Waste Management xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Waste Management

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

Energy, environmental and operation aspects of a SRF-fired fluidized bed waste-to-energy plant

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ARTICLE INFO

Article history:
Received 28 December 2016
Revised 22 April 2017
Accepted 26 April 2017
Available online xxxx

Keywords:
Detection devices
Fluidized bed combustor
Material balance
Plant shutdown
Raw materials consumption
Solid recovered fuel

ABSTRACT

A methodology based on the ISO 14031:2013 guideline has been developed and applied to a full-scale fluidized bed waste to energy plant (WtE) burning solid recovered fuel (SRF). With reference to 3 years of operation, the data on energy and environmental performance, on raw materials consumptions such as sand and diesel fuel, accidental reasons of plant shutdown, have been acquired and analyzed. The obtained results have allowed to quantify the energy and environmental performance of the WtE plant under investigation by varying the amount and mixings of the inlet waste, available in form of thickened and fluff (similar to coriander) SRF. In terms of the energy performance, the fluidized bed technology applied to the SRF was able to guarantee an adequate production of electricity (satisfying the market demands), showing a relative flexibility with respect to the inlet waste. In terms of net energy production efficiency, the plant showed values in the range of 13.8–14.9% in line with similar installations. In terms of the environmental performance, the adoption of a cleaning system based on SNCR (Selective Non Catalitic Reduction) + semi-dry scrubbing + Fabric filter generated emissions usually well below the limits set by the EU Directive 2000/76/EC as well as the Italian Law 46/2014 (more restrictive) with reference to all the key parameters. In terms of the plant shutdown, the majority of problems focused on the combustion chamber and boiler due to the erosion of the refractory material of the furnace as well as to the breaking of the superheaters of the boiler. In contrast, the mechanical and electrical causes, along with those related to the control and instrumentation system, were of secondary importance. The sand bed de-fluidization was also among the leading causes of a frequent plant shutdown. In particular, results showed how although the SRF presents standard characteristics, the use of different mixtures may affect the number of plant shutdowns. The full-scale data highlighted how the lower the rate of fluff in the mixture was, the greater the number of plant shutdown due to sand bed de-fluidization was. Finally, the aspects in terms of the energy, environmental protection and raw material consumption have been discussed with reference to similar WtE plants such as Robbins (Chicago, USA), Lidköping (Sweden), Toshima (Tokyo, Japan), Madrid (Spain), Dundee (Scotland, UK) and Valene (Mantes la Jolie, France).

1. Introduction

The incineration of municipal solid waste (MSW) is a waste treatment method which can be sustainable in terms of waste volume reduction as well as a source of renewable energy. Several technologies for waste incineration are widespread worldwide such as furnace grate, rotary kiln and fluidized bed (Van Caneghem et al., 2012). According to De Feo et al. (2012), in Europe around 90% of the plants uses furnace grate.

In a fluidized bed combustor (FBC), a bed of sand, combustion ash, or other sand-like material is suspended in an upward flowing airstream. The high turbulence created enhances combustion and promotes an efficient heat transfer and uniform mixing. Three types of fluidized bed reactors are used for waste incineration: a traditional bubbling fluidized bed (BFBC), a rotating fluidized bed (RFBC) and an (external) circulating fluidized bed (CFBC) (Van Caneghem et al., 2012).

In bubbling fluidized bed combustors (BFBC), addressed in this study, an initially stationary bed of solid particles, located in the bottom part of the combustor, is brought into a fluidized state by primary air, supplied through a distributor: the bed particles are kept in suspension at fluidization velocities between 0.5 and 3.0 m/s. For BFBC applications, the size distribution of the inlet

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http://dx.doi.org/10.1016/j.wasman.2017.04.044
0956-053X/

waste should be carefully considered in order to avoid an excessive carry-over of the fines prior to complete burnout, or segregation of large particles that will not fluidize properly. Generally, BFBC are applied to coal, bio-solids, wastewater treatment sludge and SRF/RDF (European Commission, 2006).

SRF – Solid recovered fuel – represents the evolution of RDF (refuse derived fuel) and can be the key to the revival of the energetic use of the portion of municipal and special waste which is not recycled as raw material. The classification of RDF is based on the requirements of the harmonized technical standard UNI EN 15359 which located, at an EU-level, the classification of RDF taking into account three parameters, recognized as strategic due to the environmental, technological and performance/economic importance, such as LHV (Low Heating Value, as commercial parameter), Cl (process parameter) and Hg (environmental parameter) (Massarini and Muraro, 2015).

Compared to more traditional incinerators such as grate furnaces and rotary kilns, fluidized bed combustion has shown to be a versatile technology, capable of burning practically any waste combination, with lower emissions (Tang et al., 2016).

The significant advantages of fluidized bed combustors over conventional ones include their compact furnace, simple design, effective burning of wastes with low calorific value, relatively uniform temperature and the ability to reduce emissions of nitrogen oxide and sulphur dioxide gases (Van Caneghem et al., 2012). FB technology is able to ensure the efficient combustion of wastes with different compositions and characteristics such as moisture content, heating value, ash content and density. The system is able to respond rapidly to changes in the feeding rate as a consequence of the quick establishment of a thermal equilibrium between the air and fuel particles in the bed. Consequently, FB technology is able to guarantee a constant production of energy for the market showing therefore a great flexibility in the management of the inlet waste (Bartels et al., 2008). The operation of the FB furnace at lower temperatures compared to grate furnaces helps to reduce air pollution. The technology burns fuel at temperatures of 750–900 °C, well-below the threshold where nitrogen oxides form (~1400 °C). Although the formation of pollutants depends on the operating conditions as well as the fuel properties, FB technology shows an excellent control of the chemistry inside the reactor. The minimization of carbon monoxide (CO) in the combustion gases may be performed while maintaining an optimum excess air ratio and high temperature. Considering the acid gases formed during the oxidation of sulphur containing compounds in the waste, limestone is added directly in the combustor to precipitate out sulphate during combustion. Furthermore, the production of NO_x, significantly reduced due to the low temperatures, is minimized by using an ammonia solution (NH_4OH) directly in the combustor.

The risk of agglomeration and sintering (Van Caneghem et al., 2012; Chirone et al., 2006), the presence of a high chlorine content of the waste that can enhance boiler corrosion and bed agglomeration as well as cause increased emissions of pollutants, such as HCl and PCDD/Fs (Su et al., 2015; Wei et al., 2005), are among the main disadvantages. Generally, an FBC operates with a selected bed material such as silica sand and/or mixtures of sand and combustion ash of a given average particle size. Although a limited particle growth can be tolerated, segregation and subsequent defluidization are likely to occur if the particle size exceeds the allowable maximum in view of bed mixing. Subsequently, defluidization leads to a required shutdown of the FB combustor. Numerous studies have been carried out to understand FBC defluidisation (Shabanian and Chaouki, 2017; Zevenhoven-Onderwater et al., 2006; Öhman and Nordin, 2000; Jeffers et al., 1999). Generally, it is due to in bed-particle growth phenomena such as agglomeration and sintering (Van Caneghem et al., 2012; Bartels et al., 2008). Although sintering and agglomeration are often interchangeably used to describe the same resulting effect (the increasing particle size of the bed material due), their mechanisms are different. Agglomeration is often the result of the in-bed formation of low melting point eutectic mixtures through the reaction of mostly alkali compounds of the waste feed with the silica bed materials. In these chemical transformations, Na and K are the main alkali metals responsible for agglomeration. The non-uniform temperature and local hot spots in the bed can also cause particle growth if the bed material is allowed to reach its sintering temperature (sintering phenomena) (Skrifvars et al., 1994). Agglomeration can however also occur as a result of liquid and/or salt bridges (near the feeding point of the wet feed), or can be due to the aggregate formation of the bed material with the char (the carbonaceous residue remaining after combustion) or with partly burned polymers. Since the particle growth of the bed material will eventually (on a very short or longer time scale) lead to defluidization, an appropriate prediction of the agglomeration/sintering characteristics is essential, and preferably coupled. Since the FBC-feedstock contains a significant amount of K, Cl, and Si, a noticeable amount of chlorine and alkali metals are released into the gas phase during combustion such as HCl, KCl, KOH and NaCl. These compounds may cause fouling, slagging, and high temperature corrosion in the combustor (Wei et al., 2005). In addition, major corrosion problems may take place in other parts of the plant such as the boiler superheater. In current literature, such phenomena are framed as "erosion and corrosion" (Van Caneghem et al., 2012).

Although there is a large amount of literature on the fluidized bed combustion (Tang et al., 2016; Su et al., 2015; Van Caneghem et al., 2012; Tavares et al., 2011; Chen et al., 2010; Koornneef et al., 2007), limited "quantitative" information as a consequence of the application of a rigorous and standardized methodology developed in accordance to the ISO 14031:2013 guideline, is currently available in terms of (i) energy and (ii) environmental performance, (iii) raw material consumption and (iv) intensity/frequency of plant shutdown due to accidental reasons. In particular, information on the latter is relatively limited and generally only available to the technology supplier.

With the intention of strengthening the current state of knowledge, the aim of this study was to investigate the energy and environmental performance of fluidized bed waste-to-energy (WtE) plants. For this purpose, we defined and applied a methodology based on the use of the main operational indicators suggested by the ISO:14031 guideline. By varying the mixing of the inlet SRF (thickened and fluff, the latter similar to coriander), our subgoals were the following:

- Demonstrate how the fluidized bed technology was able to ensure adequate production of electricity showing flexibility regarding the feeding;
- Demonstrate how the cleaning system adopted nowadays was able to extensively meet the emission limits established by the Law in terms of emissions;
- Estimate the typical range of consumable materials;
- Estimate the frequency and intensity of plant shutdowns and discuss the mechanisms of the main causes along with the possible remedies for prevention;
- Quantify the plant shutdown consequences in terms of the increased consumption of materials.

The use of the case study approach has allowed to obtain results that were subsequently compared with those of other WtE plants in the world (ISWA, 2012; Granatstein, 2004).