Determination of Fossil Fraction of Refuse Derived Fuel by the Selective Dissolution Method in Calorific Value Basis: Development of Simplified Method

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Abstract

Determination of net CO_2 emissions from combustion of Refuse Derived Fuel (RDF) is not straight forward due to the heterogeneous nature of the fuel. The fossil fraction of the fuel is an essential parameter for the determination of net CO_2 emissions. In the present study, the fossil fraction of RDF is determined by means of the Selective Dissolution Method (SDM) in calorific value basis. Seven artificially made RDF mixtures were tested using this method. The mixtures were prepared by mixing different proportions of plastic, paper and wood. It was found that the experimentally determined fossil fractions were very close to the theoretical values, which could be calculated based on the constituents of the artificial RDF mixtures. This indicates a high accuracy of SDM. However, SDM is a time-consuming method. Based on the artificially made RDF mixtures, a functional relationship between calorific value and fossil fraction in calorific value basis was found and plotted graphically. This means that in cases where the nature of the fossil and biogenic RDF constituents is known, determination of the calorific value, ash content and moisture content of the fuel is sufficient for determination of the fossil fraction in calorific value basis. Since these parameters can be relatively quickly determined at least within one day, and are often analysed anyway as part of the general fuel characterization, this simplified method can save a lot of time and resources compared to SDM, which takes three days to give a test result. Hence, the simplified method can be an attractive alternative to SDM when net CO_2 emissions from RDF combustion are to be determined. When performing the SDM analysis, attention should be given for the intermediate calculations since some of the ash forming matter penetrates into the filter paper used in the SDM procedure.

Key words: Refuse Derived Fuel; Solid Recovered Fuels; Selective Dissolution Method; Fossil fraction; Calorific value; Ash forming matter

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Abbreviations: AM = artificial mixture; DAF = dry and ash free; HHV = higher heating value (gross calorific value); NA = not analysed/not available; PE = polyethylene; PET = polyethylene terephthalate; PVC = polyvinyl chloride; RDF = Refuse Derived Fuel; RSD= relative standard deviation; SDM = Selective Dissolution Method; SRF = Solid Recovered Fuel

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Nomenclature

$A_{dissolved}$	Ash forming matter penetrated through the filter in dry basis by weight (kg)
$A_{dissolved \%}$	Ash forming matter penetrated through the filter as a percentage of total ash in dry basis by weight (wt%)
A_{pores}	Ash forming matter penetrated into filter pores (kg)
$A_{residue}$	Ash content of residue in dry basis (wt%)
$A_{residue-CV}$	Ash content of the scraped residue taken for calorific value analysis (kg)
A_{SRF}	Ash content of Solid Recovered Fuel sample in dry basis (wt%)
$m_{residue}$	Remaining dry mass (excluding filter) after dissolution and filtering (kg)
$m_{residue-ash}$	Mass of the ash of dissolution residue (including filter) in dry basis (kg)
$m_{residue-ash-fp}$	Mass of the ash of dissolution residue (excluding filter) in dry basis (kg)
$m_{residue-fp}$	Remaining dry mass (excluding filter) after dissolution and filtering (kg)
$m_{residue-fp-CV}$	Mass of residue (excluding filter) in calorific value analysis test (kg)
m_{SRF}	Mass of dry Solid Recovered Fuel test portion used for dissolution (kg)
q_B	Calorific value of the biomass fraction in dry and ash-free basis (kJ/kg)
q_{NB}	Calorific value of the non-biomass fraction in dry and ash-free basis (kJ/kg)
$q_{residue}$	Calorific value of the residue in dry basis (kJ/kg)
q_{SRF}	Calorific value of the Solid Recovered Fuel sample in dry basis (kJ/kg)
x_B	Combustible biomass in dry basis, expressed as a percentage by weight (wt%)
x_B^{cal}	Biomass fraction, expressed as a percentage by calorific value (%)
x_{NB}	Combustible non-biomass in dry basis, expressed as a percentage by weight (wt%)
x_{NB}^{cal}	Non-biomass fraction, expressed as a percentage by calorific value (%)

1. Introduction

Refuse Derived Fuel (RDF)[1], which is typically produced by shredding, classifying and drying municipal and industrial solid wastes, has different proportions of biomass, non-biomass and inert materials (Fig. 1 and Fig. 2). The composition depends on the nature of the origin of the waste materials as well as the waste pre-treatment, and RDF is essentially a heterogeneous fuel.

The growing concern about emissions of greenhouse gases urges the use of biomass-based waste as an alternative fuel in many industrial applications since combustion of biomass gives no net emissions of carbon dioxide to the environment. The facts that RDF contains a considerable amount of biomass and is also a less expensive fuel, explain the increasing usage of RDF as an alternative energy source in industrial applications.

In Norway, plants emitting CO_2 have to comply with the national emissions trading regulations [1, 2], which are based on the EU Emissions Trading Directive [3]. When reporting net CO_2

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[1] Refuse Derived Fuel is also called Solid Recovered Fuels (SRF).

emissions, the biomass content (or conversely the fossil fraction) of RDF is a key parameter. It can be represented by either weight, calorific value or carbon content.

According to the technical specification CEN/TS 15440:2006 [4] and the subsequent European pre-standard Draft prEN 15440 [5], four methods are available for the determination of biomass content and hence fossil fraction in Solid Recovered Fuels; the Selective Dissolution Method (SDM), the ^{14}C method, the manual sorting method and the informative reductionistic method. None of those methods are fully validated yet.

Determination of fossil fraction in RDF by SDM in weight basis was previously studied by Ariyaratne, Tokheim & Melaaen [6]. The experimental observations indicated that SDM is a method with good repeatability. However, SDM is time consuming; it takes about three days to perform an SDM experiment (although the labor work itself is limited to 2-3 hours). This suggests that SDM is not well suited for routine analyses in plants burning large amounts of RDF and taking high numbers of RDF samples per year. The previous study [6] also revealed that the ash forming matter of RDF may cause experimental errors in SDM analysis, if not properly adjusted for.

When evaluating net CO_2 emissions, the determination of fossil fraction in calorific value basis is more appropriate than weight basis. This is because, the calorific value is highly correlated with carbon content, and hence CO_2 emissions. (The heating value variation due to variation in the C/H ratio in RDF is only around 2%, as will be found by inspecting the fuel analysis results on dry and ash-free basis.) Therefore, in the present study, different artificial RDF mixtures are analysed by SDM in calorific value basis in order to determine the accuracy of this variant of the method. Furthermore, the results are used to develop a simplified method for quicker and easier determination of fossil fraction in RDF. The effect of dissolution and filter paper penetration of ash forming matter on SDM results are also discussed.

2. Materials

Spruce wood (50 wt%) and copy paper (50 wt%) 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 DAF 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 [7].

The two mixtures were mixed with each other in different proportions. Altogether seven artificial RDF samples with different higher heating values (gross calorific values) were made. The higher heating values were specified so as to obtain evenly distributed values covering a relatively broad range, from about 20 MJ/kg to about 40 MJ/kg. Table 1 summarizes the compositions of the artificial mixtures made.

Table 1. Corresponding compositions of artificial mixtures.

Mixture	Composition (wt% dry)	
	Wood-paper mix	Plastic mix
AM 1	93	7
AM 2	82	18
AM 3	68	32
AM 4	57	43
AM 5	45	55
AM 6	24	76
AM 7	0	100

3. Method

The experimental procedure mentioned in Annex D of CEN/TS 15440:2006[4] is shown in Fig. 3. However, in the present study, a number of lab operations and calculation steps were added to that procedure, in order to compensate for the penetration of ash forming matter into filter paper pores and hence to get more accurate results.

Due to difficulty of dividing a small residue[2] into two representative samples for calorific value and ash analyses, four initial samples were taken instead of three initial samples. The sample weights for the dissolution step were determined so as to obtain sufficient amounts of residue (>1 g) for the subsequent analyses. The residue was carefully scraped off the filter paper for higher heating value analysis. In order to make ash corrections in higher heating values (HHV) when required, the filter paper was weighed at the beginning and after scraping off the dried residue from the filter paper. Moreover, the mass of the residue taken for HHV analysis was registered. This modified procedure proposed by the authors is shown in Fig. 4, and more details are discussed in Subsubsection 6.3.2.

The used volumes of chemical solutions were proportioned in accordance with the sample weights. The materials were dried at 105 °C until a constant weight was achieved, using an electric oven. The ash analyses were carried out in a muffle furnace, in accordance with CEN/TS 15403:2006 [8]. For the determination of higher heating value a Leco AC-350 automatic calorimeter was used. The sample weights after drying were in the range 0.6-1.4 g. The range of the calorimeter is 13 947-34 867 kJ/kg for 1 g sample, the precision is ≤0.05 % RSD and the resolution is 1 kJ/kg. An electronic balance with a lower measuring limit of 0.1 mg was used for weighing purposes.

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[2] Residue is the remaining filter cake after the sample dissolving, filtering and drying.

4. Experimental plan

Table 2 shows the tests carried out for different materials and the final column explains the purpose of performing the particular test. Every test is carried out in three parallels. This point onwards the average value means the average of three parallels.

In addition to the fossil fraction evaluation according to the particular technical specification, the ash forming matter penetrated through the filter was calculated for a few artificial mixtures as additional information even though it does not affect the SDM results.

Table 2. The tests performed for different materials.

Material	Test	Description
Pure materials (spruce wood, copy paper, PE, PVC, PET)	Ash analysis	As a base for theoretical calculations
Wood-paper mix & plastic mix	HHV analysis	As a base for theoretical calculations
Seven artificial mixtures	Ash analysis HHV analysis	As a part of SDM for mixtures
Residue of seven artificial mixtures	Ash analysis HHV analysis	As a part of SDM for mixtures

5. Theory and Calculation

The basic theory behind the dissolution test calculation is that the biomass in RDF selectively dissolves and oxidizes in H_2SO_4/H_2O_2, while the non-biomass (fossil material) and the inert material remain in the residue [4]. Cellulose, which is the major constituent of the biomass fraction is first degraded by acid hydrolysis and gives glucose base units. The reaction is strongly pH-dependent and continues at a very strong rate at low pH and temperature well under 100 °C. Secondly, the oxidizing reagent deteriorates the physical properties of fibrous cellulose rapidly under hydrolytic conditions [9,10].

However, it should be noted that some of the ash forming matter from both biomass and non-biomass can be dissolved in the H_2SO_4/H_2O_2 solution and then penetrate through the filter, while the rest remains in the residue. Moreover, some of the ash forming matter in the residue will remain on the surface of the filter paper while some will penetrate into the pores of the filter paper. The latter phenomenon has to be compensated in some cases when calculating the biomass and non-biomass fractions of RDF in calorific value basis. These are discussed in more detail in Subsections 6.3.1 and 6.3.2.

The ash and higher heating values of pure materials and two basic mixtures are directly measured according to the methods described in section 3. Results are presented in Section 6.

5.1. Weight basis

The combustible part of the biomass and non-biomass content of RDF in weight basis are calculated using Eq. (1) and Eq. (2) [4]. For the A_{SRF}, the average of three parallels is used in all the cases.

$$x_B = \left[1 - \left\{ \frac{m_{residue} - m_{residue-ash}}{m_{SRF}} + \frac{A_{SRF}}{100\%} \right\} \right] 100\% \tag{1}$$

$$x_{NB} = 100\% - x_B - A_{SRF} \tag{2}$$

5.2. Calorific value basis

The above weight basis results are extended to calorific value basis by introducing some more equations. The higher heating values of the non-biomass and biomass fractions are calculated by Eq. (3) and Eq. (4) respectively [4].

$$q_{NB} = \frac{q_{residue}}{1 - A_{residue}/100\%} \tag{3}$$

$$q_B = \frac{q_{SRF} - (x_{NB}/100\%)q_{NB}}{1 - x_{NB}/100\% - A_{SRF}/100\%} \tag{4}$$

The fractions of biomass and non-biomass of the overall sample in higher heating value basis are determined by Eq. (5) and Eq. (6) [4].

$$x_B^{cal} = \frac{x_B q_B}{q_{SRF}} 100\% \tag{5}$$

$$x_{NB}^{cal} = 100\% - x_B^{cal} \tag{6}$$

q_{SRF} and $q_{residue}$ are again the averages of three parallels. $A_{residue}$ is calculated using Eq. (7).

$$A_{residue} = \frac{m_{residue-ash-fp}}{m_{residue-fp}} 100\% \tag{7}$$

As mentioned above, Eq. (3) and Eq. (7) should not be used directly without concerning the issues related to ash forming matter.

5.3. Ash penetrated trough the filter

As already mentioned, some ash forming matter may dissolve in the acidic solution and then penetrate through the filter. Principally, this should be CaO from paper material since the other types of acidic ash forming matter (SiO_2, Al_2O_3) from wood and coal is insoluble in acidic solutions. Eq. (8) and Eq. (9) are suggested for the determination of ash forming matter which is dissolved and penetrates through the filter.

$$A_{dissolved} = \frac{A_{SRF}}{100\%} m_{SRF} - m_{residue-ash-fp} \tag{8}$$

$$A_{dissolved \%} = \frac{A_{dissolved}}{m_{SRF} A_{SRF} / 100\%} 100\% \tag{9}$$

6. Results and discussion

The results are discussed in three subsections below. Subsections 6.1 and 6.2 discuss the results of ash and higher heating value analyses of pure materials, two basic mixtures and the artificial RDF mixtures, respectively. Next, in Subsection 6.3, the intermediate and ultimate results of the SDM test are presented and compared with theoretical evaluations. The ash dissolution and filter penetration of ash forming matter is also discussed in the latter subsection.

6.1. Results for pure materials, wood-paper mix and plastic mix

Table 3 represents the average ash and HHV analysis results for pure materials. Among the pure materials, copy paper shows the highest ash content. Since PE and PVC have ash forming matter content < 0.05% [11] and PET has 0.0037% [12], i.e. very low values, zero ash content is assumed for those plastics in the present study. Higher heating values are evaluated in dry basis, and ash corrections are done when DAF basis is required.

Table 4 shows the comparison of experimental and theoretical ash content and higher heating values for the two basic mixtures. Here, the theoretical values are based on the analyses of pure materials. There is good agreement between the two different evaluations.

Table 3. Average ash and HHV analysis results of pure materials. Relative standard deviations based on three parallels are given in parentheses.

	Spruce wood	Copy paper	PE	PVC	PET
Ash content in dry basis (wt%)	0.3 (NA)	23.8 (0.3%)	0.0 (NA)	0.0 (NA)	0.0 (NA)

HHV (kJ/kg, dry)	19 410 (0.7 %)	12 165 (0.2 %)	46 030 (0.1 %)	19 407 (0.9 %)	22 758 (0.9 %)

Table 4. Theoretical and experimental comparison of properties for two basic mixtures. Relative standard deviations based on three parallels are given in parentheses.

	Wood-paper mix		Plastic mix	
	Experimental	Theoretical	Experimental	Theoretical
Ash content in dry basis (wt%)	10.4 (0.2 %)	10.5	0.0 (NA)	0.0
HHV (kJ/kg, dry)	16 696 (0.1 %)	16 271	39 395 (0.6 %)	39 274

However, it should be noted that the theoretical calculations of artificial RDF mixtures are based on the experimental ash analyses of the pure materials and on experimental higher heating value analyses of the two basic mixtures.

6.2. Results for artificial mixtures

The average ash and HHV analyses of the artificial mixtures are presented in Table 5. These experimental measurements are required for the final fossil fraction calculations. While the second and third columns are direct experimental measurements, the values in the fourth column are calculated based on the two former columns.

Table 5. Average ash content and higher heating values of artificial mixtures. Relative standard deviations are given in parentheses.

Material	Ash content in dry basis (wt%)	Higher heating value in dry basis (kJ/kg)	Higher heating value in DAF basis (kJ/kg)
	A_{SRF}	q_{SRF}	
AM 1	9.7 (0.5 %)	18 088 (0.1 %)	20 028
AM 2	7.8 (0.6 %)	20 857 (1.0 %)	22 632
AM 3	7.3 (1.2 %)	23 779 (0.2 %)	25 658
AM 4	6.0 (1.3 %)	26 391 (0.7 %)	28 089
AM 5	5.8 (1.5 %)	28 748 (0.1 %)	30 526
AM 6	3.1 (2.3 %)	33 538 (0.1 %)	34 627
AM 7	0.0 (NA)	39 395 (0.6 %)	39 395

6.3. Results of the SDM tests

The average results including intermediate steps for different materials are presented in Table 6.

Theoretically, all q_B values should be equal to the higher heating value of wood-paper mix in DAF basis, since the wood-paper mix is the only biomass fraction in all artificial mixtures. The HHV of wood-paper mix in DAF basis can be calculated as 18 632 kJ/kg by using the HHV in dry basis and using the ash analysis data of pure materials. This figure is in good agreement with the results presented in Table 6 (average 18 300 kJ/kg).

Table 6. Average results of SDM tests, including intermediate results and ash forming matter which is dissolved.

	AM 1	AM 2	AM 3	AM 4	AM 5	AM 6	AM 7
x_B	83.1	73.8	60.9	51.1	39.3	19.8	1.1
x_{NB}	7.2	18.4	31.7	42.9	54.8	77.1	98.9
q_{NB}	39 005	38 962	39 371	39 033	39 356	39 077	39 617
q_B	18 392	18 557	18 516	18 899	18 216	17 256	18 261
x_B^{cal}	84.5	65.6	47.4	36.6	24.9	10.2	0.5
x_{NB}^{cal}	15.5	34.4	52.6	63.4	75.1	89.8	99.5
$A_{dissolved\%}$	20.7	NA	48.0	NA	64.7	NA	-

Fig. 5 shows a comparison of experimental and theoretical combustible fossil fractions in weight basis. The accuracy is very good. Fig. 6 compares experimental and theoretical fossil fractions of SDM in higher heating value basis. Three times of standard deviations are indicated in the experimental plot. All seven artificial mixture results coincide almost perfectly with the theoretical line.

6.3.1. Filter paper penetration of ash forming matters

In the present study, it was found that the measured higher heating value of the filter residue was every time around 39 MJ/kg, indicating that the residue was very close to a pure plastic mix and contained practically no ash or ash forming matter. These results indicate that the ash forming matter were not retained on the filter paper while filtering the solution, but instead had penetrated into or through the filter paper.

Hence, q_{NB} was not calculated through $q_{residue}$ and $A_{residue}$ as explained in Subsection 5.2, but instead the measurement from the calorimeter was taken as q_{NB}. It should be noted that q_{NB} is rather important for fossil fraction calculations, not $q_{residue}$. However in general, the calorimeter

measurement ($q_{residue}$) should be corrected for relevant ash content in order to obtain the q_{NB}. This general phenomenon is discussed in more detail in Subsubsection 6.3.2.

The ash forming matter penetrating through the filter paper may be due to some soluble ash forming matter present in the samples. Although this phenomenon does not affect the fossil fraction evaluation neither in weight basis nor in calorific value basis (as long as similar samples are taken for the four analyses in the test), it is of interest to quantify the dissolved amount.

The dissolved ash forming matter percentages of some of the artificial mixtures are presented in Table 6 (AM 7 is just a plastic mix, without any ash forming matter). The dissolved ash forming matter percentage increases with increasing plastic proportion, hence with reduced ash forming matter amount. This may be because a higher ash forming matter amount reduces the capability of filtering ash forming matter through the filter paper by filling it in all pores of the filter paper in the beginning of the filtration. After initial saturation of filter paper by ash forming matter, it might behave as a barrier for further filtration of ash forming matters through the filter paper. Hence, when the sample has a small amount of ash forming matter (e.g. AM 5), it takes more time to saturate the filter paper pores, allowing a higher fraction of the ash forming matter to pass through the filter.

The ash forming matter of the artificial RDF mixtures may primarily have come from the copy paper since the ash forming matter in spruce wood is negligible compared to that of the paper (Table 3). Therefore, $A_{dissolved\%}$ can be taken as the dissolved ash forming matter as a percentage of the paper ash. The average calcium content in different types of paper materials is 0.522 kg/kg dry ash [13]. Calcium exists as CaO in ash, hence the CaO amounts to 73.08 wt% (dry). The CaO in the paper material can be partly or completely dissolved in acidic solution by dissociation to Ca^{2+} and SO_4^{2-}:

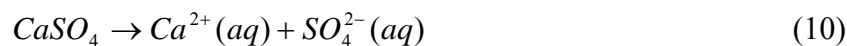$$CaSO_4 \rightarrow Ca^{2+}(aq) + SO_4^{2-}(aq) \hspace{3cm} (10)$$

Fig. 7 shows the part of the CaO in the paper ash that may have been dissolved in the acidic solution in the three cases discussed. The result supports the assumption that the ash forming matter which is dissolved in the acidic solution, and then penetrates through the filter, is a portion of the CaO present in the paper.

However, it might be of interest to further investigate other elements than Ca, though the dissolved ash forming matter does not affect the SDM result at all.

6.3.2. Methods to account for filter paper penetration of ash forming matter

Accurate calculation of q_{NB} in the general case, taking into account that some ash forming matter may penetrate into the pores of the filter paper, could be obtained by two different methods. In both cases, four initial samples are suggested for four analyses. In order to obtain a high accuracy of the test results, the similarity and homogeneity of the initial samples are very

important. Especially, S2 and S4 (Fig. 4) should be well homogenized to make sure that the dissolved ash forming matter percentages are equal for a particular test.

One possibility, which is mentioned in prEN 15440:2009 [5], is to crush the filter paper and combine this with the residue before determination of the calorific value, taking into account the contribution of the filter paper when obtaining $q_{residue}$. Then the equations (3) and (7) are directly used to calculate q_{NB}.

However, when including the crushed filter paper in the sample it might be difficult to obtain a representative sample due to the volume limitation of the sample pan of the instrument. This was indeed a restriction in the present study. In such a situation, the authors suggest another procedure.

In the alternative procedure (Fig. 4), the residue is first carefully scraped off from the filter paper and analysed in the calorimeter. Then the result is corrected using $A_{residue-CV}$ to obtain q_{NB}. $A_{residue-CV}$ can be calculated using $A_{residue}$ and the ash forming matter penetrated into the filter pores, A_{pores}, according to Eq. (11). The ash forming matter penetrated into the filter pores can be easily found by weighing the dry filter paper before filtering and after scraping the residue from the filter.

$$A_{residue-CV} = m_{residue-fp-CV}\frac{A_{residue}}{100\%} - A_{pores} \qquad (11)$$

The ash forming matter penetrated into the pores of filter paper should be taken into account when calculating fossil fraction in calorific value basis in situations where some ash forming matter is retained on the surface of the filter while some ash forming matter penetrates into the filter paper.

7. Conclusion

The Selective Dissolution Method (SDM) has been used for determination of fossil fraction in seven artificial waste mixtures mimicing Refuse Derived Fuel (RDF). There was very good agreement between experimental values and values theoretically calculated from the content of the biomass mixture and the plastic mixture. This is true both in mass basis and in calorific value basis. Hence, the accuracy of SDM can be considered good.

The results also suggest that for samples with a known composition of the fossil fraction and of the biomass fraction, one may predict the fossil fraction using only information about higher heating value, ash content and moisture content. Since these parameters can be relatively quickly determined at least within one day, and are often analysed anyway as part of routine fuel characterization, this simplified method can save a lot of time compared to SDM, which generally takes three days to give the test result. In addition to less time consumption, less chemical consumption and no need of wet-chemical analysis are other advantages of the

simplified method. Hence, the simplified method can be an attractive alternative to SDM when net CO_2 emissions from RDF combustion are to be determined. Though this simplified method is better suited for one type of of RDF, the method could be calibrated for different RDF types using SDM.

In general, no matter the source and elements present, the ash forming matter penetrated into pores of the filter paper should be taken into account when calculating the fossil fraction in calorific value basis. When there is a limitation of calorimeter with regarding the sample size, the ash forming matter issue has to be corrected as proposed in the paper.

Acknowledgements

References

[1]   Act of 17 December 2004 No. 99 Relating to Greenhouse Gas Emission Allowance Trading and the Duty to Surrender Emission Allowances. Norwegian law on emissions trading, Ministry of the Environment, Norway; 2004.

[2]   Regulation of 23 December 2004 No. 1851 Relating to Greenhouse Gas Emission Allowance Trading and the Duty to Surrender Emission Allowances. Norwegian regulation on emissions trading, Ministry of the Environment, Norway; 2004.

[3]   Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003 establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Council Directive 96/61/EC. European Commission; 2003.

[4]   CEN/TS 15440:2006, Solid recovered fuels - Method for the determination of biomass content. Technical Specification, CEN; 2006.

[5]   Draft prEN 15440, Solid recovered fuels - Method for the determination of biomass content. European Standard, CEN; 2009.

[6]   Ariyaratne WKH, Tokheim LA, Melaaen MC. Net CO_2 emissions from solid recovered fuels: evaluation of the selective dissolution method. ASME-ATI-UIT 2010 Conference on Thermal and Environmental Issues in Energy Systems, Sorrento, Italy; 2010.

[7]   Hannequart JP. Good practices guide on waste plastics recycling – a guide by and for local and regional authorities (2004), Report, Association of Cities and Regions for Recycling

[8]   CEN/TS 15403:2006, Solid recovered fuels - Method for the determination of ash content,Technical Specification, CEN; 2006.

[9]   Gerhartz W, Yamamoto YS, Campbell FT, Pfefferkorn R, Rounsaville JF. Ullmann's Encyclopedia of Industrial Chemistry, Volume A 5. 5th edition. New York: VCH; 1986.

[10] McKetta JJ, Cunningham WA. Encyclopedia of Chemical Processing and Design, Volume 7. New York: Marcel Dekker, Inc; 1978.

[11] Zevenhoven R, Karlsson M, Hupa M. Combustion and gasification properties of plastics particles. Journal of Air & Waste Management Association, Volume 47; 1997.

[12] Otaigbe JOE, Nwokonkwo HC, Onyemenonu Snr CC. Effects of solvent composition and polymer concentration on Poly (Ethylene Terephthalate) degradation in Phenol: 1,2-Dichlorobenzene blended solvent. Global Journal of Environmental Sciences, Vol.3 (1&2) 2004; 59-64.

[13] Rozic M, Macefat MR, Orescanin V. Elemental analysis of ashes of office papers by EDXRF spectrometry. Nuclear Instruments and Methods in Physics Research 2005; B 229: 117–122.

Fig. 1. Pre-dried and shredded Refuse Derived Fuel sample.

Biomass: combustible (a)	Non-biomass: combustible (b)	Inert (e)
Biomass: ash forming matter (c)	Non-biomass: ash forming matter (d)	

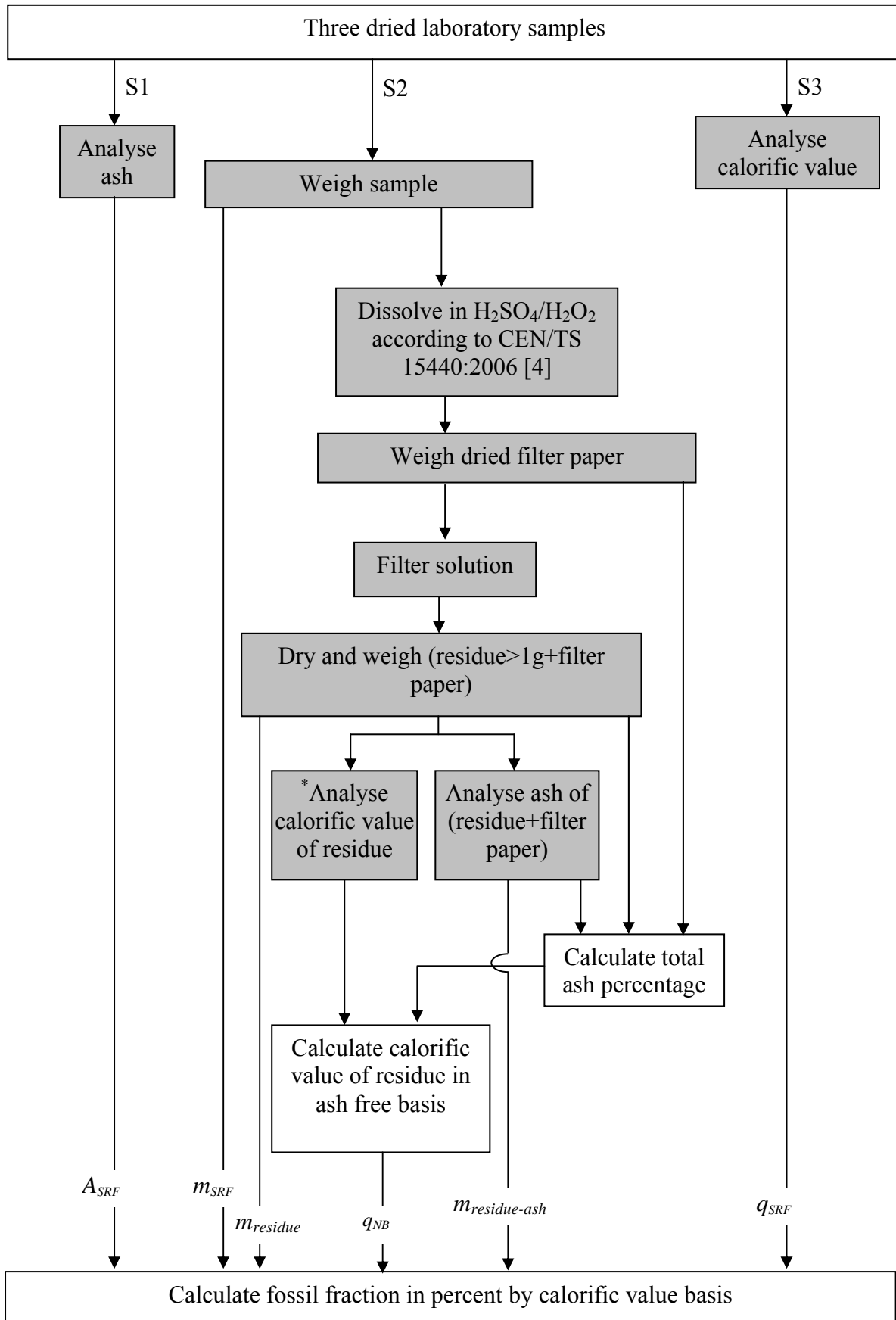Fig. 2. Representation of a dried Refuse Derived Fuel sample.

Fig. 3. Procedure for determination of fossil fraction in percent by calorific value basis according to CEN/TS 15440:2006 [4]. The procedure includes physical operations in grey blocks and calculations in white blocks. *draft prEN 15440[5] suggests to analyse calorific value of residue along with crushed filter paper.
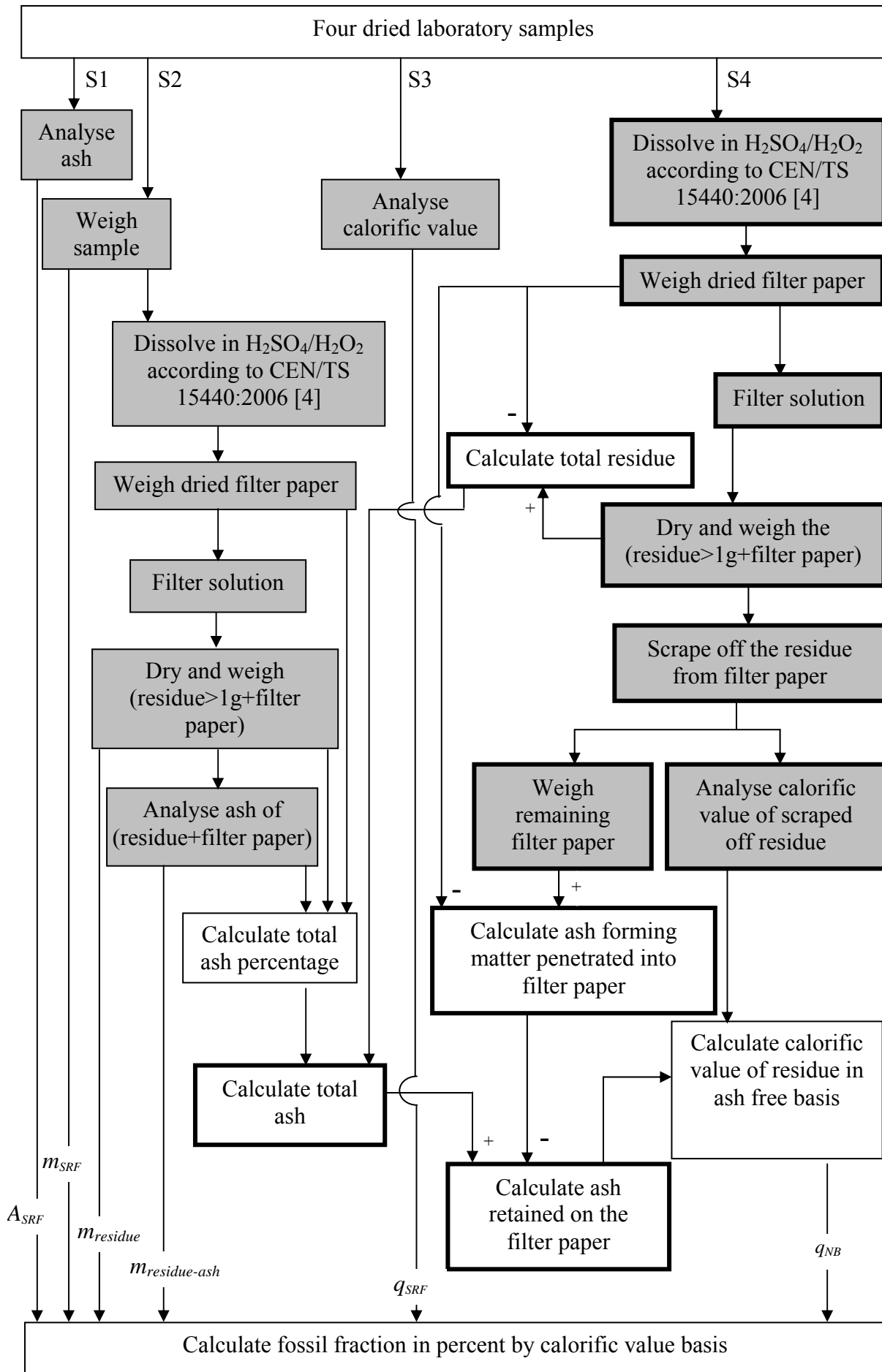
Fig. 4. Modified procedure for the determination of fossil fraction in percent by calorific value basis proposed by the authors (additional steps are indicated by thick margined blocks). The procedure includes physical operations in grey blocks and calculations in white blocks.
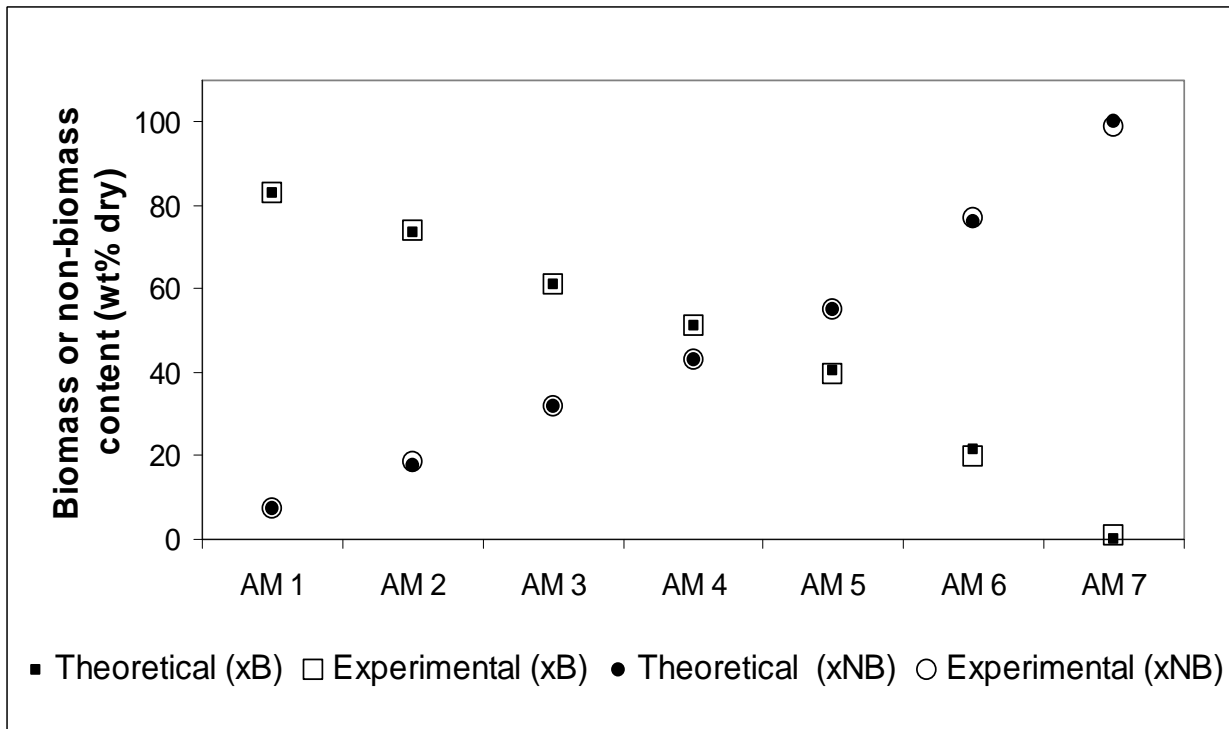
Fig. 5. Theoretical and experimental combustible biomass and combustible non-biomass contents in weight basis.
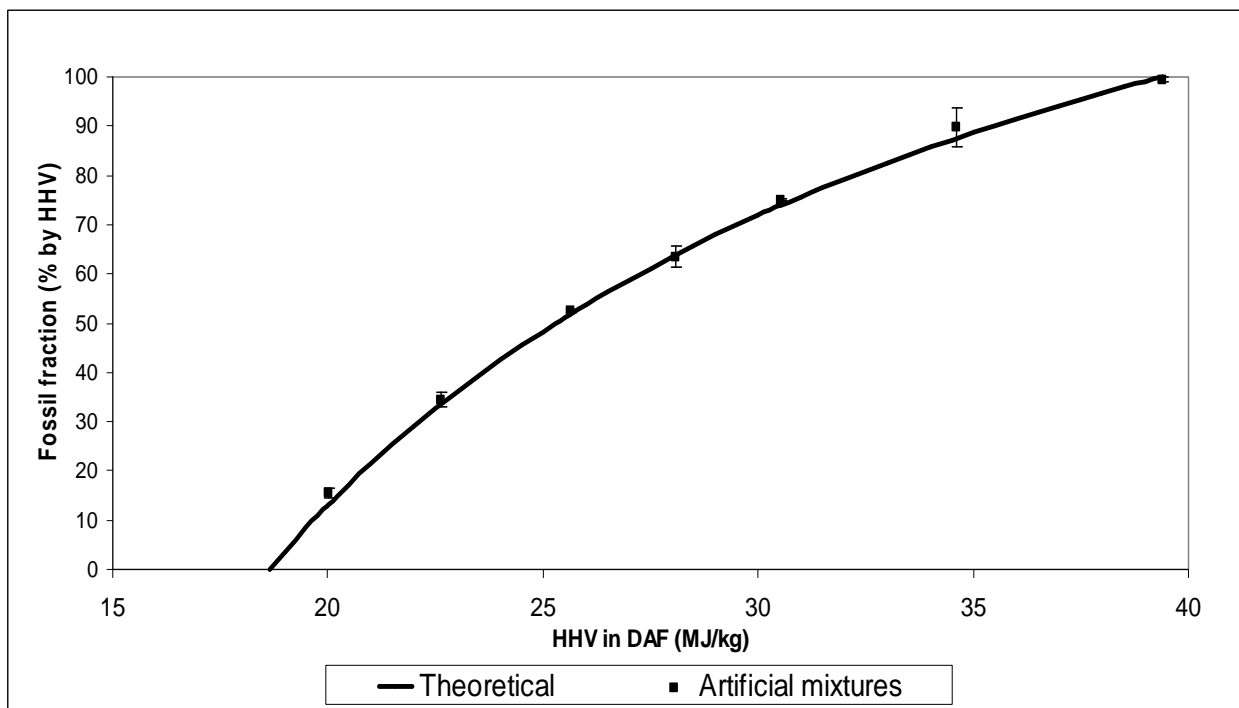

Fig. 6. Comparison of theoretical fossil fractions with Selective Dissolution Method test results.
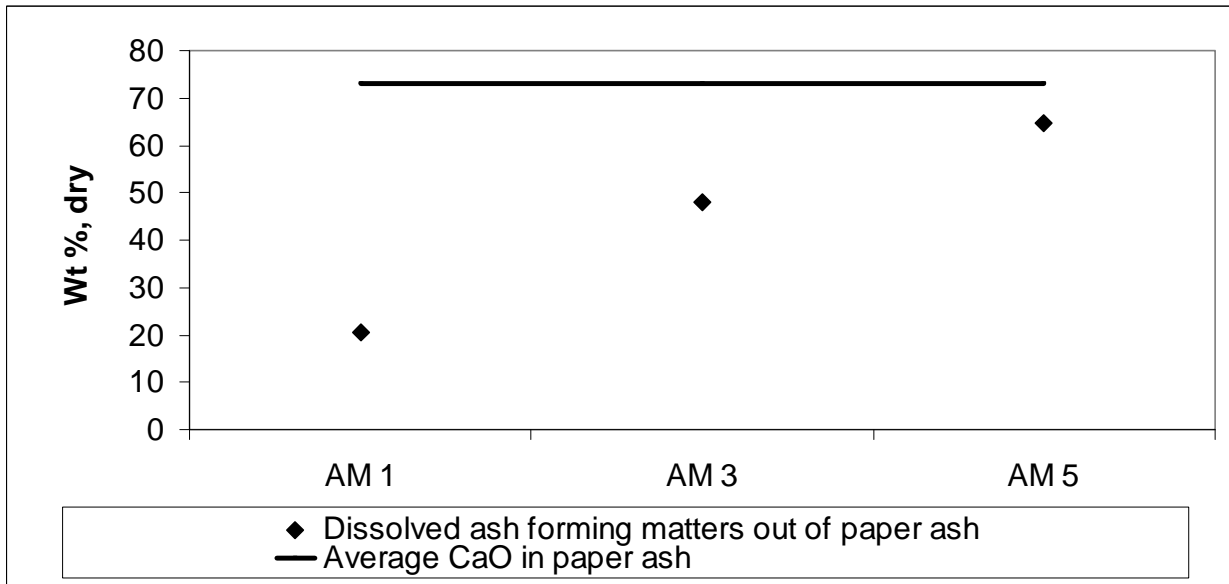
Fig. 7. Theoretical CaO content as percentage of paper ash and ash forming matter penetrated through the filter in experiments as percentage of ash forming matter in paper.