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ANALYSIS OF THE FUEL COMPOSITION OF HAZARDOUS WASTE INCINERTORS WITH RESPECT TO THE CONTENT OF BIOMASS AND FOSSIL ORGANIC MATTER

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SUMMARY: New directives of the European Union requires operators of waste-to-energy (WTE) plants to report the amount of electricity that is produced from biomass in the waste feed, as well as the amount of fossil CO2 emissions generated by the combustion of plastics. Up to now the standard method for determining the portion of renewable electricity and fossil CO2 emission is sorting of wastes into defined fractions of fossil and biogenic waste components and determining the calorific value (fossil carbon content) of these fractions. From this the share of “renewable” electricity (produced from biomass) and the fossil CO2 emissions can be calculated. This practice is labour and cost-intensive. Therefore it is usually carried out only once a year which provides only a momentum analysis of limited significance. This paper describes an alternative method for determining the biomass content in feed of WtE plants. The approach is based on standard operating data derived routinely from incinerators (e.g., volume of flue gas, O_2 and CO_2 concentration in the flue gas, steam production, amount of solid residues, …). These data are used to set up 6 mass and energy balances that allow determining the amount of biogenic and fossil organic matter in the waste feed. The advantages of the balance method are: known uncertainty range of the result, temporal resolution of the result down to daily mean values, low implementation and virtually no permanent costs. Currently the method is being implemented in more than 20 WTE plants in Europe with a collective waste throughput of 3,000,000 tons. The paper provides an overview of the operating experience of the balance method at these plants.

1. INTRODUCTION

Recent regulations of the European Community (European Parliament, 2001 & 2003) have led to new research questions:

1. What is the content of fossil organic and biogenic carbon in mixed wastes (e.g. household wastes) to be burned for energy recovery? This information is required in the frame of CO_2 trading
2. What is the fraction of electricity produced from biomass in WTE plants? This “green”

electricity is subsidized in some European states.

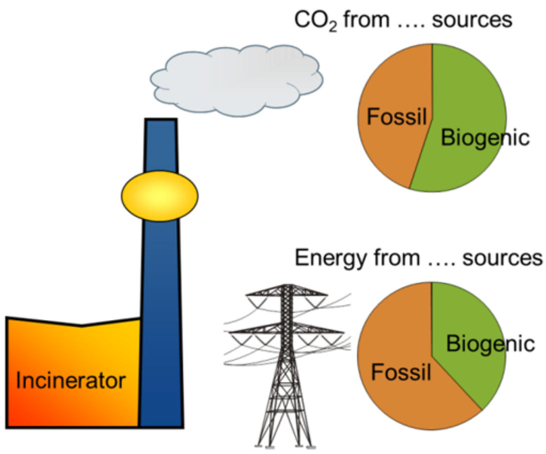

Figure 1. Research question (schematic illustration)

Until now the standard method to answer these questions has been sorting of wastes into more homogenous fractions (such as paper, plastics, glass, metals, textiles, compound materials, etc.) and determining the physical and chemical parameters of interest in each fraction. This approach is time consuming and labour intensive. The results are usually characterized by high uncertainties since a large fraction is often not analyzed due to the lack of visual recognisability. Furthermore recent investigations have shown that waste composition shows considerable variations even over time periods of a few days so that a few single sorting campaigns are not sufficient to calculate a reliable annual average (Morf et al., 2003).

In addition to sorting analysis the following alternative methods have been developed in the recent years (Staber et al., 2008): Selective Dissolution Method, Radiocarbon Method, and Balance Method. The first approach is based on the selective dissolution of biomass in a mixture of sulfuric acid and hydrogen peroxide (van Dijk et al., 2002). The method was originally developed for determining the biodegradable component of compost made from domestic waste. The reliability of the results obtained by the selective dissolution method is compromised due to the fact that some biogenic substances like lignin are not dissolvable in the applied solution whereas some fossil organic components are. Moreover, similar to the sorting analysis, the problem of sampling heterogeneous materials exists: large sample of heterogeneous waste have to be representatively transferred into a few grams for the final chemical analysis.

Another alternative approach is the 14C method (Kneissl et al., 2001). It links the biogenic carbon content of wastes to the concentration of the radioactive isotope carbon-14 (14C, half-life: 5730 years) in the carbon dioxide released during combustion. Thereby it allows a distinction of biogenic (modern) carbon, which exhibits the current 14C level, and fossil carbon in which the originally existing 14C is completely decayed. Thus, the content of biogenic carbon is proportional to its 14C content and can be determined. The approach requires extra flue gas sampling equipment and costly ^{14}C detection. Furthermore due to the fact, that the ^{14}C level of the atmosphere has not been constant in the last century (nuclear bombing tests have doubled the ^{14}C level in the 1960s), results of the radiocarbon method show in considerable uncertainties (Fellner & Rechberger, 2008).

The focus of this paper is given to the so called balance method, which has been developed at the Vienna University of Technology. The method is already routinely applied in several WtE plants in Austria and other European countries. In the frame of an ongoing research project (BEFKÖM) the balance method is for the first time also applied to a hazardous waste incinerator in Austria. Due to some delay in the research project no results about the composition of the waste feed of the hazardous waste incinerator can be provided. Hence, the present paper focuses on the description of the balance method and summarizes some results for different non-hazardous Waste-to-Energy plants in Europe.

2. DESCRIPTION OF BALANCE METHOD

The balance method combines data on the chemical composition of biogenic and fossil organic matter with routinely measured operating data of the waste-to-energy plant. The method is based on five mass balances and one energy balance, whereby the result of each balance describes a certain waste characteristic (e.g. content of organic carbon, heating value, ash content, …). In order to set up the theoretical balance equations the different materials comprised in the waste are virtually divided into four "groups": inert (m_I), biogenic and fossil organic materials (m_B, m_F) and water (m_W). Inert materials include all incombustible solid residues like glass, stones, ashes or other inorganic matter from biowastes and plastics (e.g. kaolin in paper). Biogenic and fossil organic material groups refer only to the moisture- and ash-free organic matter (see Figure 2-left side). Due to the fact that the qualitative composition of organic materials in the waste is usually well known (e.g. biogenic matter encompasses paper, wood, kitchen waste, … and fossil organic matter includes PP, PE, PET, PVC, …), the content of C, H, O, N, S and Cl of the biogenic and fossil organic materials (m_B and m_F) is easily driveable.

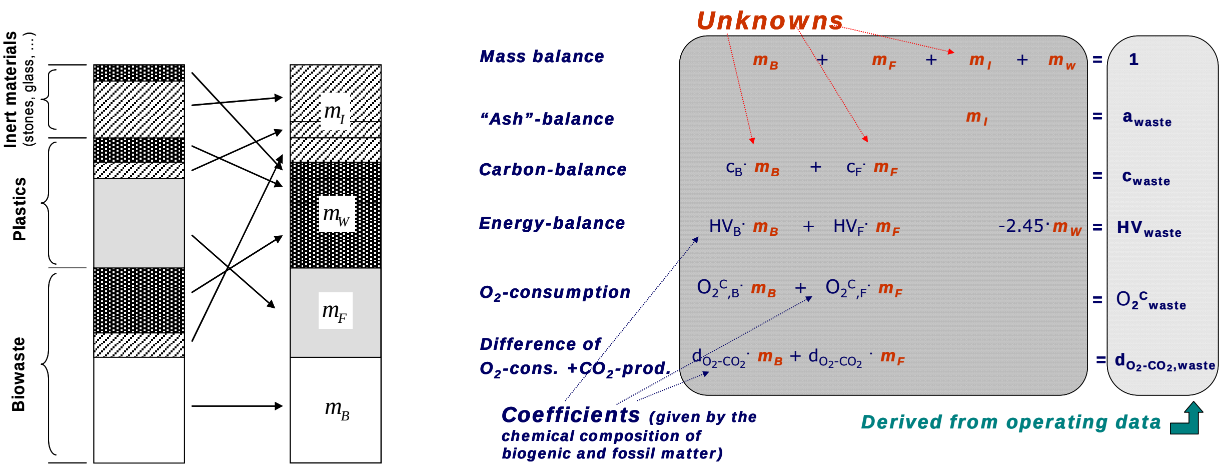

Figure 2. **Left side: Split-up of waste fractions into the four material groups (m_B, m_F, m_W, and m_I); right side: Set of equations of the balance method**

Each balance equation encompasses a theoretically derived term (left side – of equations) that has to be attuned to measured data of the plant (right side of equations). A simplified structure of the set of equations is given in Figure 2 (right side).

The 6 balances can be described as follows:

(a) Mass balance: m_B, m_F, m_W, and m_I represent the mass fraction of each material group. The sum of all mass fractions must equal 1.

(b) Ash balance: The mass fraction of the inert (inorganic) material m_I (the ash content of the waste a_{waste}) corresponds approximately to the quotient of the measured mass flow of solid residues and the waste input of the WTE plant. Mass losses or increases of inorganic matter due to e.g. the decomposition of lime ($C_aCO_3 \rightarrow CaO + CO_2$) or the oxidation of metals ($4Al + 3O_2 \rightarrow 2Al_2O_3$) are insignificant for the ash balance.

(c) Carbon balance: The average content of organic carbon C_{waste} of the waste feed derived from the operating data of the plant (i.e. volume flow of flue gas, the CO_2 concentration in the flue gas and in the combustion air, and the mass flow of the waste input) equals the product of the organic mass fractions (biomass m_B and fossil matter m_F) and their carbon contents (C_B, C_F).

(d) Energy balance: The lower net calorific value of the waste HV_{waste} determined by applying approximation formulas (e.g., Boie, Dulong, Michel) using the elementary content of C, H, O, N, and S corresponds to the calorific value derived from operating data of the plant (steam production, the net enthalpy of steam cycle, the mass flow of the waste input, and the energy efficiency of the boiler).

(e) O_2 consumption: The combustion of the organic matter consumes oxygen. Information about the chemical composition of the fuel (in particular the concentration of C, H, O, N, S, and Cl of the biogenic and the fossil material) allows evaluation of the consumption of oxygen O_2^C waste in the combustion air. This amount has to match with the oxygen depletion observable in the flue gas using operating data about the volume flow of flue gas, the O_2 and CO_2 concentration in the flue gas and in the combustion air, and the mass flow of the waste input.

(f) Difference between O_2 consumption and CO_2 production: During the combustion of solid fuels O_2 is consumed and CO_2 is simultaneously produced. Due to the difference in the chemical composition of biogenic and fossil organic matter (in particular concerning the ratio of hydrogen and oxygen content) both materials show strong distinctions in their behavior regarding O_2 consumption and CO_2 production. The following example tries to point out this issue: Whereas during the complete combustion of cellulose the consumption of O_2 equals the amount (in moles) of CO_2 generated, during the incineration of polyethylene more oxygen is consumed compared to the production of CO_2. This implies that in case of cellulose combustion, the sum of O_2 and CO_2 concentration in the flue gas (referred to the dry gas) equals the addition of O_2 and CO_2 content in the combustion air, whereas when burning polyethylene, the sum of O_2 and CO_2 in flue gas is lower than in the combustion air. The difference between O_2 consumption and CO_2 production can be assessed using information about the chemical composition of the fuel (concentration of C, H, O, N, S, and Cl of the biogenic and the fossil material). This result is equated to the flue gas data obtained at the incineration plant.

A detailed mathematical description of each equation is given in Fellner et al. (2007). The input data required for the balance method are summarized in Figure 3.

Because the system of equations (set of constraints) used within the balance method is over determined (6 equations for 4 unknowns), data reconciliation can be performed to improve the accuracy of the measurements. The improved values are used to calculate the unknown quantities (m_B, m_F, m_W, and m_I) including their uncertainties. These results are used in conjunction with the carbon balance to determine the amount of fossil CO_2 emissions.

Prior to data reconciliation for determining the mass fractions, the input data (operating data of the plant) are checked regarding their plausibility. Thereto existing correlations between the flue gas and the steam production are used (e.g. during the combustion of organic matter the consumption of one mole O_2 corresponds to an energy generation of 360 to 400 KJ; and the combustion of 1 g organic carbon produces a heat amount of 34 up to a maximum of 44 kJ).

The calculations according to the balance method are only performed with plausible data.

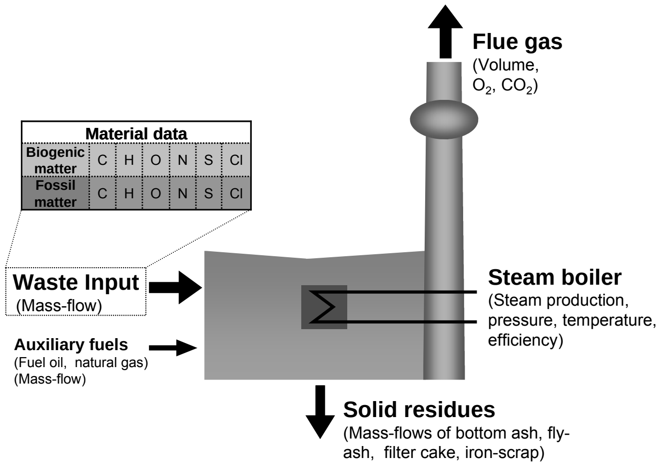

Figure 3. Required input data of the balance method

3. RESULTS

As mentioned above the balance method is already applied in several WTE plants. In the following results of different applications are summarized.

3.1. Waste-to-Energy plant in Austria applying the Balance Method

Figure 4 shows the trends of energy sources (from biogenic matter) on a monthly basis for an Austrian WTE plant. The results indicate a varying composition of the waste feed throughout the considered year. The ratio of energy from biogenic sources varies from 42% (February) to 59% (October). During the same time an inverse fluctuation of the fossil carbon content is observed (not shown here). This implies, that single sampling campaigns (as used for sorting analysis, or selective dissolution method) will inevitably lead to wrong results.

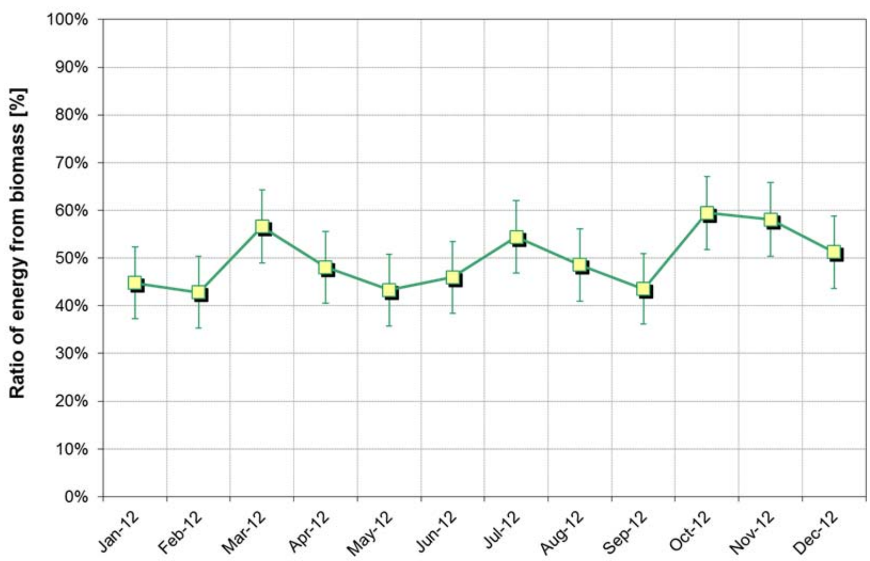

Figure 4. Ratio of energy produced from biomass

Considering annual values (see Figure 5) the fraction of the energy content of biomass in the waste feed amounts to 50.0 ± 2.8 %; the remaining part is generated from fossil fuels (plastics in the waste feed and auxiliary fuels). The annual fossil CO_2 emissions from the WTE plant are 38,400 ± 1,800 tonnes, in relation to 50,100 ± 1,900 tonnes of CO_2 from biomass. The decrease in uncertainty of annual values in comparison to monthly values is due to the statistical reduction of uncertainty when aggregating mean values.

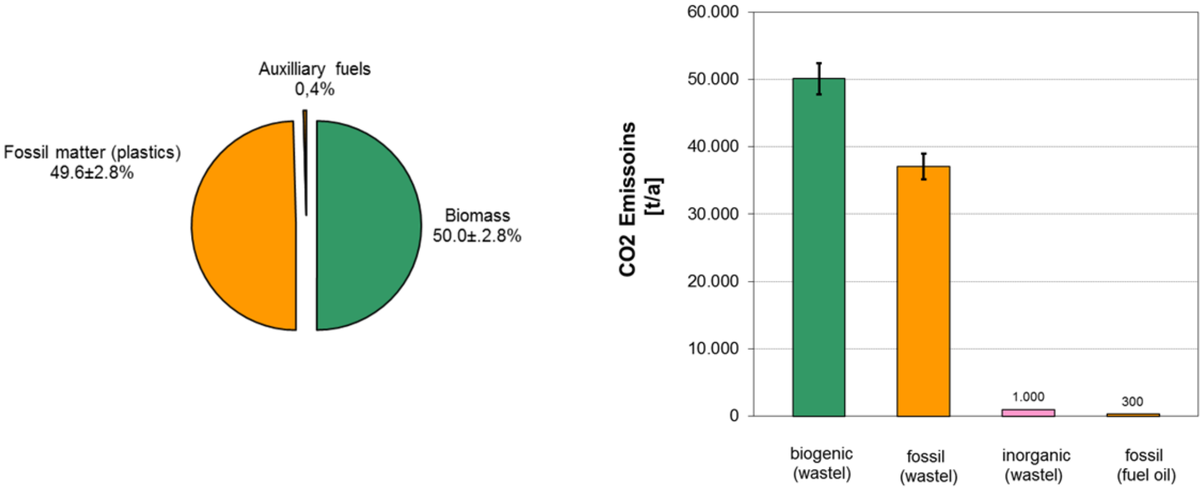

Figure 5. Annual results for the ratio of energy sources (left) and the origin of CO_2 emissions (right)

3.2. Application of the Balance Method in different European Countries

In the meantime the balance method has been applied to more than 20 different waste incinerators in 8 European countries. In Figure 6 the results of some of those plants (in terms of the ratio of energy from biogenic sources) are summarized. The values for the different plants vary between 31% and 61%. Also for the same plants (e.g., WTE 2) considerable variations in the waste composition (annual mean values) are observable for different years (36% to 44%).

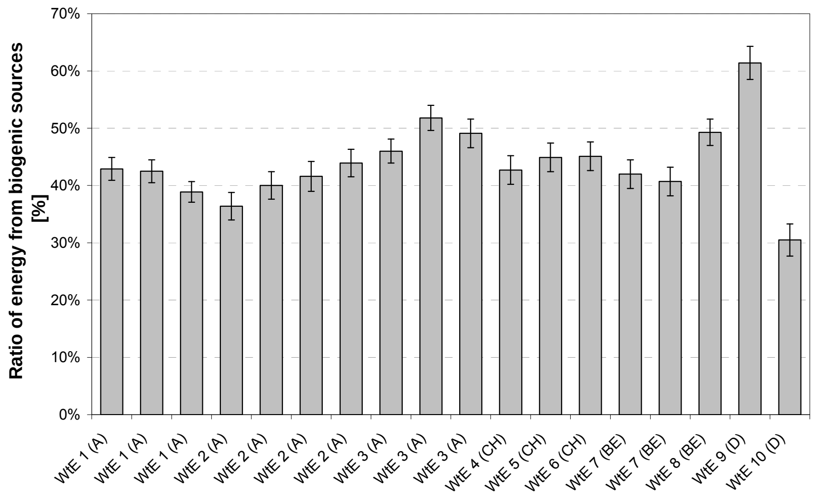

Figure 6. Summary of results of the balance method for 10 different WtE plants in 4 European countries (A … Austria, CH … Switzerland, BE … Belgium, D …. Germany)

3.3. Inter-Comparison of the Balance Method with the Radiocarbon Method

In cooperation with the Swiss Federal Laboratories for Materials Testing and Research (EMPA) the balance method and the radiocarbon method have been applied for a test period of one month to 3 different waste incinerators in Switzerland (Mohn et al., 2008). The inter-comparison measurement at three different plants resulted in an excellent agreement of both methods (see Figure 7). The observed differences in the results were generally far below the methodological uncertainties of each method, thus indicating the reliability of the balance method.

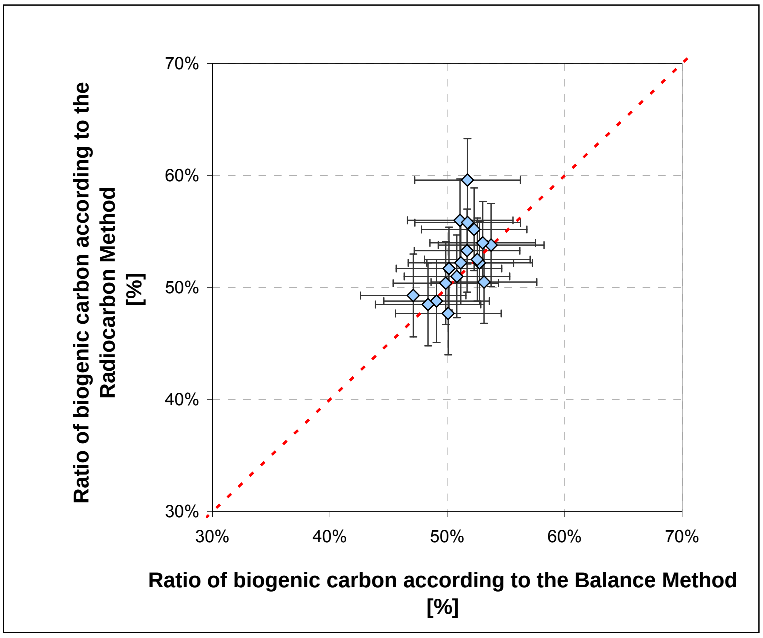

Figure 7. Results of inter-comparison measurements using the balance method and the radiocarbon method

Since the balance method uses only routinely measured operating data, the costs for its application encompass only the efforts for the data analysis. In general the annual costs for the WtE operators applying the balance method are below € 4,000, which is evanescent small in comparison to alternative methods. In the recent year a software for the balance method (BIOMA) has been developed which enables operators to determine their waste composition (e.g., biogenic content) online without additional efforts regarding data analysis. Due to the ongoing plausibility checks of the operating data prior their application in the frame of the balance method, the software is also beneficial for identifying measurement errors (e.g., flue gas volume).

CONCLUSIONS

The balance method determines the waste composition (content of biomass and fossil matter) without additional sampling of input or output streams of the WTE plant. This a major advantage in comparison to alternative methods where number and size of waste samples required have to be large in order to obtain representative results. By contrast, the balance method considers the total waste feed. It uses operating data which are recorded continuously. Hence, operators can evaluate the waste composition for any time period required. Thus, it is possible to identify trends, and also the variability, in the composition of the waste. The results obtained by the balance method are given by an average value and a probable error, which is statistically computed from the uncertainty of all input parameters by error propagation. The assured statistical quantification of the probable error represents a significant improvement compared to existing methods, which either conceal errors or estimate them roughly. Currently the method is routinely applied in more than 20 WtE plants in Europe.

REFERENCES

European Parliament (2001). Directive 2001/77/EC on the Promotion of Electricity Produced from Renewable Sources in the Internal Electricity Market. Official Journal of the European Communities, L283: 33-40.

European Parliament (2003). Directive 2003/87/EC on the Establishing a Scheme for greenhouse gas emission allowance trading within the EU. Official Journal of the European Union, L275: 32-46.

Fellner, J. and Rechberger, H. (2009). Abundance of ^{14}C in biomass fractions of wastes and solid recovered fuels. Waste Management, 29(5): 1495-1503.

Fellner, J., Cencic, O. and Rechberger, H. (2007). A New Method to Determine the Ratio of Electricity Production from Fossil and Biogenic Sources in Waste-to-Energy Plants. Environ. Sci. Technol., 41(7): 2579-2586.

Kneissl, P. (2001). Method for Determining the Relationship of Renewable to Non-Renewable Sources of Engery. WO 02/06730 A1, Austria.

Mohn, J., Szidat, S., Fellner, J., Rechberger, H., Quartier, R., Buchmann, B. and Emmenegger, L., 2008. Determination of biogenic and fossil CO_2 emitted by waste incineration based on $^{14}CO_2$ and mass balances. Bioresource Technology, 99: 6471-6479.

Morf, L.S., Ritter, E. and Brunner, P.H. (2003). Online-Messung der Stoffbilanz auf der MVA Spittelau - Phase B (In German: Online measurement of substance balances at the WTE plant Spittelau), Institute for Water Quality, Resources and Waste Management, Vienna University of Technology.

Staber, W., Flamme, S. and Fellner, J. (2008). Methods for determining the biomass content of waste. Waste Management and Research, 26(1): 78-87.

van Dijk, E. A.; Steketee, J. J.; Cuperus, J. G. (2002). Feasibility Study of Three Methods for Determining the Biomass Fraction in Secondary Fuels; Final Report, TAUW, Deventer, Netherlands.