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Research Paper

On time measurement of the efficiency of a waste-to-energy plant and evaluation of the associated uncertainty

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ABSTRACT

An automatic system for calculating the lower heating value (LHV) of waste was implemented and analysed for an existing waste-to-energy plant. The calorific value was determined by the indirect method using the whole combustion chamber and heat recovery steam generator as the calorimeter. On the basis of this fundamental information it was also possible to evaluate on time the gross and net efficiency of the plant. The main results indicated that the LHV varied daily, from 4000 to 13,000 kJ/kg, even if the average monthly values ranged from about 7300 to 10,000 kJ/kg. The uncertainty associated with these values was ±0.82% with a confidence interval of 95%. The corresponding gross and net efficiencies were about 18% and 8%, respectively, with an associated uncertainty < 1.4%. The LHVs of waste were in good agreement with those measured by a calorimetric bomb, even if they had a higher uncertainty level of about 5.6%.

1. Introduction

Substitution of fossil fuels with renewable sources is one of the key factors for achieving the EU 2020 and EU 2030 goals [1]. Among the different renewable energy sources municipal solid waste can make an important contribution because of the large amount renewable materials present in it, such as paper, wood, textiles and organics [2]. Direct combustion followed by energetic recovery of the heat generated is one of the most diffused and effective practices worldwide. In the EU28 about 61 Mtonnes of municipal solid waste, corresponding to about 26% of the total amount generated, are processed for energetic recovery in about 450 waste-to-energy (WtE) plants [3,4]. Depending on the geographical area, climatic conditions and local legislation, WtE plants can recover only electrical energy (mainly in Southwestern Europe), only heat or both if operated in combined heat and power mode (mainly in Northern Europe) [5]. The most diffused technical solution adopted for WtE plants is based on a waste combustor coupled with a Rankine steam cycle [6]. Different combustors are currently available at the industrial level, such as rotary kilns and fluidized bed but, due to its high availability, flexibility and efficiency, moving grates are the most used worldwide [6–9]. In the last years the greatest concern about waste combustion is due to its environmental and human health impact [5]. Nowadays, both stringent legislation on gaseous emissions [10] and modern gas cleaning technologies [5,9] have led some reseachers to state that new WtE plants are among the cleanest and most reliable sources of energy [11]. For these reasons most of the attention concerning WtE plants is currently focused on their efficiency and performances for increasing energy recovery. An average efficiency of 21.7% was reported by the Confederation of European Waste-to-Energy Plants (CEWEP) [3] for those facilities recovering only electrical energy, whereas for those operating in combined heat and power mode, average electrical and heat recovery efficiencies of 15% and 37.1%, respectively, have been reported. Similarly Tabasova et al. [9] reported a power generation ranging from 0.3 to 0.7 MWh/tonne for combined heat and power and exclusively electricity recovery plants, respectively. These parameters are also influenced by the size of the WtE plant, technologies (*e.g.* gas cleaning systems) and the climatic conditions. Furthermore these figures were generally obtained by an ex-post analysis and are useful for evaluating the performances of the plant in a given period (*e.g.* one year). Methods and systems able to return promptly reliable information about real-time performances are of fundamental importance for effectively and efficiently managing the plant. Among the information necessary for this goal (*e.g.* electricity, heat,

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auxiliary fuels), the lower heating value (LHV) (kJ/kg) of the waste burned is one of the most important yet difficult to obtain parameters. In fact, the composition of municipal solid waste is subject to a significant spatial and temporal variation [12] making its composition and consequently its LHV quite variable. In general the LHV can be determined by three different approaches: proximate and / or ultimate analysis; direct methods; indirect methods. Proximate and ultimate analyses as direct methods, widely reported in the literature [13–16], are based on the information obtainable from more or less complex laboratory analyses. For this reason they are not suitable for the case considered since they are costly, lengthy [13] and are able to return data only on the specific waste sample analysed (*i.e.* ~ 1 kg) with limited representativeness for the whole amount of waste burned (*i.e.* >100 tonnes/day). On the other hand, as recommended by the EC guidelines [17], indirect methods using the whole combustor and boiler system as calorimeter are more indicative and potentially able to furnish continuous and real time information useful for the energetic management of the plant. Considering the lack of literature about this topic, the present study reports the implementation and analysis of the indirect method for measuring the LHV of waste and its use for calculating the energetic efficiency of an existing WtE plant. The uncertainty of the indirect system was assessed and results are also compared with those obtained by the direct methods based on laboratory analyses.

2. Materials and methods

The study was carried out on an existing WtE plant for not hazardous municipal waste operating in central Italy with technical features similar to those of other facilities operating in Southwestern Europe.

2.1. Existing WtE

The plant consisted of four main sections (Fig. 1): Grid combustion of 14.5 MW; a heat recovery steam generator (HRSG); gas cleaning; a 3000 kW steam turbine power plant. The first section consisted of three moving grids enclosed by an adiabatic combustion chamber. Waste was loaded from the storage tanks into the combustor feeder by a crane bridge, whereas primary combustion air was supplied under the girds by electric fans. Movement of the grids conveyed the waste from the feeding to the discharge sections where the slags were extracted by water baths and belt conveyors. From the grid the combustion gases first moved to the combustion chamber, on top of which the secondary air was introduced, and then to the post-combustion chamber. The latter was also equipped with auxiliary fuel (*i.e.* diesel) nozzles for maintaining the gas temperature > 850 °C, if necessary, as required by the EU legislation on WtE. At the post-combustor outlet the gases entered the HRSG consisting of the following three main components according to the gas flow: evaporator (EV); super heater (SH); economizer (ECO). In the EV the heat of the gases was used for generating saturated steam at about 250 °C and 40 bars. The saturated steam was then withdrawn from the evaporator drum and superheated to about 380 °C in the SH and then expanded in the bleed steam turbine. After expansion the steam was condensed at about 45 °C and 0.1 bar in the air-cooled condenser and then pumped to the degasser, fed by the bleed, operated at about 2.0 bars at 130 °C. From the degasser the water was pumped up to 48 bars and inserted in the ECO for pre-heating by the exhaust gases from the SH to about 250 °C before being reintroduced again into the evaporator. At the economizer outlet the gases entered the semi-dry basic reactor for removal of acid compounds and then the fabric filters. Between the fabric filters and the basic reactor active carbon was also injected for heavy metals and further dioxin removal.

2.2. LHV and efficiency measurement

Measurement of the LHV of the waste by the indirect method was performed by a mass and energy balance carried out at the combustor and HRSG system as a whole (Fig. 2) on the basis of Eqs. (1) and (2). Considering that all the parameters of Eqs. (1) and (2) can be measured, calculated and/or assumed on the basis

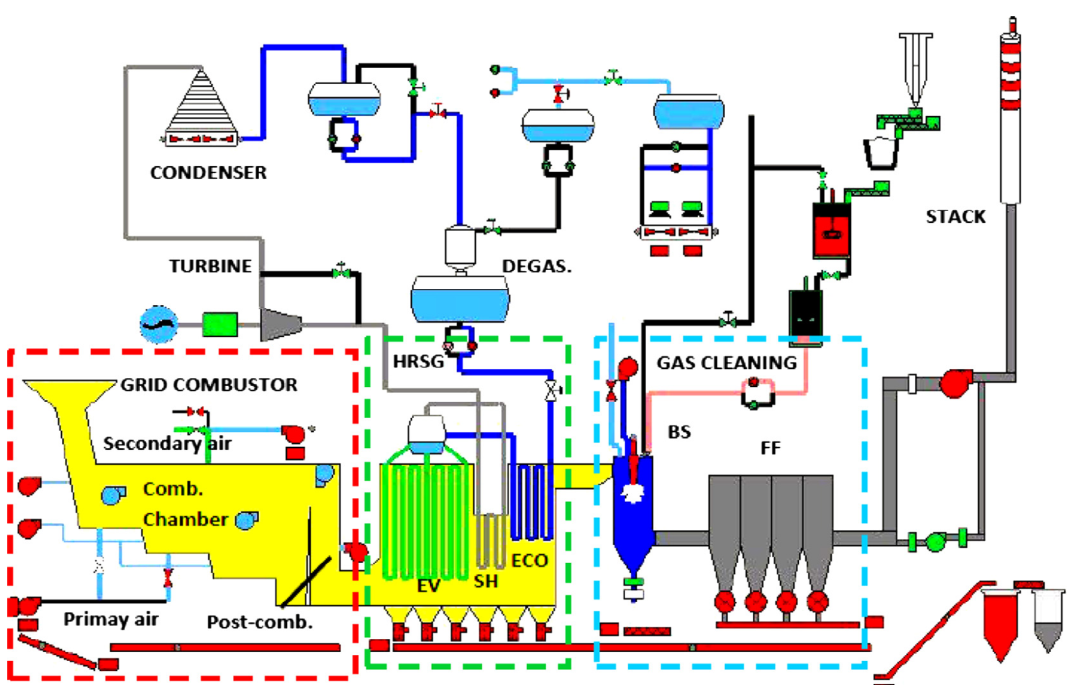

Fig. 1. Schematic of the waste-to-energy (WtE) plant and main components. (HRSG=heat recovery steam generator – EV = evaporator – SH = super heater – ECO = economizer – BS = basic reactor – FF = fabric filters).