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Determination of biomass fraction for partly renewable solid fuels

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ABSTRACT

Biomass-based waste fuels are used in many industrial applications since combustion of biomass gives no net emissions of carbon dioxide. Some waste fuels, e.g. RDF (refuse derived fuels), contain not only biomass, but also some fossil material, hence can be classified as partially CO_2 neutral fuels. The biomass fraction of a mixed solid fuel is an essential parameter for the determination of net CO_2 emissions. It is also important to know the accuracy of the different biomass fraction determination methods. In the present study, the biomass fraction of artificially made RDF was determined by means of the SDM (selective dissolution method) in total carbon basis and also by the ^{14}C method in total carbon, weight and calorific value bases. Then the relative accuracy was compared using findings from a previous study. SDM shows very high accuracy in weight and calorific value basis. The ^{14}C method gives comparable results in most cases, but shows considerable deviations for some samples. The SDM results in total carbon basis show less accuracy compared to the other bases. When performing the SDM analysis in total carbon basis, one should correct for ash forming matter in order to increase the accuracy of the biomass fraction determination.

1. Introduction

The world economy is strongly dependent on fossil fuels. Rising fuel prices and the Kyoto Protocol are driving a shift towards renewable energy sources to reduce CO_2 emissions. In that sense, energy from waste plays an important role in tackling climate change, by displacing the use of fossil fuels and by providing a more environmentally sustainable method for waste management. Since wastes or SRF (solid recovered fuels) are generally composed of fossil and biogenic materials, only part of the CO_2 emissions is accounted for in greenhouse gas inventories or emission trading schemes. However, quantifying accurately the biomass fraction is not straight-forward. Hence, development of proper methodologies for the measurement of the biogenic fraction in mixed waste fuels is necessary to be in compliance with the reporting requirements.

RDF (refuse derived fuel), also called SRF (solid recovered fuel), is typically produced by shredding, classifying and drying municipal and industrial solid wastes, and is a very heterogeneous fuel [1–3]. It contains several materials, such as paper, plastics, wood, organic waste, fabrics, rubber and metals in very different compositions, depending on the origin of the waste [1,4]. Table 1 shows compositions of some different RDF materials found in the literature. However, column 2 in the table refers to RDF samples manually sorted by authors. This RDF sample was collected from a cement plant where RDF is used as an alternative fuel in the precalciner unit. The facts that RDF contains a considerable amount of biomass and is also a less expensive fuel, explains the increasing usage of RDF as an alternative energy source in industrial applications [1] [5,6]. Cement industry [7–9] and power plants ([2,4,10]) are few potential examples where RDF is used as fossil fuel replacements.

In Norway, plants with significant CO_2 emissions have to comply with the national emissions trading regulations [12] [13], which are based on the EU Emissions Trading Directive [14]. When reporting net CO_2 emissions, the biomass content (or conversely the fossil fraction) of RDF is a key parameter. It can be represented by weight, calorific value or carbon content.

Four methods for the determination of biomass content and hence fossil fraction in solid recovered fuels are published in technical specification CEN/TS 15440:2006 [15], the subsequent European pre-standard Draft prEN 15440 [16] and later in NS-EN

Abbreviations: AM, artificial mixture; AMS, accelerated mass spectrometry; DAF, dry and ash free; HHV, higher heating value (gross calorific value); NA, not analyzed/not available; PE, polyethylene; PET, polyethylene terephthalate; pMC, percent modern carbon; PVC, polyvinyl chloride; RDF, refuse derived fuel; RSD, relative standard deviation; SDM, selective dissolution method; SRF, solid recovered fuel.

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Nomenclature

$A_{residue}^{total}$ ash content of residue out of total original sample in dry basis (wt%)
A_{SRF} ash content of solid recovered fuel sample in dry basis (wt%)
$C_{bio,SRF}$ biogenic carbon content of solid recovered fuel in dry basis (wt%)
$C_{plast-mix}$ total carbon content of dried plastic mix sample (wt%)
$C_{residue}$ total carbon of dissolution residue out of residue in dry basis (wt%)
$C_{residue-ash}$ total carbon content of residue ash in dry basis (wt%)
C_{SRF} total carbon content of solid recovered fuel in dry basis (wt%)
$C_{Theo,SRF}$ theoretical total carbon content of dried solid recovered fuel sample in dry basis (wt%)
C_{wp-mix} total carbon content of dried wood-paper mix sample (wt%)
$m_{residue-ash}$ weight of residue ash in dry basis (kg)
m_{SRF} weight of total original sample in dry basis (kg)
q_{SRF} calorific value of the solid recovered fuel sample in dry basis (kJ/kg)
q_{wp-mix} calorific value of the wood-paper mix sample in dry basis (kJ/kg)
$W_{wp:plast}$ wood-paper mix: plastic mix ratio in solid recovered fuels in dry basis (kg/kg)
x_B^{cal} biomass fraction, expressed as a percentage by calorific value (%)
x_B^{TC} biomass content in dry basis by total carbon (wt%)
$x_{B,Theo}^{TC}$ theoretical biomass content in dry basis by total carbon (wt%)
x_B^{wt} biomass content in dry basis by weight (wt%)
$x_{B,Com}^{wt}$ combustible biomass content in dry basis by weight (wt%)
x_{NB}^{cal} non-biomass fraction, expressed as a percentage by calorific value (%)
$x_{residue}$ dissolution residue out of total original sample in dry basis (wt%)
$^{14}C_{REF}$ ^{14}C content of reference (100% biogenic carbon) in dry basis (pMC)
$^{14}C_{SRF}$ ^{14}C content of solid recovered fuel in dry basis (pMC)

15440:2011 [17]. These are; the SDM (selective dissolution method), the ^{14}C method, the manual sorting method and the informative reductionistic method.

Investigations related to this research field have been carried out by several authors. AMS (accelerator mass spectrometry) radiocarbon analyses have been applied on carbon dioxide sampled at the stack of three power plants burning natural gas, landfill biogas and solid recovered fuel derived from municipal solid waste [18]. The same procedure has been used for waste incinerators [19]. ^{14}C analysis for flue gas is recommended by some more authors [20,22], and some of them [20,21], have proved the reliability of the method by comparison with those based on carbon mass input and output and an energy balance data of the relevant plants. The bio-based content of manufactured products has been found by some researchers using radiocarbon dating procedures [23]. Further information can be found for ^{14}C contents of different biogenic waste as well as mixtures of different wastes and solid recovered fuels [24]. The repeatability and accuracy of SDM have previously been investigated by the current authors, and a simplified method has been developed [25,26]. An alternative method called the balance method has been developed to determine fossil and biogenic CO_2 emissions from waste-to-energy plants [27]. Similarly, a method to determine the mass, energy and carbon content of biogenic and fossil matter in RDF is described by combining standard chemical information about biogenic and fossil material with data from a chemical analysis of the RDF [28]. In another paper [29], the balance method, SDM and the ^{14}C method are explained in detail. In still another study, a method to evaluate the renewable and non-renewable energy fractions released during combustion of bio-fuels and bioliquids that could be produced through chemical processes is presented [30]. A comparison of the manual sorting method and SDM for a range of process streams from a mechanical–biological treatment plant has also been presented [31]. Further, one may find comparison between manual sorting, SDM and reductionistic method results in Refs. [11] and [32]. Similarly, some authors have used the ^{14}C method, sorting analyses and the balance method in order to determine the fossil fraction in municipal solid waste (waste and flue gas) in Sweden [33].

In the present study, different artificial RDF mixtures are analyzed by SDM in total carbon basis and ^{14}C method in weight basis, calorific value basis and total carbon basis. These results are compared with previous findings of SDM for weight basis and calorific value basis [25] in order to compare the accuracy of the SDM method and the ^{14}C method. Furthermore, the effect of biomass ash forming matter on the SDM result in total carbon basis is analyzed, and possible corrections are proposed.

Table 1
Composition (wt%) of some RDF samples.

Type	Our analysis	[11]	[3]	[10]	
				Flemish region	Italy
Plastics	13.4	25.0	29.2	31.0	23.0
Paper/cardboard	15.6	19.0	8.1	13.0	44.0
Wood	10.0	8.0	4.6	12.0	4.5
Tissue/sanitary products		12.0			
Fabrics/textile	4.3	14.0	7.4	14.0	12.0
Leather/rubber	0.1	3.0	1.1		
Carpets/mats		3.0			
Liquid packaging board		3.0			
Food/biological waste	2.2		0.0		14.0
Glass	0.6		0.0		2.5
Metal	0.3		1.1		
Ceramic	0.9		0.0		
Fines	52.6	13.0	48.5		
Other				30.0	

2. Materials

Spruce wood (50 wt%, dry and ash free; DAF) and copy paper (50 wt%, DAF) were mixed to mimic the biomass content in RDF, whereas polyethylene (PE, 74 wt%), polyvinyl chloride (PVC, 20 wt %) and polyethylene terephthalate (PET, 6 wt%) were mixed to mimic the fossil fraction of RDF (all weight fractions in dry and ash free basis). Prior to mixing, the pure materials were separately ground into <1 mm particles and then dried in an oven to remove the moisture. For the grinding, a Retsch SM 2000 grinding apparatus was used. The PE: PVC: PET proportion in the plastic mix was according to data on plastic manufacturing and recycling rates in Western Europe [34]. Table 1 shows that the wood:paper ratio