Waste Management xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Waste Management

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

Experimental research of sewage sludge with coal and biomass co-combustion, in pellet form

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ARTICLE INFO

Article history:
Received 29 October 2015
Revised 14 April 2016
Accepted 17 April 2016
Available online xxxx

Keywords:
Sewage sludge
Coal
Biomass
Pellet
Co-combustion

ABSTRACT

Increased sewage sludge production and disposal, as well as the properties of sewage sludge, are currently affecting the environment, which has resulted in legislation changes in Poland. Based on the Economy Minister Regulation of 16 July 2015 (Regulation of the Economy Minister, 2015) regarding the criteria and procedures for releasing wastes for landfilling, the thermal disposal of sewage sludge is important due to its gross calorific value, which is greater than 6 MJ/kg, and the problems that result from its use and application. Consequently, increasingly restrictive legislation that began on 1 January 2016 was introduced for sewage sludge storage in Poland.

Sewage sludge thermal utilisation is an attractive option because it minimizes odours, significantly reduces the volume of starting material and thermally destroys the organic and toxic components of the off pads. Additionally, it is possible that the ash produced could be used in different ways. Currently, as many as 11 plants use sewage sludge as fuel in Poland; thus, this technology must be further developed in Poland while considering the benefits of co-combustion with other fuels.

This paper presents the results of experimental studies of the mechanisms and kinetics of sewage sludge, coal and biomass combustion and their co-combustion in spherical-pellet form. Compared with biomass, a higher temperature is required to ignite sewage sludge by flame. The properties of biomass and sewage sludge result in the intensification of the combustion process (by fast ignition of volatile matter). In contrast to coal, a combustion of sewage sludge is determined not only burning the char, but also the combustion of volatiles. The addition of sewage sludge to hard coal and lignite shortens combustion times compared with coal, and the addition of sewage sludge to willow Salix viminalis produces an increase in combustion time compared with willow alone.

1. Introduction

Based on the EU definition (Directive of the European Parliament and Council Directive 2009/28/EC of 23 April 2009), sewage sludge is a form of biomass. Thus, sewage sludge combustion must be compared with biomass and coal combustion.

A recent publications (Environmental Protection, 2011–2013; Kijo-Kleczkowska et al., 2014, 2015) reported on the production of different types of sewage sludge in Poland between 2000 and 2013, the sewage sludge management methods used in Poland in 2000, 2005, 2010, and 2013, and the thermal treatment methods of sewage sludge. Overall, the following conclusions were made: Municipal sewage sludge and industrial sewage sludge were managed differently depending on the year, with the greatest interest in this method for the disposal of municipal sewage sludge and industrial sludge occurring in 2010 and 2013, respectively. Similar amounts of municipal and industrial sewage sludge were stored. Larger quantities of industrial sewage sludge than municipal sewage sludge were stored until 2013. More industrial sewage sludge than municipal sewage sludge was subjected to thermal treatment. Sewage sludge was only used for agricultural and industrial purposes in 2000, when more industrial sewage sludge was disposed of. Municipal and industrial sewage sludge were often used to grow plants and produce agriculture compost; however, more attention was given to this disposal method for industrial sludge in 2013. In addition, sewage sludge was used for land reclamation, including agricultural, after 2000.

The amount of sewage sludge recycled using thermal methods increased for both municipal sludge and industrial applications, potentially due to their nature, which was influenced by the heavy metal and pathogenic organism contents within the sewage sludge.

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http://dx.doi.org/10.1016/j.wasman.2016.04.021
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Please cite this article in press as: Kijo-Kleczkowska, A., et al. Experimental research of sewage sludge with coal and biomass co-combustion, in pellet form. Waste Management (2016), http://dx.doi.org/10.1016/j.wasman.2016.04.021

The combustion of sewage sludge as waste and its co-combustion with other fuels (e.g., coal, biomass) is one of methods of thermal treatment. High combustion efficiencies can be achieved if the combustion process is properly designed to consider the unique properties of the fuel. Because biomass is considered a carbon-neutral fuel, co-combustion of sewage sludge with biomass may produce lower CO_2 emissions and decrease the cost of electricity.

The increase of the amount of sewage sludge produced in Poland and the stringent legal regulations in the field of environmental protection could result in the combustion of sewage sludge with and without other fuels in the future. Thus, these combustion processes must be studied in further detail.

2. Review of the literature regarding combustion and co-combustion of sewage sludge with other fuels

According to Nadziakiewicz (2001), depending on the fuel and the type of sewage sludge being burned, the combustion process can be divided into two types of thermal utilisation processes: conventional burning and incineration. The main objective of combustion is obtain heat for energy processes, while the main objective of the process of incineration is only a marked decrease or eliminate the volume of waste harmful to the environment. In the case of sewage sludge connects these two objectives for the energy use of the waste. This paper shows that sewage sludge can be a fuel with an heating value of practical interest.

According to Wandrasz (2000), the thermal degradation process of organic substances can be divided into successive stages that depend on, among others, the temperature during waste combustion. The steps involved for transformation during the degassing of waste are detailed below:

- at 100–200 °C: hygroscopic thermal drying; moisture removal;
- at 250 °C: deoxidation, which is the structural breakdown of a substance due to the separation of its water with associated carbon atoms, and depolymerisation, which is the release of sulphur compounds and the initiation of hydrogen sulphide decomposition;
- at 340 °C: the beginning of the formation of aliphatic compounds and the release of other aliphatic compounds and methane;
- at 380 °C: the carbonising phase;
- at 400 °C: the beginning of the formation of compounds from CO and C and N;
- at 400–600 °C: the processing of bituminous compounds in oil and tar;
- at 600 °C: the cracking of bituminous substances and formation of aromatic compounds (benzene derivatives);
- above 600 °C: the dimerization of olefin-ethylene-butylene, transformation reactions of ethylene cyclohexane, dehydrogenation to butadiene, and thermal aromatisation to benzene and hydrocarbons of higher orders;
- above 1200 °C: the melting of inorganic substances and liquid slag and the formation of methane that can be decomposed into hydrogen and carbon via pyrolysis.

The thermal decomposition of sewage sludge occurs at significantly lower temperatures than coal. Similar to coal, a drying phase is required for separation and pyrolysis. During thermal decomposition of these waste materials, gaseous, liquid, and char states are obtained. With increasing temperature, the proportion of gaseous substances increases, and the proportions of liquid and char decrease (Kordylewski, 2005; Werther and Ogada, 1999).

Compared with the combustion of solid fuels, the combustion of sewage sludge char is the longest stage of combustion process. This finding potentially resulted from the relatively slow thermal decomposition rate of the sewage sludge and the small portion of carbon fixed in the sewage sludge char, which was approximately 10% and favourable for rapid char oxidation and sewage sludge with high porosities (Werther and Ogada, 1999).

Particularly, the combustion of sewage sludge is important when considering the benefits of recycling these wastes, including odour minimization, a significant reduction in the volume of sewage sludge, the possibility of using the fly ash produced, and the thermal destruction of organic and toxic ingredients. In addition, dried sewage sludge is attractive for use as an fuel because its calorific value is comparable to that of lignite. Consequently, it is reasonable to burn the waste to recover its energy content. Given the considerable development of combustion technology, the competitiveness of this method relative to other sewage sludge disposal methods should be emphasized. However, combustion, similar to all waste disposal methods, has its own various problems, including the presence of heavy metals and the need for exhaust gas purification over a wide range. These problems result from the variety of contaminants present in the sewage sludge. The high moisture content should be stressed, which limits autothermal combustion and necessitates the provision of additional fuel (Werther and Ogada, 1999) or requires suitable pre-treatment, such as drying.

To choose the right technology, sewage sludge combustion is dictated by the BAT (Best Available Techniques) principle, which states that fluidized bed technology is the best solution due to its high combustion efficiency (Gromiec and Koć, 2009). The following are examples of such structural solutions in Poland: sewage sludge combustion in Dębogórze-Gdynia (Pająk, 2012) and the first and most modern installation of hazardous waste combustion, PYROFLUID™.[1]

Sewage sludge co-combustion in rotary kilns is ideal for disposing of organic compounds that are resistant to high temperatures. In the cement industry the temperature in rotary kilns can reach even 2000 °C (Brochure of Polish Cement Association). Sewage sludge must meet two primary criteria to become a fuel in the cement industry. The sewage sludge must have a calorific value of no less than 11.5 MJ/kg (based on the "Lafarge" - a company involved in producing building materials) or 14 MJ/kg (based on other cements) after drying. In addition, the chlorine content of the sewage sludge should not exceed 5% of the total sewage sludge weight (Rosik-Dulewska, 2008).

Sewage sludge can be a valuable fuel. Tables 1 and 2 show the characteristics of installations used for sewage sludge drying and combustion in Poland (Pająk, 2012).

Stasta et al. (2006) highlighted that the water content in the sewage sludge depends on the dewatering process used at the wastewater treatment plant. These authors stressed that the high water content in the fuel hinders combustion in a cement kiln because (1) the temperature in the cement kiln may decrease to the temperature limit of clinker creation, which can decrease the product quality, and (2) a large amount of evaporated water can increase the flow of flue gases, which can overload the systems that manage the emitted gas and ventilators.

Bień (2012) noted that in 2011 the amount of sewage sludge in co-combustion products containing other alternative fuels by the cement company "Cemex" was only 1.5% (by mass). Poland has 11 municipal sludge combustion plant, what may result from the economic aspect. The costs of sewage sludge combustion in Poland are up to six times more expensive compared with agricultural use.

[1] www.veoliawaterst.pl/onas/casestudy/orlen_eko.html.

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