International Journal of Applied Engineering Research ISSN 0973-4562 Volume 18, Number 4 (2023) pp. 273-277
© Research India Publications. https://dx.doi.org/10.37622/IJAER/18.4.2023.273-277

Experimental studies on accelerated solar evaporation of municipal solid waste leachate

V. Veeravel[1,2], G. Kumaresan[3], S.V. Srinivasan[1]*

[1]Environmental Engineering Department, CSIR - Central Leather Research Institute,Chennai – 600020, India

[2]University of Madras, Chepauk, Chennai – 600 005, India

[3]Institute of Energy Studies, Department of Mechanical Engineering, Anna University, Chennai – 600025, India

*(*Corresponding author E-mail ID: srinivasansv@yahoo.com)*

Abstract

Solar evaporation is one of widely accepted concept for treatment and disposal of different solids as well as liquid wastes generated from domestic and industries by replacing conventional treatment and disposal methods. This solar evaporation has several advantages like low cost, minimization of secondary pollutants and residues etc. Municipal solid wastes (MSW) generated is also disposed in open dumps or landfills, which leads to generation of leachate and contaminates the nearby land, ground water and water bodies depending on the location conditions in addition to public health issues. This research mainly focuses on accelerated solar dryer for management of leachate generated from municipal solid waste landfill which could be efficiently used for all seasons and reduce the evaporation time. In this study, leachate evaporation using solar dryer has been experimented. From the results, it is observed that the daily average temperature between from 9 AM to 5 PM has increased inside solar dryer compared ambient temperature outside solar dryer. Results from the evaporation studies with leachate showed that the volume of leachate reduced by 5-fold within 16 days of experimental period. This reduction of volume of leachate and subsequent disposal along with organic fractions of MSW in composting and anerobic digestion, ensures sustainable management of leachate and reducing the impact of leachate on public health. This sustainable approach of MSW leachate with accelerated solar is cost effective and environmentally friendly and addresses the Sustainable Development Goals (SDGs) like Good health and wellbeing (SDG4), Clean water and Sanitation (SDG6) and Sustainable cities and communities (SDG11).

Keywords: Solar evaporation, solar dryer, MSW leachate, leachate treatment, drying rate

1.0 Introduction

India is situated in the tropical zone of the earth receiving considerable amount of solar radiation (4 to 7 kWh) almost through the year (upto 300 days). The global radiation varies from 1600 to 2200 kWh/hr per annum (Arjunan 2009). Hence, solar based energy, heating, drying etc has a significant application in Indian domestic and industrial sectors with benefits like low operational cost and excellent performance. The foremost concern in its acceptance are absence of continuous supply, more capital intensive initial cost and seasonal variations and land constrains (Reddy and Painuly 2004; Davies 2016). Use of solar energy is a having potential application for moisture removal in solid wastes and evaporation of concentrated saline or organic wastewater. Drying of foods, agricultural products, saline liquor and sludge's using solar energy are carried by open solar drying (Pawale et al. 2015). This method is the cheapest and economical option, but it is a labor-intensive process, requires larger area, slower drying rate and not suitable for monsoon season. Various types of open sun drying are specified based on the location, method of processing or solar radiation utilization method. Based on the economics, solar drying is a feasible alternative (Roopa et al. 2019).

Due to population growth and urbanization, the municipal solid waste generation is also increasing considerably both in rural and urban areas. However, due to non-segregation of organic and other recyclable wastes, the mixed MSW generated is collected and disposed in open dumping's leading to contamination of land and ground water in the vicinity of dump sites. Due to presence of high moisture content, the management of MSW through thermal waste to energy technologies has become difficult tasks even in the developed and developing countries.

In addition, urban local bodies are not able to provide adequate infrastructure for safe treatment and disposal of segregated wastes and also scientifically designed landfill due to financial constraints. Hence, the most popular and secure technique for disposing of solid wastes at the moment is the disposal of municipal and industrial waste in landfills. These landfill creates environmental and public health issues in terms of odour problem, leachate generation and greenhouse gas emissions (Goulette 2000; Glawe et al. 2005; Ngoc and Schnitzer 2009; Tun and Juchelková 2018). But the main issues with municipal solid waste disposal via the land filling approach leads to generation of substantial volume of leachate (Naveen et al. 2013). This landfill leachate creates public nuisance and lead to breeding place for mosquitoes, fly and rodent nuisance and lead to unhygienic conditions in and around the landfill and dump sites. Generally, landfills go through at least four stages of decomposition: (a) an initial aerobic phase, (b) an anaerobic acid phase, (c) an initial methanogenic phase, and (d) a stable methanogenic phase(Christensen et al. 2001). The rate of oxygen penetration into the landfill may outpace the rate of microbial oxygen depletion once the waste has been thoroughly broken down. The anaerobic landfill is therefore predicted to transition into an aerobic habitat over time. Each site has different seasonal and site-specific leachate properties, including pH, BOD, COD, ammonia, microbes, heavy metals, and phosphate(Mojiri et al. 2021). Hence, it is very difficult to implement a treatment and disposal strategy for leachate as it contains very complex contaminants. The conventional methods followed are solar evaporation using open pans and in very few cases expensive disk and plate type membrane system are implemented. Hence, there is need to develop an economical, effective and sustainable process for treatment and disposal of leachate. In this study, the experimental studies have been investigated for reducing the volume of the leachate using closed accelerated solar dryer by evaporation of leachate and to improve the public hygiene and health in the area.

2.0 Materials and Methods

A lab scale solar dyer has been designed with size of 1.5 m x 4.0 m and fabricated with Mild Steel tubes as structural support. Polycarbonate sheet of 6 mm double wall was used as transparent material to accumulate the heat inside the solar dryer as shown in Fig.1. Six temperature and humidity sensors are placed inside the solar dryer in order to monitor the temperature and humidity inside the solar dryer. The temperature and humidity were monitored from 9 AM to 5 PM during the study period. Similarly, the outside ambient temperature was measured using weather meter (Kestrel 5500 Weather Meter).

The leachate for the study was collected from the Perungudi municipal solid waste (MSW) dumpsite. The characterization of the leachate in terms of main parameters like pH, Chemical Oxygen Demand (COD) and Total Dissolved Solids (TDS) were analyzed using AAPHA standards.

Leachate samples were kept in plastic trays and evaporated inside the solar dryer to evaluate the efficiency of evaporation inside the dryer. The performance of the leachate evaporation was monitored on daily basis by measuring the weight of leachate in the dryer at the end of each day at 5 PM.

One exhaust fan has been installed in the solar dryer to remove the moisturized air during the solar drying. This would increase the efficiency of the solar dryer (Gallali et al. 2000). Inside solar dryer, the other parameters such temperature and humidity were also monitored.

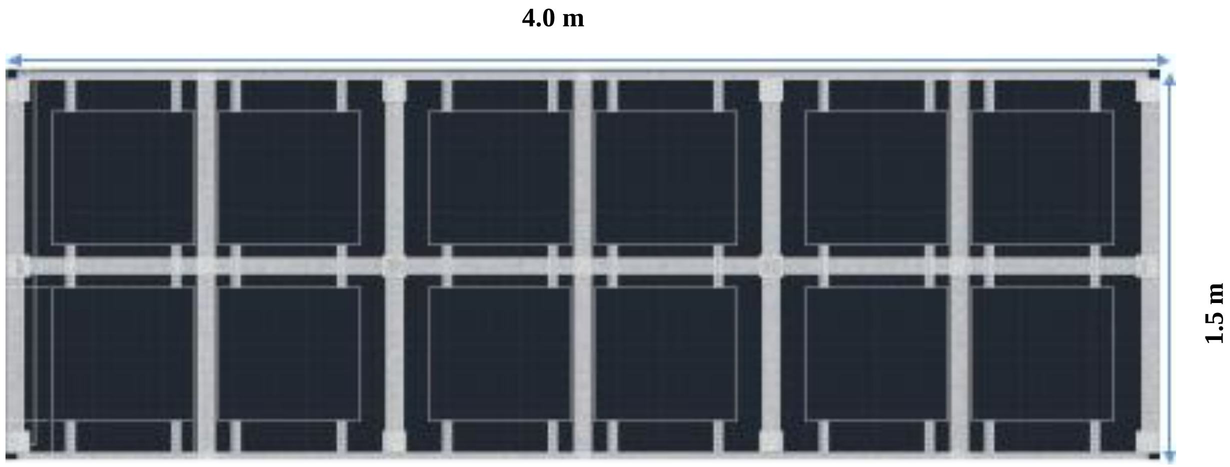

Fig. 1 Layout of the drying area

4.0 Results and Discussion

4.1 Characteristics of Leachate from Municipal Solid Waste (MSW) site

The evaporation of the MSW leachate is used to reduce the volume of leachate for further disposal so as to reduce the impact on public health. The characteristics of leachate collected from Perungudi municipal solid waste site is given in Table 1.

Table 1: Characteristics of Leachate from MSW

Parameters	Perungudi MSW site
pH	7.9
Total solids (TS)	1207
Total Dissolved Solids (TDS)	754
Chemical Oxygen Demand (COD)	1962

All values are given in mg/L except pH.

From the Table 1, it is observed that pH is found in the alkaline range with considerable COD and TDS. It is reported that the organics present in terms of COD is found to be in the medium range high, but still the leachate generated should be treated in a sustainable manner (Rajendiran et al. 2022, 2023). It is reported that the organics present in leachate is very complex in nature and the conventional treatment of leachate is very difficult.

4.2 Temperature profiles inside and outside solar dryer

The temperature profile inside and outside of solar dryer has been monitored and shown in Fig 2. It is observed that the temperature inside the solar dryer is higher than the ambient temperature outside solar dryer. This higher temperature inside the solar dryer would increase the evaporation rate of leachate inside the solar dryer. This results in accumulation of the humidified air inside the solar dryer, which could be easily removed with the installed exhaust system. This would accelerate and improve the evaporation efficiency of the solar dryer. The amount of water that may be removed from a surface as vapor varies on the environment inside solar dryer, including airflow direction and speed, surface area, ambient temperature and humidity.

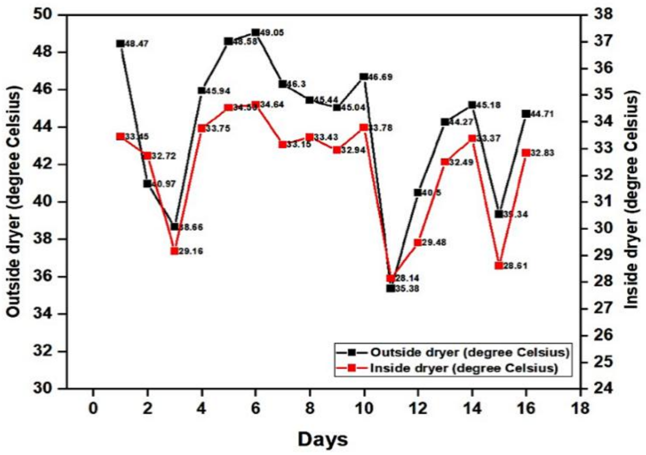

Fig. 2 Temperature profile inside and outside of solar dryer during the experimental period

The temperature is the main factor which affects the evaporation efficiency of the solar dryer. The temperature inside the solar dryer act as a driving force to remove the water present in the leachate. However, the water vapour inside the solar dryer has to be removed using the exhaust systems to increase the efficiency (Poblete et al. 2016; Moyo et al. 2018).

4.3 Evaporation of Leachate from Municipal Solid Waste (MSW)

It is reported that the presence of higher TS content in the waste results in higher evaporation rate (Colin 2008; Sandali et al. 2019). Due to solar drying, the final TS concentration of the leachate increased by 5 times (6000 mg/L) from the initial TS content (1207 mg/L) as shown in Fig 3. Similarly, the other parameters such as COD also would have increased at the end of solar drying which showed the leachate is in concentrated form with considerable volume reduction of five-fold. Reduced volume and concentrated leachate could be disposed along with other organic fractions of solid waste treatment during composting or anaerobic digestion. It was also observed that after end of solar radiation in a day, subsequently further drying would proceed to certain extend and it would be completely stopped during the mid-night. However, exhaust system provided ensures that the water vapours were completely removed from solar dryer otherwise during late night hours, the water vapour evaporated from the leachate would condensate again inside the solar dryer (Bouraoui and Ben Nejma 2020).

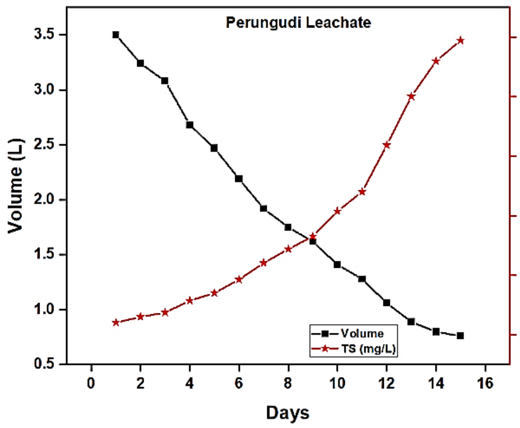

Fig.3 Drying of leachate from MSW site

Leachate will typically be dried using heat in three phases i.e., a constant rate of drying phase, a first falling rate period, and a second falling rate period. Free water is eliminated during the constant drying rate interval (Bennamoun 2012). The interstitial water is said to be removed during the first falling rate interval, while the surface water is reportedly removed during the second falling rate period (Tun and Juchelková 2019). Depending on the kind of leachate characteristics and the drying conditions, the ultimate moisture content in the leachate is primarily chemically bonded water. A moist zone, sticky zone and eventually agglomeration would be the physical characteristics of the total solids contents dependent on the solids concentration, in addition to differences in moisture content and drying rates. From the present studies, it was calculated that 2.74 kg of water was removed in 16 days. Hence, the average drying rate is calculated by using the formula:

Average drying rate = M(w) / (T(d) x S)

where M(w) denotes the mass of water removed in Kg, T(d) denotes the time taken by solar to remove the mass of waste in hours and S is surface area of the trays in m^2. For the current study, the average drying rate is found to be 0.113 $Kg_{(water\ removed)}.m^{-2}h^{-1}$. Similar results were reported by many researchers who have carried the experiments using the liquid waste. However, for drying of solid wastes, the average drying rate reported is more than 0.4 $Kg_{(water\ removed)}.m^{-2}h^{-1}$. In addition, the other advantage of this solar drying is destruction of pathogens or pasteurization of the leachates due to high temperature as high as 70°C being generated during peak solar radiation at mid noon of the day. Hence, after solar drying, concentrated leachate would be free from pathogens and handling of concentrated leachate would become easy (Meierhofer and Landolt 2009).

Conclusion

From the results of this study, it is concluded that the use of closed solar dryer has accelerated and improved the evaporation rate of the MSW leachate. The study would help the municipalities and urban bodies in adopting these solar drying methods for effective management of leachate with reduced volume in concentrated form and pathogen free which could be treated and disposed along with other organic fractions of solid waste like composting or anaerobic digestion. This closed solar dryer also ensures effective utilization during the rainy seasons. Based on the outcome of lab scale studies, a pilot plant could also be designed and implemented in future for effective management of leachate and to reduce the impact on public health. The outcome of this study also addresses the UN Sustainable development goals (SDG4, SDG6 and SDG11) and National Missions (Swachh Bharat and Smart city).

Acknowledgement

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

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