ARTICLE IN PRESS

Energy Conversion and Management xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Energy Conversion and Management

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

Applying waste heat recovery system in a sewage sludge dryer – A technical and economic optimization

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ARTICLE INFO

Article history:
Available online xxxx

Keywords:
Energy and economic optimization
Waste heat recovery
Sewage sludge drying
Natural gas

ABSTRACT

Drying of digested sewage sludge, as an important alternative to sludge disposal at dumping sites, should comply with the requirements of high energy efficiency as well as economic feasibility. The technical and economic optimization analysis of installing a waste process heat recovery unit in a medium-temperature belt dryer operated in a municipal waste water treatment plant was carried out. Inlet capacity of the plant is 1.83 Mg of wet sludge per hour.

The post-process air was indicated as a source of waste heat and the configuration of a heat recovery system was proposed. The main objective of the research was to find the optimal size of a chosen type of waste heat recovery heat exchanger for preheating ambient air to the process. The maximization of Net Present Value, and, alternatively, also Net Present Value Ratio were selected for the objective function of the optimization procedure. Simulation of yearly operation of waste heat exchanger was made for a range of different heat exchanging areas (101–270 m^2) regarding given parameters of a post-process air and different temperatures of ambient air.

Energy performance of the modernization was evaluated and economic indices were calculated for each of the analyzed cases. The location of the maximum of optimization function was found and the calculations show higher profitability of the cases with larger waste heat exchanger. It can be concluded that the location of optimum of the objective function is very sensitive to the price of natural gas supplied to the system and less sensitive to the electricity price.

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1. Introduction

Sewage sludge production in the world has increased dramatically with the growth of the global population, urbanization and industrialization. The management of municipal sewage sludge is a difficult and expensive problem affecting many countries around the world [1]. In the European Union (EU) as a whole, the annual production of sewage sludge exceeds 10 million tonnes of dried sludge DS [2], while in China the amount of sewage sludge produced in 2010 is estimated to reach 8.0 million tonnes DS [3] – as a result of the rapid progress of urbanization and the continuous improvement of sewage treatment facilities [4].

In the global context, it is believed that the sludge output in the coming decades would remain to be gradually increased [5]. On the basis of [6] it can be claimed that annual sewage sludge production in EU will exceed 13 million tons DS up to 2020. According to [7], the quantity of sludge which will be annually produced in Poland by the year of 2018 will exceed 700 thousand tons DS. By the year of 2022 this amount is expected to reach almost 750 thousand tons DS which gives 22% of growth comparing to the year of 2010. Due to growing amount of sludge as well as environmental protection issues, the handling of sewage sludge is becoming one of the most significant challenges in wastewater management. According to UWWT Directive (CEC, 1991), the collection and treatment of municipal wastewater is compulsory for agglomerations with population equivalent (p.e.) of more than 2.000.

Abbreviations: BF, biofilter unit; CHP, cogeneration of heat and power; CS, cooling scrubber; ChS, chemical scrubber; DPB, discounted payback time; DS, dried sludge; G, electricity generator; HA, heat accumulator; HE, existing heat exchanger; HED, heat exchanger in design; IRR, Internal Rate of Return; NPV, Net Present Value; NPVR, Net Present Value Ratio; P1, circulation pump; P2, intermediate water pump; PE, Piston engine; TC, turbo-compressor; TOC, total organic carbon.

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http://dx.doi.org/10.1016/j.enconman.2016.02.064
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Please cite this article in press as: Tańczuk M et al. Applying waste heat recovery system in a sewage sludge dryer – A technical and economic optimization. Energy Convers Manage (2016), http://dx.doi.org/10.1016/j.enconman.2016.02.064

The growing amount of sewage sludge to be processed entails development of municipal wastewater treatment systems and sludge treatment systems in particular. The municipal sludge can be treated by many means. During the last 20 years, there has been a major change in the way in which sludge is disposed from the traditional methods, including landfill and agricultural use [8]. In some countries, national legislations have set very strict limits for the organic matter or total organic carbon (TOC) contained in sludge: e.g. Germany or Austria, where sludge landfilling is practically prohibited or Poland where from the year of 2016 permission for sludge depositing to landfills will emerge from its gross heating value [9].

Traditional methods of sewage sludge treatment are now more widely replaced with thermal processing which allows for a significant reduction in the weight and volume of transformed sludge [10] which can also be noticed in Poland [11]. Municipal waste water is a potential source of chemical energy and thermal sludge processes usually lead to energy recovery [12]. It can be employed as a renewable fuel, especially in its dry form [8]. In the face of the increase of global energy demand [13] thermal proceeding of sewage sludge is particularly interesting and worth emphasizing.

A review of the available sewage sludge utilization methods and the relevant thermal processes is available in [5], and an updated review with focus on thermochemical conversion methods was presented in [14]. The most popular thermal technologies for utilizing municipal sewage sludge to obtain useful forms of energy are combustion and co-combustion. The various issues related to the combustion of sewage sludge and the future trend showing the increasing role of sludge incineration is presented in [15]. It is important to point out that treatment of the sludge before incineration is strongly influencing the combustion process, regarding emissions and energy effectiveness, as presented in [16]. A particularly interesting technology for thermal utilization of dried sewage sludge are cement plants due to favorable conditions of high temperature combusting process in rotary kilns. As reported in [17] due to catalytic effect of metal oxides (CaO, Fe_2O_3, and NiO) contained in the sludge, it provides favorable conditions for the reduction of both NO_x and CO in the cement manufacturing process.

Another perspective for thermal utilization of the sewage sludge is using a broad number of techniques based on pyrolysis, gasification or processes carried out in fluidized bed reactors. The study presented in [18] discusses the varieties of the municipal sewage sludges on the yields and compositions of the gaseous and liquid pyrolysis products. The utilization of the sewage sludge in the combined screw/rotary kiln pyrolysis gasifier was proposed in [19]. The pilot installations of sewage sludge gasification in the fluidized bed are introduced in [20] where different aspects of plant commissioning and operating are discussed.

There are also alternative technologies focusing on sludge energy recovery: production and energetic utilization of sludge-based alternative fuels. A concept of production line of sewage sludge alternative fuels with addition of wood wastes and animal utilization wastes on the basis of drying technique was proposed and analyzed in [21]. Fluidized bed combustion of pelletized biogenic fuels from sewage sludge was presented in [22] as one of the most viable technologies for the exploitation of biogenic fuels. An experimental study on solid fuel production from sewage sludge by employing steam explosion is the subject of the discussion included in [23]. Biogas as an alternative fuel coming from the anaerobic digestion of the sewage sludge is another example of sludge energy recovery technology [24]. Another promising approach for converting sewage sludge into alternative energy carriers is microbial fuel cells (MFCs) technology, according to [25]. A novel cloth-electrode assembly microbial fuel cell (CEA-MFC) was proposed in [26] for a direct electricity production from sewage sludge.

The majority of sewage sludge thermal utilization processes should be preceded by dewatering and then drying of sludge. There are many sludge drying techniques but most of them are based on one of the following biomass drying methods: convective, conductive and finally solar drying [27]. Dryers, except solar ones, need heat generated in integrated sources fed with fossil or alternative fuels (such as biogas or dried sludge) [28]. Drying process can also be supplied with waste heat recovered from other processes [29], including drying process itself (partially). There is also a possibility to combine different methods and consequently to apply hybrid dryers or combined dryers. Regardless of the methodology of drying, energy efficiency of the process should always be high. Optimum efficiency level should, however, result from economic factors. One of the possibility to make sewage sludge drying more efficient is to recover waste heat from the process. Such mean always decreases demand for energy input to the drying plant.

The aim of work is to find optimal size of waste heat recovery unit for a municipal sewage sludge drying plant supplied with heat generated in CHP units fuelled with natural gas.

2. System description

The study concerns a modernization of an existing sludge drying plant by modifying the arrangement of heat exchangers used for waste heat recovery. The sludge drying plant uses the technology of medium temperature drying in a belt dryer, with air as the drying medium.

The analyzed sewage sludge drying plant is located within a structure of a municipal sewage treatment plant size 200,000–250,000 p.e. In this plant, sewage sludge management is distinguished by certain phases:

- anaerobic digestion of sewage sludge in closed digestion chambers,
- dewatering with the use of centrifuges and hygienization process by lime addition,
- drying of dewatered sludge.

Useful energy carriers generated in the sewage treatment plant comprise biogas and dried sewage sludge. The biogas is utilized in two CHP units located outside of the drying system. The dried sewage sludge is sent to a cement plant and combusted in cement kilns. Accordingly, no local low-cost fuel is available for the drying purposes and it is required to cover the energy demand by purchasing external fuel (natural gas). Parameters of the sludge being processed and a summary of design parameter of analyzed belt dryer is presented in Table 1.

Maximum design annual capacity of the drying plant reaches 16,000 tonnes of dewatered sludge. Regarding availability factor

Table 1
Main design parameter and performance data of a case study belt dryer.

Parameter		Value
Inlet sludge capacity	$\dot{m}_s$	1.83 t/h
Sludge moisture at inlet (after dewatering)	r_{ws}	80%
Drying temperature	t_d	110 °C
Evaporation rate	$\dot{m}_w$	1.32 t/h
Dried sludge production capacity	$\dot{m}_d$	0.51 t/h
Sludge moisture at outlet	r_{wd}	10%
Specific heat consumption	q_{th}	1.0 kW h/kg H_2O
Specific electricity consumption	q_{el}	0.085 kW h/kg H_2O
Heat demand	$\dot{Q}_d$	1300 kW
Electric power demand	N_{eld}	110 kW
Post-process air temperature	t_3	76 °C
Ambient air mass flow rate	$\dot{m}_{a1}$	3.44 kg/s
Post-process air mass flow rate	$\dot{m}_{a3}$	3.44 kg/s

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