WATER RESEARCH 82 (2015) 47–57

Available online at www.sciencedirect.com

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journal homepage: www.elsevier.com/locate/watres

Evaluation of solar sludge drying alternatives by costs and area requirements

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ARTICLE INFO

Article history:
Received 31 January 2015
Received in revised form
24 April 2015
Accepted 24 April 2015
Available online 12 May 2015

Keywords:
Drying cost
Greenhouse solar dryer
Sludge drying
Solar panel
Optimization
Thermal dryer

ABSTRACT

Thermal drying is a common method to reach above 90% dry solids content (DS) in sludge. However, thermal drying requires high amount of energy and can be expensive. A greenhouse solar dryer (GSD) can be a cost-effective substitute if the drying performance, which is typically 70% DS, can be increased by additional heat. In this study feasibility of GSD supported with solar panels is evaluated as an alternative to thermal dryers to reach 90% DS. Evaluations are based on capital and O&M costs as well as area requirements for 37 wastewater treatment plants (WWTPs) with various sludge production rates. Costs for the supported GSD system are compared to that of conventional and co-generation thermal dryers. To calculate the optimal costs associated with the drying system, an optimization model was developed in which area limitation was a constraint. Results showed that total cost was minimum when the DS in the GSD ($DS_{m,i}$) was equal to the maximum attainable value (70% DS). On average, 58% of the total cost and 38% of total required area were associated with the GSD. Variations in costs for 37 WWTPs were due to differences in initial DS ($DS_{i,i}$) and sludge production rates, indicating the importance of dewatering to lower drying costs. For large plants, GSD supported with solar panels provided savings in total costs especially in long term when compared to conventional and co-generation thermal dryers.

1. Introduction

Today, 53% of sewage sludge produced in Europe is reused in agricultural applications, while 21% is incinerated (Escala et al., 2013). Despite this overall delineation, there are some countries that almost entirely use sludge in incineration such as the Netherlands and Switzerland (PURE, 2012). Yet, high water content of sludge may constitute a limitation for its beneficial use (Chai, 2007). Current legislations and good practices restrict DS of sludge for different beneficial sludge management options. According to Madlool et al. (2011) and Mokrzycki and Uliasz- Bochenczyk (2003), alternative fuel sources should have lesser than 20% water content. Sewage sludge should contain high DS in order to enhance combustion efficiency, provide safe operation and reduce emissions during combustion (Chai, 2007). Meanwhile, high DS is essential to meet the criteria in regulations relevant to sewage sludge landfilling and reduces transportation costs of sludge to agricultural lands (Chai, 2007; Bux and Baumann, 2003). In Turkey, the Landfill Directive of EU is adopted and this regulation (MoEF, 2010a) restricts sludge disposal into landfills unless DS is greater than 50%. According to the regulation on the use of domestic and urban wastewater treatment sludge

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http://dx.doi.org/10.1016/j.watres.2015.04.043
0043-1354/

on land (MoEF, 2010b), a WWTP serving a population equivalent higher than one million has to dry its waste sludge at least to 90% DS. In the EU proposed regulation on sludge (Working Document on Sludge 3rd Draft, 2000), one of the advanced treatment options is listed as thermal drying which requires the temperature of the sludge particles to be higher than 80 °C with a reduction of water content to less than 10%. These regulations as well as disadvantages caused by high water content of sludge in its beneficial usages enforce WWTP operators to dry waste sludge.

While thickening and dewatering can remove 7% and 35% of the total amount of water, respectively, drying can remove up to 62% additional water content if applied in succession (Flaga, 2007). Transportation, storage, packaging and retailing are easy and cost efficient for dried sludge. Drying increases the calorific value of sludge. Thereby, sludge can be incinerated without auxiliary fuel. Moreover, its potential as an alternative fuel in cement factories improves. Dried sludge is also beneficial for agricultural purposes (Stasta et al., 2006). Drying makes sludge hygienic (without pathogenic organism), improves sludge structure and increases its market value (Flaga, 2007; Chen et al., 2002). Yet, sludge drying can be an energy intensive process.

Two commonly used drying techniques to obtain higher than 50% DS are thermal and solar drying. Thermal drying can provide up to 95% DS (Mujumdar and Zhonghua, 2008). Generally fossil fuels are used to heat the drying surface or drying air (Flaga, 2007; Fonda and Lynch, 2009). Emissions and high energy cost constitute disadvantages of a thermal dryer. Typically, required energy is 2627 kJ/kg-biosolid or 2595 kJ/kg-water (0.72 kW/kg-water) for sludge drying (Fonda and Lynch, 2009; Lowe, 1995). There are two basic problems in using a thermal dryer. The first one is the sticky phase of the sludge and the second one is the risk of ignition and burning of sludge during drying process (Flaga, 2007; Malhotra, 1989).

Solar drying is becoming a popular option to replace mechanical thermal dryers (Mathioudakis et al., 2013). Solar drying uses renewable energy and applicable in many parts of the world. Traditionally, it has been applied in the form of sun drying beds. Recently sun drying beds are converted into GSDs by covering the drying area, providing sludge mixing and ventilation. A GSD is cheaper, its operation is easy, and it does not need skilled labor compared to thermal dryers (Ritterbusch and Bux, 2012). It is environmentally friendly and has very low CO_2 emissions compared to thermal dryers as no fossil fuel is used or little energy is used for ventilation and mixing only (Bux and Baumann, 2003). Nevertheless, this system cannot reach 90% DS at reasonable time periods compared to thermal dryers although good results have been reported in warm climates (Seginer et al., 2007; Bennamoun, 2012; Meyer-Scharenberg and Pöppke, 2010). Depending upon the particular system installed, ability of a GSD to dry sludge depends on geographical location and season (Fonda and Lynch, 2009). Therefore, this system may need to be supported with additional energy to improve final DS. Solar panels can be used to provide additional energy to reach 90% DS or to minimize required sludge drying area (Mathioudakis et al., 2009).

This study evaluates the use of solar power panels in combination to a GSD to dry sludge to 90% DS to enable its use as a fuel. The system is proposed as an alternative to expensive thermal drying. To be compatible with short drying times by thermal dryers, continuous operation is assumed, such that energy is utilized during night time for drying. Evaluations are based on capital and operational costs as well as area requirements. Solar panels provide auxiliary heat to further dry the sludge in the GSD to reach 90% DS. Costs are compared to that for conventional and co-generation aided thermal drying. 37 WWTPs in Turkey are considered. Cost functions and an optimization model are utilized to determine costs and area requirements. The optimal costs for GSDs supported with solar panels for all WWTPs are determined using Excel Solver.

2. Methodology

2.1. Cost functions

Typically, 90% and 70% DS are achieved by thermal dryers and GSDs, respectively (Flaga, 2007; Mangat et al., 2009; Bux and Baumann, 2003; Ritterbusch and Bux, 2012). Therefore, a GSD should be supported with auxiliary heat in order to reach higher DS (i.e. 90% DS). In this study, solar panels are used to support a GSD to reach the DS that can be attainable by thermal dryers. Analyses are based on capital and O&M costs as well as area requirements.

The capital cost of a GSD is comprised of installation cost which is based on the required drying area such that

$$Z_{C_{GSD},i} = A_{GSD,i}C_{C_{GSD},i} + A_{GSD,i}C_{L,i}f_{L,i} \tag{1}$$

Where $Z_{C_{GSD}}$,i is the capital cost of GSD i (€), $A_{GSD,i}$ is the required base area of the GSD at WWTP i (m^2), $C_{C_{GSD}}$,i is the unit installation cost of GSD i (€/m^2), $C_{L,i}$ is the unit land cost (€/m^2), and $f_{L,i}$ is a factor for land requirement other than the GSD itself if required ($f_{L,i} \geq 1$). $A_{GSD,i}$ is calculated based on the evaporation rate in a GSD at a given location and target DS of sludge. Sludge drying in a GSD is affected by evaporation rate, feeding rate and thickness of sludge over drying area (Seginer and Bux, 2006; Seginer et al., 2007). GSDs are closed systems and drying environment can be controlled through mixing of sludge and ventilation. Therefore, apparent evaporation rate can be higher than the pan evaporation rate reported by meteorological monitoring agencies. Seginer et al. (2007) provided below equation to calculate the evaporation rate in a GSD, which is adopted in this study as well.

$$e_{V,i} = \left(\rho Q_v 1.964*10^{-11}\right)\left[(R_{o,i}+1100)^{2.322}(T_{o,i}+13)^{1.292} \times (Q_v)^{-0.577}(Q_m+0.0001)^{0.013}(DS_{i,i}+0.26)^{-0.353}\right] \tag{2}$$

Where, $e_{V,i}$ is the average evaporation rate at location i (kg/m^2-hr), ρ is the air density (1.13 kg/m^3), Q_v is the ventilation rate (m^3/m^2-hr), $R_{o,i}$ is the solar irradiation at location i (W/m^2), $T_{o,i}$ is the ambient air temperature at location i (°C), Q_m is the air mixing rate (m^3/m^2-hr), and $DS_{i,i}$ is the initial DS of the sludge at location i (kg solids/kg sludge). Required base area for the GSD at a given location is calculated as

$$A_{GSD,i} = \frac{m_{e,i}}{e_{V,i}} \tag{3}$$