the sludge, and so the drying rate still shows a downward trend [25].

In case of chemical sludge, during experimentation it is observed that the formation of microscopic surface cracks which would gradually form and get wider as drying advances. This drying process appeared to occur at a speed that is approximately constant over time. As the sludge's surface is still wet, cracks may form in areas with surface flaws or low local moisture content due to rapid water loss in these areas, which results in local shrinkage of the sludge surface and cracking. The water evaporates more quickly due to the fractures, which leads to the sludge cracking at the sludge cracks and around the cracks. The drying rate of the sludge still indicates a decreasing trend, despite the fact that the rise in cracks has a very small impact on it. But, for the sludge kept outside the solar dryer, the cracks are very minor.

But in case of bio-sludge, the crack formation is very little and at the end of drying stage it became like texture of sand [26, 27].

Fig 7. Dried Sludge with cracks

3.3 Additional advantages of solar dryer

The solar drying method is also led to partial sludge sanitization in addition to water evaporation. The solar drying process with higher solar radiation may remove the microbe fully. The partial sludge disinfection in this case may be attributed to the microorganisms' exposure to solar UV radiation, raised sludge temperatures, and concurrently decreased sludge moisture content [28]. In addition, during monsoon seasons, the closed solar dryer proposed n this study can be effectively used compared open sludge drying beds.

4. Conclusion

The chemical and biological sludge produced by the tannery operations was exposed to solar dryer experiments in the current study. The sludge produced in CETPs must be disposed of according to current regulatory standards in a secure landfill system on weight basis. The sludge's moisture content was significantly reduced which would reduce the disposal cost of sludge that needs to be disposed in SLF system and cement industries. This helps to reduce the overall treatment cost of CETP and also it can be effectively used during monsoon.

Acknowledgement

The authors acknowledge Director, CSIR – Central Leather Research Institute, Chennai for providing support for this research activity.

5. References

1. Baviskar VS, Salunkhe DB, Nikam CP, et al (2022) Simple and low-cost Cu2S/TiO2 architecture for 3G ETA solar cell: Fabrication, characterization and their performance. Nano-Structures and Nano-Objects 32:. https://doi.org/10.1016/j.nanoso.2022.100919
2. Von Zabeltitz C (1994) Effective use of renewable energies for greenhouse heating. Renew Energy 5:479–485. https://doi.org/10.1016/0960-1481(94)90419-7

3. Raj A, Sharma V (2023) Case studies: An insight into green energy resources, infrastructure, economies, energy schemes, and sustainability in India. Bionanotechnol Towar Green Energy Innov Sustain Approach 295–317. https://doi.org/10.1201/9781003316374-15
4. Barlev D, Vidu R, Stroeve P (2011) Innovation in concentrated solar power. Sol Energy Mater Sol Cells 95:2703–2725. https://doi.org/10.1016/j.solmat.2011.05.020
5. Aboltins A, Palabinskis J (2011) Investigations of Heating Process and Absorber Materials in Air Heating Collector. Proc World Renew Energy Congr – Sweden, 8–13 May, 2011, Linköping, Sweden 57:3991–3998. https://doi.org/10.3384/ecp1105739 91
6. Di Fraia S, Massarotti N, Vanoli L (2018) A novel energy assessment of urban wastewater treatment plants. Energy Convers Manag 163:304–313. https://doi.org/10.1016/j.enconman.2018.02.058
7. 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. Sol Energy 159:722–732. https://doi.org/10.1016/j.solener.2017.11.032
8. Kumar M, Sansaniwal SK, Khatak P (2016) Progress in solar dryers for drying various commodities. Renew Sustain Energy Rev 55:346–360. https://doi.org/10.1016/j.rser.2015.10.158
9. Garg HP, Datta G, Bhargava AK (1989) Performance studies on a finned-air heater. Energy 14:87–92. https://doi.org/10.1016/0360-5442(89)90082-0
10. Husham Abdulmalek S, Khalaji Assadi M, Al-Kayiem HH, Gitan AA (2018) A comparative analysis on the uniformity enhancement methods of solar thermal drying. Energy 148:1103–1115. https://doi.org/10.1016/j.energy.2018.01.060
11. Karaca G, Dolgun EC, Kosan M, Aktas M (2019) Photovoltaic-Thermal solar energy system design for dairy industry. J Energy Syst 3:86–95. https://doi.org/10.30521/jes.565174
12. Pirasteh G, Saidur R, Rahman SMA, Rahim NA (2014) A review on development of solar drying applications. Renew Sustain Energy Rev 31:133–148. https://doi.org/10.1016/j.rser.2013.11.052
13. El-Sebaii AA, Shalaby SM (2012) Solar drying of agricultural products: A review. Renew Sustain Energy Rev 16:37–43. https://doi.org/10.1016/j.rser.2011.07.134
14. Ekechukwu O V. (1999) Review of solar-energy drying systems I: An overview of drying principles and theory. Energy Convers Manag 40:593–613. https://doi.org/10.1016/S0196-8904(98)00092-2
15. Motevali A, Minaei S, Khoshtagaza MH (2011) Evaluation of energy consumption in different drying methods. Energy Convers Manag 52:1192–1199. https://doi.org/10.1016/j.enconman.2010.09.014
16. Zhao J, Wu Q, Tang Y, et al (2022) Tannery wastewater treatment: conventional and promising processes, an updated 20-year review. J Leather Sci Eng 4:.

https://doi.org/10.1186/s42825-022-00082-7
17. Bharagava RN, Saxena G, Mulla SI, Patel DK (2018) Characterization and Identification of Recalcitrant Organic Pollutants (ROPs) in Tannery Wastewater and Its Phytotoxicity Evaluation for Environmental Safety. Arch Environ Contam Toxicol 75:259–272. https://doi.org/10.1007/s00244-017-0490-x
18. Pathe PP, Suresh Kumar M, Kharwade MR, Kaul SN (2004) Common Effluent Treatment Plant (CEPT) for wastewater management from a cluster of small scale tanneries. Environ Technol 25:555–563. https://doi.org/10.1080/09593332608618562c
19. Puchana-Rosero MJ, Lima EC, Mella B, et al (2018) A coagulation-flocculation process combined with adsorption using activated carbon obtained from sludge for dye removal from tannery wastewater. J Chil Chem Soc 63:3867–3874. https://doi.org/10.4067/s0717-97072018000103867
20. Masmoudi A, Ben Sik Ali A, Dhaouadi H, Mhiri H (2021) Draining solar drying of sewage sludge: Experimental study and modeling. Environ Prog Sustain Energy 40:1–12. https://doi.org/10.1002/ep.13499
21. Bennamoun L (2012) Solar drying of wastewater sludge: A review. Renew Sustain Energy Rev 16:1061–1073. https://doi.org/10.1016/j.rser.2011.10.005
22. An-nori A, Ezzariai A, El Mejahed K, et al (2022) Solar Drying as an Eco-Friendly Technology for Sewage Sludge Stabilization: Assessment of Micropollutant Behavior, Pathogen Removal, and Agronomic Value. Front Environ Sci 10:. https://doi.org/10.3389/fenvs.2022.814590
23. Wzorek M (2021) Solar drying of granulated waste blends for dry biofuel production. Environ Sci Pollut Res 28:34290–34299. https://doi.org/10.1007/s11356-021-12848-3
24. Bok A (2017) Advantages and disadvantages of the solar drying of sewage sludge in Poland. Czas Tech 171–179. https://doi.org/10.4467/2353737xct.17.217.7760
25. Osvaldo Garanto (2016) Solar Sludge Drying Technology and Dried Sludge as Renewable Energy—Closing the Loop. J Traffic Transp Eng 4:. https://doi.org/10.17265/2328-2142/2016.04.005
26. Ficza I (2010) Matematical Model of Solar Drying of Sewage Sludge. 63
27. Afshari F, Khanlari A, Tuncer AD, et al (2021) Dehumidification of sewage sludge using quonset solar tunnel dryer: An experimental and numerical approach. Renew Energy 171:784–798. https://doi.org/10.1016/j.renene.2021.02.158
28. Mathioudakis VL, Kapagiannidis AG, Athanasoulia E, et al (2009) Extended Dewatering of Sewage Sludge in Solar Drying Plants. Desalination 248:733–739. https://doi.org/10.1016/j.desal.2009.01.011