Applied Thermal Engineering 116 (2017) 792–798

Contents lists available at ScienceDirect

Applied Thermal Engineering

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

Research Paper

Low-temperature drying of industrial biosludge with simulated secondary heat

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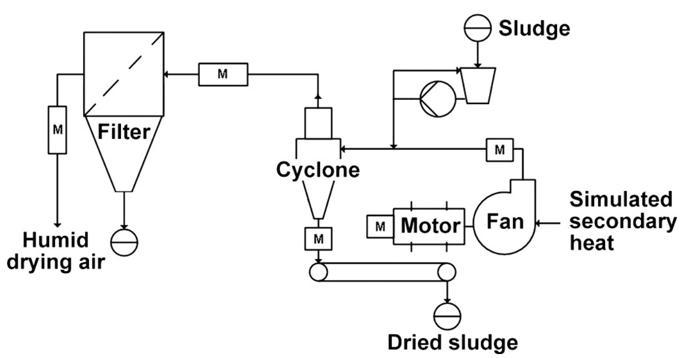
HIGHLIGHTS

- Pure biosludge was dried with a pilot-scale dryer using simulated secondary heat.
- Dry solids content of sludge increased from 9% to 19–68% during the experiments.
- Energy consumption of drying varied within 0.6–1.7 kWh kg^{-1} H_2O.
- Energy efficiency with secondary heat competitive to industrial scale dryers.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 26 September 2016
Revised 10 January 2017
Accepted 4 February 2017
Available online 7 February 2017

Keywords:
Biosolids
Convective drying
Process integration
Regression modelling
Response surface methodology
Waste heat

ABSTRACT

Drying is an energy-intensive unit operation and future sludge dryers should be able to take advantage of the secondary energy of industrial environments. This work reports the use of a pilot cyclone for drying biosludge at low temperatures and simulating the use of secondary waste heat. The pilot-scale experiments were performed according to an experimental design and the results interpreted using principal components and multiple linear regression. The dry solids content of processed sludge increased from 9 to 19–68% during the experiments with a predicted energy consumption of <1.7 kWh kg^{-1} H_2O. However, the combined energy consumption was 80–230% higher indicating that the efficiency of sludge drying was governed by the availability of secondary heat. Drying sludge to solid contents sustainable for fossil fuel replacement at pulp and paper mills could be performed with secondary heat at a temperature of 70 °C, a pilot-scale feeding capacity of 170 kg h^{-1} and a corresponding energy consumption of 1.0 kWh kg^{-1} H_2O. The results suggest that the use cyclones could be an efficient option for future sludge drying at pulp and paper mills.

1. Introduction

Industrial and municipal wastewater treatment processes generate significant quantities of residual sludge biomass, which is currently inefficiently utilized. Within the pulp and paper industry organic sludge residues are generated during recycled fibre processing or primary and secondary wastewater treatment processes by mechanical, chemical or biological methods. Traditionally these residues have been landfilled or incinerated, which however suffer from poor economics due to current trends in waste regulation and the need for drying or energy-intensive evaporation in the recovery boilers of pulp and paper mills [1]. In Sweden the industry produces approximately 550,000 dry tonnes of organic sludge residues

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http://dx.doi.org/10.1016/j.applthermaleng.2017.02.010
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every year, 75% of which is incinerated in the solid fuel or recovery boilers of pulp and paper mills [2,3]. However, the energy potential of generated sludge residues has been estimated as 2 TWh per year, only half of which is currently utilized [3]. Sludge management costs can constitute up to 60% of the overall costs of wastewater treatment plants [4] making sludge the most significant solid waste issue at most pulp and paper mills.

Industrial waste biomass is an ideal energy source as it is produced in large quantities at specific locations with relatively stable properties. In addition, it is often readily available, low-cost and does not compete with land requirements for food production [5]. However, efficient energy recovery from sludge through incineration, pyrolysis or gasification requires active drying for upgrading the feedstock. Within the pulp and paper industry sludge is mechanically dewatered using filter or screw presses and centrifuges, which face difficulties in removing the intracellular or chemically bound water from sludge suspensions [6]. In addition, secondary biosludge is generally more difficult to dewater than primary sludge and thus most mills dewater a mixture of primary and secondary sludge [4]. In general mechanically dewatered sludge has an approximate energy content of 2–6 MJ kg^{-1}, which is significantly lower compared to bark (7 MJ kg^{-1}) and black liquor (12 MJ kg^{-1}), which are the predominant biofuels of pulp and paper mills [7].

Further drying of dewatered sludge can be performed with direct, indirect or combined drying systems [8] relying on different mechanisms for heat transfer. In direct dryers, such as rotary drum, flash or belt dryers, heat is transferred by convection through direct contact with hot gas in the form of air, flue gas or steam. The operation of indirect dryers, such as rotary disc or rotary tray driers, is based on conduction and radiation as the heated medium is physically separated from the drying material [9]. Fluidized bed dryers can be good examples of combined systems relying both on convection and conduction by inclusion of immersed heating tubes. In general indirect systems have the advantage of avoiding a potentially contaminated heat-carrying medium, as direct systems can operate on higher temperatures [8,10].

For increasing the efficiency of sludge utilization efforts should be made for efficiently upgrading the feedstock. As drying is an energy-intensive unit operation, novel drying processes should be able to utilize the low-temperature secondary energy of industrial environments [11,12]. Important contributions in the field have previously been reported by Hippinen and Ahtila [11] with a rotary laboratory evaporator for activated sludge and Lee and Cho [13] with a pilot system for sludge that consisted of three individual cyclones in series. In addition, Hayashi and Shimada [14,15] reported the use of a laboratory jet dryer for sludge and Dzik and Czerski [16] a multicyclone dryer for straw and lignite. We have previously used a novel low-temperature drying pilot for convective drying of recycled paper [17] and mixed sludge [18] residues from pulp and paper mills. However, pure biosludge is especially problematic to most mills due to respective difficulty of drying coupled with a limited capacity for incineration of mechanically dewatered sludge even in light of additional sludge management costs. Hence this work focuses on the use of the drying pilot for upgrading pure biosludge with inlet air temperatures equivalent to potentially available secondary heat, and the use of regression techniques for respective process modelling.

2. Material and methods

2.1. Sludge sampling and sample processing

Biosludge samples were delivered by a regional pulp and paper mill producing bleached sulphate pulp (750,000 t y^{-1}) for fine paper production (810,000 t y^{-1}). Mill effluents were biologically treated in an activated sludge process preceded by primary gravitational settling. The surplus sludge from secondary clarification was dewatered with a belt press and a centrifuge producing approximately 120 t d^{-1} (db) of pure biosludge. A sludge shipment of approx. 2.5 t was received and stored in a cold container (+4 °C) prior to drying. Each sludge container was sampled and the individual samples were combined, homogenized and partitioned by coning and quartering [19]. The attained sample was characterized as previously described [17] and the attained results are provided in Table 1. After sampling the containers were dried as received.

2.2. Drying experiments

The pilot experiments were performed with a pilot-scale cyclone dryer on representative five minute intervals, Fig. 1. The equipment and sludge feeding through a screw pump were allowed to stabilize before the experiments to ensure representative temperature, humidity and material flow conditions. The use of secondary heat (⩽90 °C) was simulated through combustion of pellets in a separate combustion unit. Temperature, relative humidity and absolute and differential pressure values within different parts of the process were measured using instruments from GHM-Greisinger (GHM Messtechnik, Germany) and Pentronic (©Pentronic, Sweden). The instruments were used in their factory settings with approximate accuracies within ±0.2–1.5% of given full scale values. Mean values of relevant temperature, relative humidity, absolute and differential pressure, and electricity consumption values representative of the experimental interval were used for process calculations as the process was running stable during all of the experiments. Processed sludge was sampled three times during the experiments and subsequently sealed in plastic bags. At the end of each day, three approximately 300 g samples of the feed and processed sludge were placed on stainless steel plates and their dry solids contents measured after holding in a drying chamber at 105 °C overnight. Mean values of the three samples were then used for further calculations and regression modelling.

The experiments were organized according to an experimental design composed of 17 individual experiments including three repetitive center-points. Inlet air temperature, sludge feeding rate and humid drying air recirculation were respectively varied on three different levels within 50–90 °C, 100–250 kg h^{-1} and 1–3 indicating minimum to maximum air recirculation. However, as experiments combining low inlet air temperature (50 °C) with high sludge feeding rate (250 kg h^{-1}) proved problematic they were excluded from the design requiring two additional experiments compared to conventional central composite designs [20].

Table 1
Biosludge characterization.

Parameter	Unit	Biosludge
Dry solids content (105 °C)	% (wb)	9.4
Moisture content (105 °C)	kg H_2O kg^{-1} (db)	9.6
Loss-on-ignition (LOI, 550 °C)	% (db)	83.0
Ash content (550 °C)	% (db)	17.0
Higher heating value (HHV)	MJ kg^{-1} (db)	19.5
Lower heating value (LHV)	MJ kg^{-1} (db)	18.2
Volatile content (900 °C)	% (db)	68.4
S (1350 °C)	% (db)	1.4
C (1050 °C)	% (db)	45.1
H (1050 °C)	% (db)	5.9
N (1050 °C)	% (db)	6.6
Cl	% (db)	0.40

wb = wet basis.
db = dry basis.