Waste Management xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Waste Management

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

A practical method to calculate the R1 index of waste-to-energy facilities

Federico Viganò *

Department of Energy, Politecnico di Milano, Via Lambruschini 4/A, 20156 Milan, Italy
LEAP (Laboratorio Energia Ambiente Piacenza) Scarl, Via Bixio 27/C, 29121 Piacenza, Italy
MatER (Materials and Energy from Refuse) Study Centre, c/o LEAP Lab, Italy

ARTICLE INFO

Article history:
Received 27 February 2017
Revised 26 September 2017
Accepted 28 September 2017
Available online xxxx

Keywords:
R1
Waste-to-Energy
Energy efficiency
Lower Heating Value, LHV
Energy content

ABSTRACT

According to Directive 98/2008/EC, the operation carried out by an incinerator of Municipal Solid Waste (MSW) is classified either as energy recovery (R1) or as disposal (D10) depending on the result achieved by the application of the R1 formula. In 2011 the DG Environment of the European Commission (EC) issued some non-binding guidelines on the interpretation of such a formula that clarified many aspects related to its application. A point not fully clarified by the EC guidelines is the determination of the energy contained in the treated waste (E_W). For this term of the formula, reference is made to the indirect method for the calculation of boiler thermal efficiency, as defined by the norm EN 12952-15. However, the application of such a norm to an entire year of operation of a Waste-to-Energy (WtE) boiler is not immediate. Therefore, a practical method for the calculation of the E_W term has been developed in the framework of a collaboration between the MatER Study Centre and the Lombardy Region (Italy). The method is based on: (i) the identification of the most reliable data available from the Distributed Control System (DCS) of the plant; (ii) the definition of a control volume around the boiler(s) also based on the availability of data; (iii) the closure of the mass balance for such a control volume; (iv) the energy balance of the same control volume that gives, thus, the E_W term of the R1 formula. The method has been applied in 2015–2016 to nine plants, generating a number of interesting data reported and discussed in this work, such as R1 index values, Lower Heating Values (LHV) of the treated wastes, main sources of energy losses in WtE boilers, etc. For one case study, discussed in detail in this work, the law of propagation of uncertainties has been applied according to the ISO/IEC Guide 98–3, leading to the assessment of the accuracy of the method, which resulted in ±2.4% with a confidence level of circa 95%.

1. Introduction

According to Directive 2008/98/EC (EU, 2008), the operation carried out by an incinerator of Municipal Solid Waste (MSW) is classified either as energy recovery (R1) or as disposal (D10) depending on the result achieved by the application of the R1 formula (Eq. (1)).

$$R1 = (E_P - E_I - E_F)/(0.97 \cdot (E_W - E_F)) \cdot CCF \quad (1)$$

The directive gives concise definitions of the various terms, leaving room for arbitrary interpretations. Therefore, in 2011, the DG Environment of the European Commission issued some non-binding guidelines on the interpretation of such a formula (EC, 2011). Many operative aspects were clarified, although only conceptual specifications were given for the quantification of the E_W term (the energy contained in the treated waste). In fact, for the determination of the E_W term reference is made to the indirect method for the calculation of boiler thermal efficiency, as defined by the norm EN 12952-15 (CEN, 2003).

Such a norm regards the acceptance testing of water-tube boilers fed with solid fuels different from waste (as explicitly stated by the norm). To determine the E_W term, the EC guidelines also refer to two additional documents, one (RF, 2008) available only in French, the other (FDBR, 2000; 2013) available both in German and in English. Both these documents regard the acceptance testing of Waste-to-Energy (WtE) boilers and apply the indirect method for the calculation of boiler efficiency, as defined by the EN 12952-15 norm, to the specific case of waste-fired boilers. However, the application of any of the three procedures (the one described in the norm and the other two derived from it) to an entire year of operation of a WtE facility is not immediate. Indeed, the three procedures are designed to be applied to a single boiler at a time, in very controlled conditions (typical of acceptance testing), with the proper collection of bottom and boiler ashes, with the

* Address: Department of Energy, Politecnico di Milano, Via Lambruschini 4/A, 20156 Milan, Italy.
E-mail address: federico.vigano@polimi.it

https://doi.org/10.1016/j.wasman.2017.09.036
0956-053X/

Nomenclature

A	Ash (in waste)
BREF	BAT Reference document
CEMS	Continuous Emissions Monitoring System
CHP	Combined Heat and Power
CM1	Combustible Matter of type 1
DA	Dry Air
DG	Directorate General
DEA	Dry Excess Air
FA	"False Air"
FGTS	Flue Gas Treatment System
LHV	Lower Heating Value
MSW	Municipal Solid Waste
NCV	Net Calorific Value (=LHV)
PM	Particulate Matter
SCR	Selective Catalytic Reduction
SRF	Solid Recovered Fuel
WtE	Waste-to-Energy
BAT	Best Available Technique
CCF	Climate Correction Factor
CEWEP	Confederation of European WtE Plants
CM2	Combustible Matter of type 2
DCA	Dry Combustion Air
DCS	Distributed Control System
DSFG	Dry Stoichiometric Flue Gas
EfW	Energy-from-Waste
FGR	Flue Gas Recirculation
H	Humidity (absolute, of air)
M	Moisture (in waste)
MU	Measurement Unit
NG	Natural Gas
RDF	Refuse Derived Fuel (=SRF)
SNCR	Selective Non-Catalytic Reduction
URW	Unsorted Residual Waste
WV	Water Vapour

insulation of the water-/steam-side (i.e. no continuous or intermittent blow-down), etc. They use arithmetically averaged values (flow rates, temperatures, pressures, concentrations) instead of weighted averaged values, since during acceptance testing operating conditions must be kept as stable as possible. They do not take into account secondary aspects that can be neglected on the time basis of an acceptance test, but that give appreciable contributions on annual basis, like water vapour coming from bottom ash quenching baths, which enters the combustion chamber or is collected and injected together with secondary air into the gas-side of the boiler.

Currently in Italy there are forty-one Municipal Solid Waste (MSW) incinerators (ISPRA, 2016), including also those fed with RDF/SRF only. Eleven of these plants (of which nine for general MSW and two for RDF/SRF only) are in Lombardy, making it the leading Italian region for WtE operations. Moreover, in Italy most of the waste management rules are set by regions and there have only recently been some interventions (RI, 2014; 2016) of the national government to rationalize WtE and food waste operations. Therefore, in 2012, Lombardy was the first Italian region to set the requirement (RL, 2012) for MSW incinerators to annually report the R1 index achieved, as well as to authorize some incinerators for both R1 and D10 operations instead of D10 only. Furthermore, Lombardy's rules require that within 2017 and, afterward, at least every five years, the R1 calculation must be either carried out or verified by an independent body.

In the first three years of application of these rules (2012–2014), the various operators of MSW incinerators active in Lombardy presented very nonuniform calculations, with results showing, in some cases, great variations from year to year. This variability was mainly due to the various methods adopted to determine the E_W term, ranging from approximate energy balances to averaging of the results of sample analysis. Therefore, in the framework of a long-lasting collaboration between the Lombardy Region and the MatER Study Centre, the hereinafter called MatER guidelines (Viganò, 2017) have been developed. Such a document defines and presents a practical method to annually calculate the R1 index achieved by a WtE facility.

The MatER guidelines adhere as strictly as possible to all the indications of the EC guidelines, by adopting the procedure set by the EN 12952-15 norm. The few departures from those documents are due to, on one hand, the will of warranting physical coherence and, on the other hand, the adaptation of the procedure to the application on the time basis of one year of operation, whilst keeping as simple as possible the overall procedure.

Although a full survey on the state of application of the R1 formula in the European countries has not been carried out, most of the difficulties encountered in the Lombardy Region are likely to be encountered also in other countries. For example, the UK government prepared a proforma spreadsheet (UK, 2016) for calculating the R1 of WtE facilities based on the EC guidelines, on the FDBR norm and on some other sources. Even though the method is not fully documented, the calculation of the E_W term is clearly based on an adaptation of the FDBR method to the annual basis, since the required inputs are annual amounts (tonnes of steam produced, cubic meters of preheated air and so on).

The CEWEP Energy Report III (Reimann, 2012), which calculated the values of R1 index achieved by 314 European WtE plants in 2007–2010, evaluated the E_W term by means of initial energy balances as mentioned in the EC guidelines, in combination with the NCV formula from BREF WI Chapter 2.4.2.1 (EC, 2006) and the FDBR guideline.

Only a few studies can be found in the literature with a specific focus on the methodology to calculate the R1 index and the E_W term. A recent article (Ozansoy, 2016) on the possible improvements of the R1 formula, states: "The discussion on the R1 thermal energy efficiency formula and its application in the assessment of EfW plants is still in its infancy days and is yet to attract the interest of academic research".

The need to adapt standard methods for the application on annual basis is evident. The method presented in this work, in addition to this adaptation, introduces also some other peculiar innovations.

2. Determining the E_W term

The basic principle introduced by the norm EN 12952-15 to allow the application of the indirect method for the calculation of the boiler efficiency is the definition of a closed control volume. Once a control volume is set, mass and energy balances can be applied to all the material streams crossing the boundary of such a volume, as well as to all the other energy flows (i.e. in the forms of work and heat).

Please cite this article in press as: Viganò, F. A practical method to calculate the R1 index of waste-to-energy facilities. Waste Management (2017), https://doi.org/10.1016/j.wasman.2017.09.036