Assessing the 3T method as a replacement to R1 formula for measuring the efficiency of waste-to-energy plants

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Extended Abstract

In general, technologies that utilize waste streams for energy production are defined as "energy from waste". But "waste-to-energy" is the term that addresses the energy production by means of thermal treatment of non-hazardous waste. Although, novel thermal processes like gasification and pyrolysis are becoming more popular, the term "waste-to-energy" primarily refers to combustion of municipal solid waste. Nonetheless, this is not a restrictive terminology since on one hand other thermal processes are gradually gaining ground and on the other hand technological innovation allows the efficient thermal treatment of hazardous waste.

Historically, all the "Waste Framework Directives" that have been issued by the European Commission, separate the waste management strategies into Recovery Operations and Disposal Operations. The Directive 2008/98/EU of the European parliament and of the council of 19 November 2008 on waste and repealing certain Directives, defines the Recovery Operations on ANNEX I and the Disposal Operations on ANEX II. Waste-to-energy technologies have the inherent problem that they do not belong entirely on the one category or the other. On one hand, waste is used principally as a fuel for

energy generation and thus they belong to category 1 of the Recovery Operations, i.e. R 1. On the other hand, the residues of the treatment are landfilled on land and thus they belong to category 10 of the Disposal Operations, i.e. D 10. This issue has been of high importance because each waste-to-energy facility could be considered an energy production or a disposal facility according to the category that is assigned. This influences the level of the gates fees that should be paid to the facility in order to receive the waste. In case that a waste-to-energy facility is categorized as a D10 then the gates fees that should be paid are identical to the landfill tax, which is not preferred.

In order to address this issue European Commission integrated the R1 formula (that was developed by Dr. Dieter Reimann) in the second revision of the Waste Framework Directive of 2008 and has kept it since then. The R1 formula is defined in equation 1 as follows:

$$R1: (E_p - (E_f + E_i)) / 0.97 * (E_w + E_f) \qquad (1)$$

With the symbols having the following meanings:

E_p: annual energy produced as heat or electricity. It is calculated with energy in the form of electricity being multiplied by 2.6 and heat produced for commercial use multiplied by 1.1 (GJ/year)

E_f: annual energy input to the system from fuels contributing to the production of steam (GJ/year)

E_w: annual energy contained in the treated waste calculated using the net calorific value of the waste (GJ/year)

E_i: annual energy imported excluding Ew and Ef (GJ/Year)

0.97: factor accounting for energy losses due to bottom ash and radiation.

Therefore, practically the formula can be “translated” as shown in equation 2:

$$R1 = \frac{(\text{Energy produced} - \text{Energy from fuels} - \text{Other energy imported})}{0.97 * (\text{Energy of waste input} + \text{Energy from fuels})} \qquad (2)$$

The parameters for each waste-to-energy facility are inserted to the R1 formula and the ones who have values over 0.65 (or 0.6 for older plants) achieve the R1 status. It should be denoted that the R1 formula played an important role in assisting the waste-to-energy plants to receive a legal status, especially during a period that the specifics of the waste-to-energy technologies where not fully understood by the lawmakers. Therefore, the significance of the R1 formula for the waste-to-energy sector should be stated.

Nonetheless, the formula has several inconsistencies that have been addressed by several researchers since its introduction. First, the formula is not thermodynamically correct and the results that are derived from the formula are be comparable to technologies out of the waste-to-energy bubble. It must be pointed out that the R1 formula does not claim to be a pure energy efficiency formula but a "utilization efficiency" formula. But this is a statement that is far from reality since on one hand the "energy produced" refers to the gross energy production and not the net energy production and on the other hand the fact that electricity or heat enters the network does not necessarily means that it will be utilized. Second, there are several ambiguities in the definition of the terms E_w and E_f. Third, the term E_p is defined as the "annual energy produced as heat or electricity. It is calculated with energy in the form of electricity being multiplied by 2.6 and heat produced for commercial use multiplied by 1. 1 (GJ/year)". But the factors 2.6 and 1.1 do not have a meaning although they resemble to the primary energy factors. Also, although the electricity production is promoted with this 2.6 factor, the formula fails its scope since a significant production of heat is necessary in order to achieve R1 status. Fourth, the term "0.97" is used to reflect the energy losses due to bottom ash and radiation, but this is also a value that has no actual thermodynamic meaning.

Except the inconsistencies that can be found in the R1 formula, there also issues that remain unanswered. The R1 formula is restricted to incineration plants and does not provide a solid framework for the integration of novel technologies like pyrolysis and gasification which produce gaseous, liquid and solid fuels with significant heating value. Also by utilizing a formula with no thermodynamic basis the comparison with other competing waste management strategies, e.g. combustion vs landfill gas, becomes impossible. Finally, waste-to-energy plants are not only energy production units but also metal recovery facilities. It is the case, that almost 1% of the total municipal solid waste by weight is aluminum. Also, the quality of the recovered metals is dependent on their oxidation level. Different technologies would provide a different range and quality of recovered metals but this is not considered from the R1 formula.

In order to address the previously mentioned issues, this study introduces a new method for assessing the efficiency of waste-to-energy plants. For the development of the method we consider that the most significant parameters are the following:

- Combined Heat and Power efficiency, because it is the most important parameter for assessing an energy plant.
- Physical exergy efficiency of Heat and Power, defined as B_{ph}. The reason is that electricity has significant higher quality than heat and by means of exergy we can reflect this aspect without the addition of any arbitrary factors (like 2.6).
- Chemical exergy efficiency of the recovered metals, defined as B_{ch} to reflect the recovery of the metals of interest
- Chemical exergy efficiency of the products of thermochemical conversion defined as Prod-B_{ch}. Thus, the syngas from gasification or the biooil from pyrolysis can be taken into consideration.

By combining these four parameters we can develop a trapezoidal radar graph which provides a generalized solution for all waste-to-energy plants as it is shown in Figure 1.

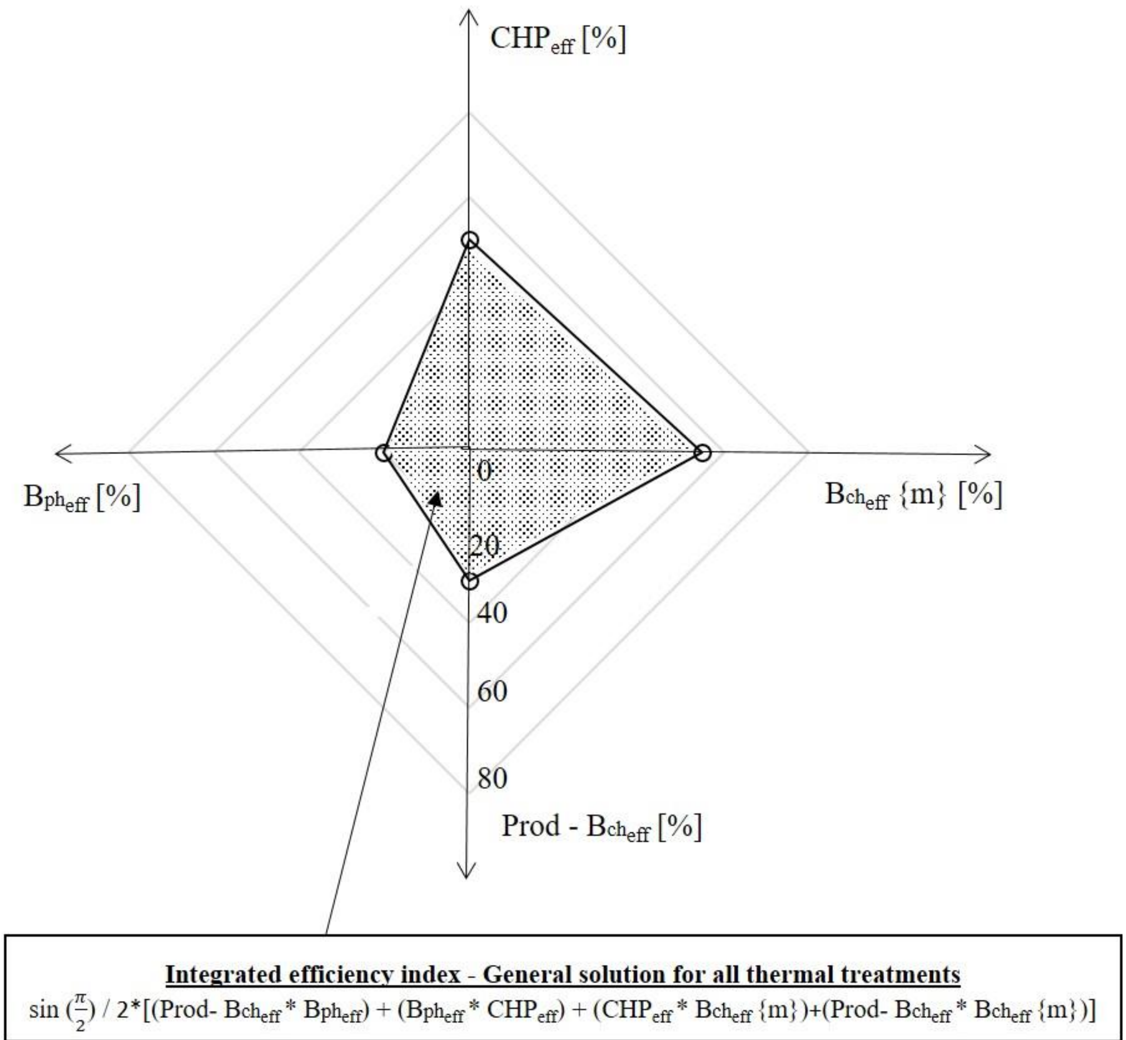

Figure 1. Generalized solution for assessing the efficiency of waste-to-energy plants

The overall efficiency can be assessed by calculating the area of the trapezoid of Figure 1. This generalized solution is defined from now on as “Trapezoidal Thermodynamic Technique” or with the abbreviation “3T”. As we mentioned in the beginning of this abstract, the clear majority of the waste-to-energy plants are incinerators of municipal solid waste. Thus, the generalized solution of Figure 1 can be simplified to the solution of Figure 2.

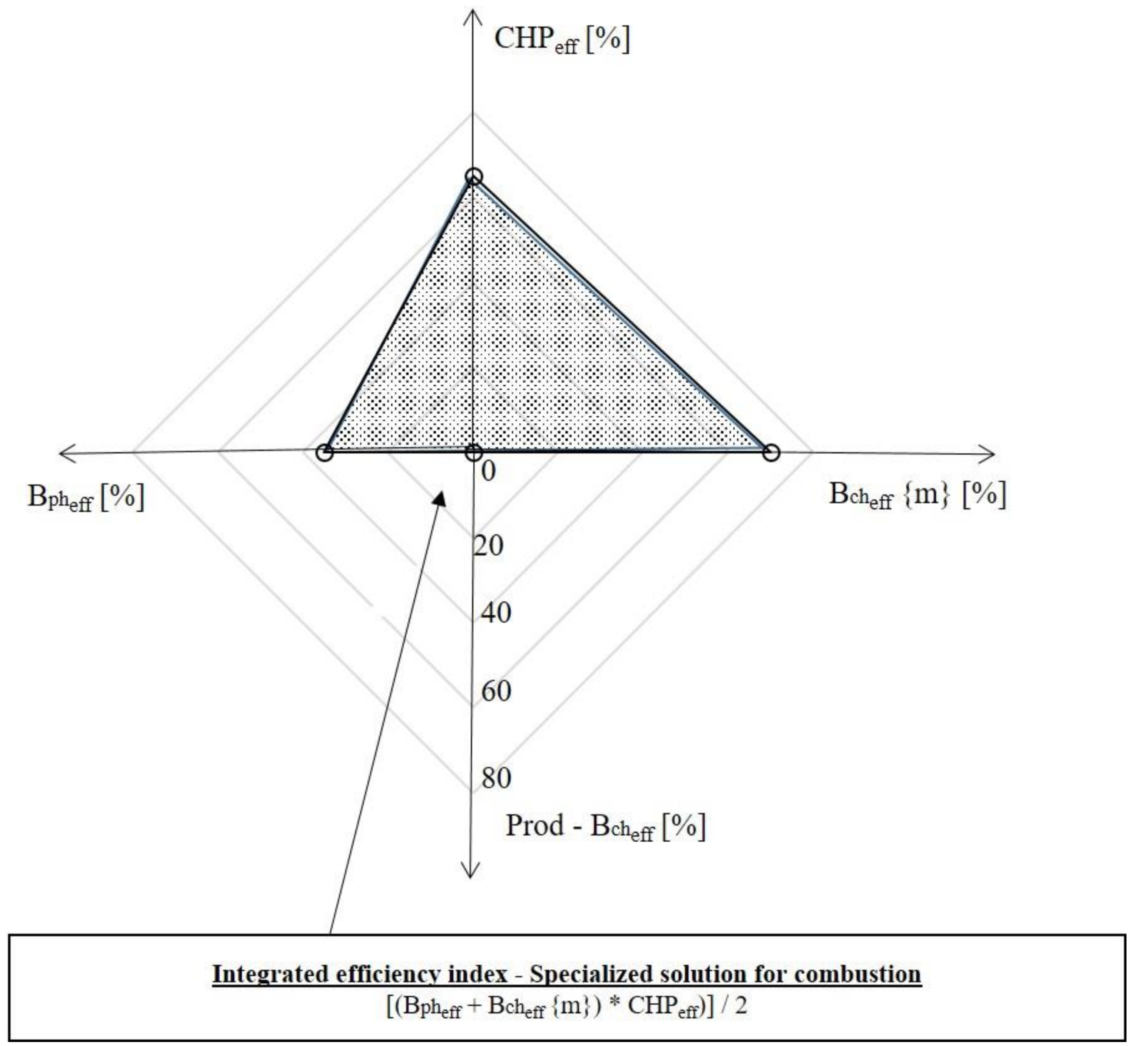

Figure 2. Specialized 3T solution for combustion waste-to-energy plants

In Figure 2 the trapezoid is simplified to a triangle because the products of combustion do not have any heating value. Thus, the method can be defined as "Triangular Thermodynamic Technique", where the overall efficiency can be calculated from the area of the triangle.

The overall aim of this study is to suggest an objective solution that can be used to develop a database of both visual and numerical data. In Figure 3, we present a ternary diagram where two different combustion waste-to-energy plants are placed in different areas of the ternary diagram according to their performance in each individual parameter, i.e. CHP – Physical exergy – Chemical Exergy. The parameters have been normalized to add to 100 and the size of the triangles represents the efficiency of the plants and is in accordance to the area that was calculated from the specialized solution of Figure 2. Therefore, we could say that the idea of Figure 3 can work as an efficiency map for waste-to-energy plants.

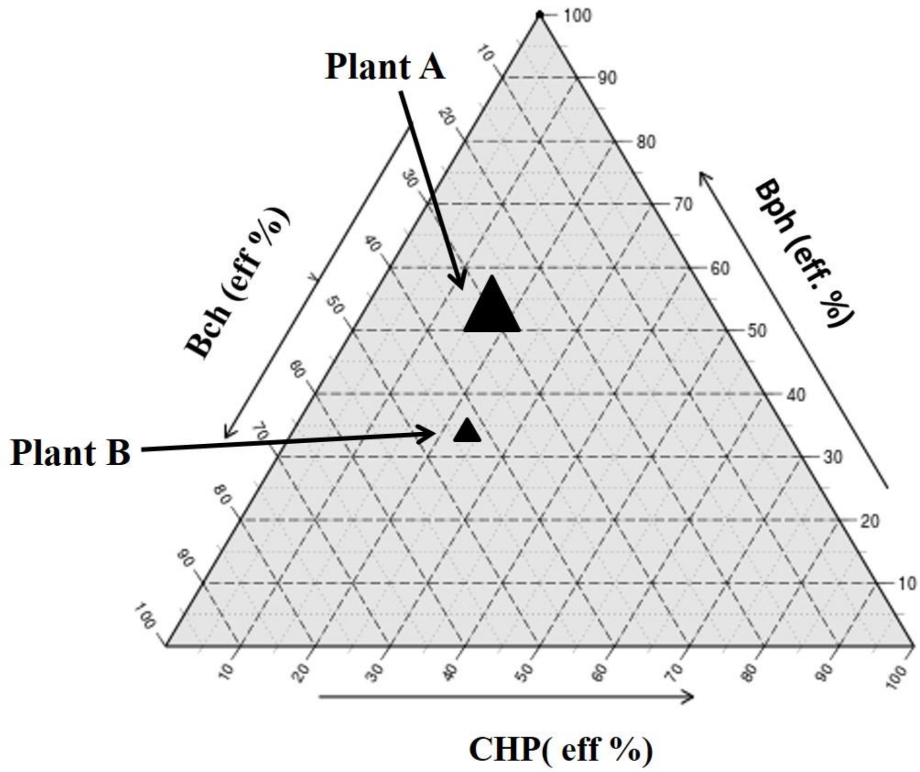

Figure 3. Example of an efficiency map of waste-to-energy plants

Reference

European Commission. (2008). Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives**.** Brussels, Belgium.