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Research article

Thermal treatment of medical waste in a rotary kiln

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ABSTRACT

This paper presents the results of a study of an experimental system with thermal treatment (incineration) of medical waste conducted at a large complex of hospital facilities. The studies were conducted for a period of one month. The processing system was analysed in terms of the energy, environmental and economic aspects. A rotary combustion chamber was designed and built with the strictly assumed length to inner diameter ratio of 4:1. In terms of energy, the temperature distribution was tested in the rotary kiln, secondary combustion (afterburner) chamber and heat recovery system. Calorific value of medical waste was 25.0 MJ/kg and the thermal efficiency of the entire system equalled 66.8%. Next, measurements of the pollutant emissions into the atmosphere were performed. Due to the nature of the disposed waste, particular attention was paid to the one-minute average values of carbon oxide and volatile organic compounds as well as hydrochloride, hydrogen fluoride, sulphur dioxide and total dust. Maximum content of non-oxidized organic compounds in slag and bottom ash were also verified during the analyses. The best rotary speed for the combustion chamber was selected to obtain proper afterburning of the bottom slag. Total organic carbon content was 2.9%. The test results were used to determine the basic economic indicators of the test system for evaluating the profitability of its construction. Simple payback time (SPB) for capital expenditures on the implementation of the project was 4 years.

1. Introduction

Waste management, i.e., the collection, transport, recovery and neutralisation of waste, as well as the supervision of these activities and the places where waste is neutralised, are among the most important issues of environmental protection. The importance of waste management continues to grow due to the progression of civilisation and increase in the quantity of waste (Qu et al., 2013). Medical waste is defined as any solid or liquid waste that is generated from treating human beings in a hospital or clinic, clinical diagnosis and pathological testing and medical research (Abd El-Salam, 2010; Patwary et al., 2011a,b; WHO, 2002).

In many developed countries, the regulations and laws for the management and disposal of medical waste are extremely strict (Chaerul et al., 2008; Duan et al., 2008; Insa et al., 2010; Jang et al., 2006; Woolridge et al., 2008; Zimmer and McKinley, 2008). One example is the European Union member countries, which have enacted numerous directives that mandate the appropriate collection, transport, processing and storage of such waste. Moreover, people in the EU have a strong belief in the need for the appropriate handling of this type of waste. The high level of awareness and harsh legal provisions and measures are the reason for the exploration of appropriate technologies for disposing of medical waste. Some of the most advanced elements of waste management are the thermal conversion processes of waste, which involve the oxidation of waste through incineration, gasification or distribution (such as pyrolysis). The main advantages of this type of process are as follows:

- the possibility of converting waste into a safe form;
- significant reduction in its weight and volume;
- the possibility of recovering substantial levels of heat.

In the case of waste with a high calorific value, such as plastic or medical waste (medical waste also includes a high plastic element content (Lee et al., 1991)), the process of thermal disposal involves gasification or pyrolysis. These processes (Miranda et al., 2013) and their detailed reaction mechanisms and simulation models, including the elimination of redundant species and reactions, rate-of products and reaction flux analysis and uncertainty analysis, have been reported (Chiarioni et al., 2006; Conesa et al., 1996; Dai

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et al., 2001; Kovács et al., 2007; Lee and Kim, 1996; Leung and Wang, 1999; Li et al., 1999; Mani et al., 2011; Mani and Nagarajan, 2009; Singhabhandhu and Tezuka, 2010; Wallman et al., 1998).

The process of thermal treatment for medical waste must meet a number of requirements. The most important are the following:

- appropriate transformation of bottom ash into a safe form. Research confirms that such a form can be used in agriculture and construction (Rajor et al., 2012),
- emissions into the atmosphere in accordance with the applicable legal requirements. Flue gas cleaning systems in this type of installation must guarantee high efficiency and reliability (Alvim-Ferraz and Afonso, 2003; Grochowalski, 1998; Lemieux et al., 2004),
- highly efficient utilisation of the potential for waste energy that is both simple and less burdensome for the environment.

Dean described heat recovery from hospital systems of medical waste incineration (Dean, 1996). He discussed the possibility of producing steam using waste heat from the incineration of medical waste. He showed that the use of such a heat recovery system significantly reduced the annual operating costs of a hospital boiler room.

Bujak reported experimental studies of useful energy flux and the thermal efficiency coefficient of the system of thermal conversion of waste, including heat recovery (Bujak, 2009). The system was equipped with shelving/stepped hearths. Studies have shown that the flow of useful energy and energy efficiency depend on the load of the incinerator. An increase in the incinerator load resulted in an increased stream of useful energy and an increased energy efficiency ratio.

This paper presents the results of a pilot study conducted in a large hospital where a special rotary kiln was installed for the thermal disposal of medical waste. The studies were conducted for a period of one month. During that time, the system being analysed operated stably and smoothly for 720 h at full capacity. The changeability of the waste flux being incinerated was small. Its deviation from the average value did not exceed 10%.

2. Management of plastic waste before and after the system upgrade

The hospital uses the heat for technological purposes, heating, ventilation and hot water. According to calculations, the total heat demand is 1.0 MW. The main and largest consumers of heat are technological devices associated with hospital operations. They require saturated steam power. The other heat consumers or heat exchangers are supplied with hot water at a temperature of 90 °C. The production of saturated steam and hot water takes place in a hospital boiler room, which is fired with natural gas with a high methane content and thermal capacity of $Q = 1200$ kW. Medical waste generated in the hospital as a result of treatment was originally exported to regional waste disposal facilities.

Fig. 1 shows the thermal management structure after the system upgrade. The upgrade included the design and construction of a special medical waste incineration system based on a rotary kiln with co-current combustion. According to documents developed by the European Union (European IPPC Bureau, 2006), medical waste incineration in a rotary kiln is currently the best available technique (BAT).

The experimental system studied uses a unique construction of the combustion chamber (rotary kiln). Due to the relatively high calorific value of waste (approximately 25 MJ/kg) and the need for secondary combustion (afterburn) of bottom ash, an appropriate volume-to-length ratio ($l = 5.8$ m) for the rotary kiln was established. According to British Standard BS 3316 (BS, 1987a,b,c,d), the maximum thermal unit load of the combustion chamber cannot exceed 350 kW/m^3. The value adopted for the pilot system was considerably lower at 140 kW/m^3. The heat recovery system was equipped with a special water-tube boiler. The system complies with the mandates imposed on the waste incineration process. The temperature in the secondary combustion (afterburner) chamber is continuously kept above 1100 °C, and the required residence time of the flue gas is 2.5 s.

The test system was located in the hospital, allowing the heat generated by the waste incineration process to be used efficiently. Saturated steam and hot water produced during the process are sent to the hospital boiler room via a pipeline. After modernisation, the heat source is used as the main/supplementary or reserve source. This means that the existing natural gas-fired boilers are only switched on during severe frosts (average of 20 days per year) or stoppage periods of the waste disposal facility.

3. Description of the technology and measurement system

3.1. Thermal recycling technology

The research system of plastic waste incineration (Fig. 2) consists of the following elements:

A. Waste loading system – the container with its contents is automatically weighed and recorded by the computer system. Waste is then lifted by a lift to the rotary kiln hopper. Next, the hydraulic piston introduces it to the combustion chamber. The automatic loading system prevents the loading of waste in the following cases:
   - during start-up, when the required temperatures in the rotary kiln and secondary combustion (afterburner) chamber are too low
   - during the operation, when the required temperatures have exceeded the maximum value or the allowable air emission limit values have been exceeded.

B. Rotary combustion chamber (rotary kiln) – rotates at a continuously adjustable speed within the range of 1–10 revolutions per hour. It can also work in a cyclical/periodic manner. The setting of the speed determines the efficiency of the system and the level of burnout of bottom ash. The setting also has an impact on the emission of fly ash (dust). The direction of the movement of waste incinerated in the kiln is consistent with the direction of movement of the flue gas. The rotary chamber is supported by a gas burner, which is used to heat the kiln during start-up and maintain the desired temperature in the kiln during system operation. The vacuum of −50 Pa is maintained during the process of thermal treatment of waste within the rotary kiln. The rotary kiln is long with a simultaneously large diameter. In the pilot system, the accepted aspect ratio was 4:1 (length:diameter).

C. The secondary combustion (afterburner) chamber or thermoreactor – during the thermal treatment in a rotary kiln, waste is decomposed into more solid and gaseous products. The gaseous products pass into the combustion chamber. Thermal destruction of organic substances and their oxidation to the final products of combustion occur at high temperatures in the secondary combustion (afterburner) chamber. The chamber dimensions provide sufficient residence time of the flue gas of 2.5 s and a sufficient temperature of over 1100 °C. The temperature in the secondary combustion (afterburner) chamber is automatically controlled with a modulated gas burner or additional air. An emergency chimney is an integral part of the