MONITORING OF RENEWABLE ENERGY YIELD OF MIXED WASTES BY IMAGE ANALYSIS OF INPUT RESIDUAL WASTE MATERIALS

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SUMMARY: A novel image analysis method has been developed by Cranfield University. Following on from a recent study, this approach has been applied alongside calorific values and $\%^{14}C$ to determine the renewable energy content of mixed wastes. This method determines the composition of the mixed waste material, and then using calorific values and biogenic carbon (^{14}C) content the renewable energy potential of the mixed waste sample can be accurately determined. The correlations between actual (known) weights and composition of the components and the values from the image analysis are compared; these correlations ($r \geq 0.988$) were found to be highly significant ($p<0.005$). The renewable energy contents (as a % of the total energy) were calculated to be between 0.64 and 3.98 below the actual values. Potential applications for the image analysis tool include a) renewable energy potential of mixed wastes prior to combustion, and b) certification of solid recovered fuels [SRF].

1. INTRODUCTION

The development of renewable energy technologies has become more prominent in recent years as the causes of climate change are mitigated alongside the European Union-set targets of producing 20% of electricity from renewable sources by 2020 (Council of the European Union 2009; Lupa 2011). Energy produced from biomass (Becidan *et al.* 2007; Defra 2008; Panoutsou *et al.* 2009; Mabee *et al.* 2011; Qiao *et al.* 2011; Whittaker *et al.* 2011) and the bio-based fraction of wastes (Séverin *et al.* 2010; Wagland *et al.* 2011; Velis *et al.* 2012) presents a sustainable and secure solution to the renewable energy strategies.

Recovering value from waste materials is of key importance for the development of a sustainable future. Whilst the reuse, recovery and recycling of wastes is of interest, a significant proportion of residual waste remains that is either non-recoverable for various reasons, or has no commodity value. Therefore the thermal treatment of residual wastes is a management option that is popular across Europe, and is becoming more prominent in the United Kingdom [UK] as policy influences moving away from landfill disposal and for the generation of renewable energy.

In order to fully understand the value, or potential value, of residual waste materials it is necessary to understand the composition and properties of the mixed waste streams. Currently,

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operators carry out time-consuming and expensive studies to gain information on the percentages of material not recycled in the residual waste (Resource Futures 2009). There is an increasingly high cost and time premium associated with undertaking such waste analysis, yet there is a need for constant monitoring of the waste stream to support and monitor the implementation of the waste strategy (Burnley *et al.* 2007). The common approach of direct waste sampling involves hand sorting waste into individual components (Burnley 2007a; Burnley 2007b; Burnley *et al.* 2007); this is time consuming and carries a number of issues regarding labour costs and health and safety concerns.

Waste is a valuable resource in terms of renewable energy, as a large fraction of residual wastes (specifically commercial & industrial and municipal solid waste) consists of biomass-derived materials, such as paper, card, wood and organics (food and garden waste). The aim of this paper is to demonstrate the link between understanding the physical composition of a mixed waste material, and the renewable energy potential.

Determination of the biogenic carbon content of heterogeneous waste is a key parameter for analysing renewable energy yield potential. It is important to be able to quantify the biogenic fraction of carbon relative to the fossil derived carbon source.

There are three well known methods for determining the biogenic carbon content of mixed wastes, including-

1. Carbon 14 (^{14}C) method (European Committee for Standardisation 2007; Fellner *et al.* 2009);
2. Selective dissolution method (Séverin *et al.* 2010);
3. Manual sorting (Séverin *et al.* 2010).

The ^{14}C method is accepted as the most accurate method (Mohn *et al.* 2008; Palstra *et al.* 2010), however requires the capture of flue gas and offsite analysis using specialist analytical equipment (Accelerated Mass Spectrometer, AMS). The selective dissolution method relies on the feature that is common to most biogenic materials, which is that they dissolve and are oxidised in acidic solutions. The non-biogenic fraction remains intact, and so the mass difference between the remaining solids and the initial mass represents the biogenic content of the sample. A limitation of the selective dissolution method is that not all biogenic materials behave in this way (e.g rubber) (Séverin *et al.* 2010), and so this can introduce errors. Finally, manual sorting requires careful sampling and sorting into waste categories, which can be disruptive to the site operations, take considerable time and have a number of health and safety considerations. Also, it is accepted practice in the UK for the manual sorting approach to assume that certain components are 100% biodegradable/biogenic (such as paper) whilst others (textiles) are 50% biodegradable/biogenic (Ofgem 2011). This can also introduce a number of errors through these assumptions, for example some textiles are synthetic (<50% biogenic) and some are from natural fibres (>50% biogenic).

A new approach has been developed by Cranfield University which can accurately determine the composition of a mixed waste material (Wagland *et al.* 2012). The method previously developed is used in this study alongside ^{14}C and gross calorific values [GCV] in order to calculate a) the composition, b) the biogenic fraction of the total sample, and c) the biogenic energy content. This study therefore presents the application of the novel methodology to the application of mixed wastes in order to accurately determine the renewable energy potential of mixed wastes. The system recommended would be suitable for placement above a conveyor belt in a waste treatment facility, and would enable the calculation of the renewable energy content before the waste undergoes thermal treatment.

2. MATERIALS AND METHODS

2.1. Waste materials and preparation

The waste components used in this study were gathered from materials collected from the Cranfield campus of Cranfield University. These included source-segregated components [paper, card, aluminium cans and dense plastic], film plastic, green waste, textiles, inert (rubble) and waste wood. Each component was then retained for image analysis, and then dispatched to third party laboratories for analysis.

For the image analysis, the waste components were weighed before being added together to produce two different batches of mixed wastes. Variations were chosen to ensure that each waste sample was sufficiently different and so sample A did not include film plastic and inert; sample B did not include textiles. As a result of this mixing, the composition of each of these batches was known prior to image analysis.

Each of the waste components sent to the third party laboratories was prepared by each respective laboratory in accordance with the European standard method statement. Approximately 250 g of each component was sent for proximate and ultimate analysis; whereas <50 g of each component was sent for biogenic carbon (^{14}C) analysis.

2.2. Proximate, ultimate and biogenic analysis

The moisture content of the samples, along with the GCV were analysed in accordance with the relevant standard methods (European Committee for Standardisation 2010a; British standards Institute 2011b; British Standards Institute 2011a) at Marchwood Scientific [Southampton, England]. The net CV [NCV] was calculated from the GCV as defined by the standard method (British Standards Institute 2011a).

The biogenic carbon fraction was calculated for each sample by Beta Analytic [London, England] in accordance with the European standard (European Committee for Standardisation 2007). The technique used by Beta Analytic requires an AMS. Here the sample is combusted to form CO_2, which is then converted to graphite by passing over a hot Fe catalyst with H_2. The graphite target is then bombarded by Caesium [Cs] ions to release C ions. The rapid detection of $^{12}C^{4+}$, $^{13}C^{4+}$ and $^{14}C^{4+}$ ions allow for the calculation of the ratio of ^{14}C to $^{12}C/^{13}C$ (European Committee for Standardisation 2007).

2.3. Image analysis

Each of the two waste samples produced were spread evenly to represent a typical conveyor belt as used to transport waste in treatment processing facilities. A 1 m^2 quadrat was placed over each part of the waste, and a digital image captured of each section. The quadrat was placed ensuring that all waste was covered during this process, whilst avoiding overlap between sections.

The digital images were then processed using Erdas Imagine (v9.3) to crop and geometrically correct the images before the placement of an 11x11 dot-grid over the image, as described in a previous study (Wagland *et al.* 2012). Each dot covering each of the waste component categories was manually selected, and the number of dots covering each component was counted digitally. The unprocessed image is shown in Figure 1, and the geometrically corrected image with selected dots is shown in Figure 2.



Figure 1. Placement of quadrat on mixed waste sample.



Figure 2. Processed image with completed dot-grid analysis.

In a previous study (Wagland *et al.* 2012), individual components of fixed volume (30 litres) were weighed to determine the density (g/cm^3) of each component (European Committee for Standardisation 2010b). However errors were encountered using this approach, and so in this study the individual components were spread out and subjected to image analysis in order to calculate a mass per dot (kg/dot) for each component.

3. RESULTS AND DISCUSSION

The weight and overall composition of the samples used are summarised in Table 1. The GCV, NCV and %^{14}C is provided for each waste component.

Table 1. Summary of samples and properties of each waste component.

Component	Weight (kg)		% Composition		Gross CV [MJ/kg]	Net CV [MJ/kg]	^{14}C (%)
	A	B	A	B			
Paper	11.9	17.5	27.9	38.5	13.5	12.6	94
Card	12.9	3.6	30.2	7.9	13.0	12.1	100
Dense plastic	4.6	1.4	10.8	3.1	29.2	27.2	1
Film plastic	-	0.5	-	1.1	41.3	39.1	1
Metal	1	1.8	2.3	4	-	-	-
Garden waste	3.4	4.5	8	9.8	11.8	11.0	96
Textiles	2.2	-	5.2	-	14.0	13.0	86
Wood	6.7	4.2	15.7	9.2	13.2	12.3	90
Inert	-	12	-	26.4	-	-	-
Total	**42.7**	**45.5**					

As shown in Table 1, the CVs are highest for the components with the lowest 14C content, which is a know phenomena when comparing biomass and non-biomass samples. Due to the fact that biomass contains more oxygen, and is therefore oxygenated, less of the carbon is available for further oxygenation. Subsequently, the energy per unit of carbon is lower for biomass than non-biomass materials; 0.39 MJ/kg (GCV) and 0.47 MJ/kg respectively (Voong *et al.* 2007).

As shown in Table 1 the composition of each of the prepared waste samples vary. Sample A contained significantly higher proportions of card, dense plastics and wood waste than sample B, and contained textiles but did not contain the inert material and film plastics used in sample B. The GCV and NCV measured for each component are similar to those reported in other studies (Burnley *et al.* 2011; Wagland *et al.* 2011), with the dense and film plastics yielding significantly higher energy content than the other components (Burnley *et al.* 2011).

The weighted average GCV and NCV for sample A for the composition shown in Table 1 were 14,582 and 13,556 KJ/kg respectively, and 9,975 and 9,281 KJ/kg respectively for sample B. Sample A has the higher energy content due to significantly greater proportions of card and wood, whereas sample B contains 26.4% inert material, which obviously does not have an energy value.

The results of the image analysis for each of the two samples are shown in Table 2,

highlighting the weight of each component determined by this technique and the percentage composition.

Table 2. Component weight and % composition determined by image analysis.

	Weight (kg)		% Composition	
Component	**A**	**B**	**A**	**B**
Paper	19.6	23.4	25.7	38.9
Card	20.9	5.4	27.4	9.0
D.Plastic	10.0	1.8	13.1	2.9
F.Plastic	-	0.8	-	1.3
Metal	2.1	2.2	2.8	3.7
Garden waste	6.7	4.1	8.8	6.8
Textiles	4.1	-	5.4	-
Wood	12.9	3.8	16.9	6.3
Inert	-	18.7	-	31.0
Total	**76.4**	**60.2**		
Correlation (r)	**0.992**	**0.988**	**0.993**	**0.988**

The weighted average GCV and NCV for the composition determined by image analysis, as shown in Table 2, were 14,875 and 13,828 KJ/kg for sample A respectively and 9,463 and 8,806 KJ/kg respectively for sample B. These are very close to the weighted average GCV and NCVs reported for the prepared samples, which is due to the accuracy of the composition reported by image analysis for both samples.

It is clearly shown in Table 2 that the image analysis technique over-estimates the weight of each component in most cases, with wood and garden waste in sample B being exceptions. This is a limitation of the method that requires further consideration and investigation. Whilst the weights are over-estimated, they are done so proportionately. This is shown by the very strong correlations ($r = 0.992$ and 0.988 for sample A and B respectively). Likewise there is also a very strong correlation ($r = 0.993$ and 0.988 for samples A and B respectively) between the percentage composition of the prepared waste sampled and the values determined by image analysis. The significance of these correlations are $p<0.005$ for each case.

The differences between the known mass of the components and the determined mass of waste components are due to the transfer of dot count to weight. As a result, the conversion used requires careful consideration, as this error is likely to be more pronounced in waste samples of much greater depth where overlap and hidden components are expected. The impacts of greater depth could be minimised by measuring the depth of the waste, or by controlling the depth by ensuring that the samples are more spread out and do not exceed a certain height.

Table 3. % Renewable energy of the samples calculated from the known composition and as determined by image analysis.

	% Renewable energy	
	GCV	NCV
Sample A	74.7	74.7
Sample B	80.3	80.1
Image analysis Sample A	70.7	70.7
Image analysis Sample B	79.6	79.4

As shown in Table 3, the percentage renewable GCV and NCV calculated from the known composition and from the image analysis-derived composition for sample A were lower than for sample B. This is due to the significantly greater proportion of dense plastic in sample A, which contributed to a large fraction of the total energy content but was only 1% biogenic according to the results of the ^{14}C analysis. The percentage renewable energy determined by image analysis was lower than values calculated from the known sample mixtures; however these are still similar being between 0.64 and 3.98 below the actual values.

The method outlined in this paper offer an early insight into a novel method which shows potential for use in the determination of renewable energy content prior to thermal treatment. There are two key applications of such a method, 1) net renewable energy content of a mixed waste prior to combustion, and 2) classification of solid recovered fuels [SRF]. In the classification of SRF, the net renewable energy content could be determined by the SRF producer, and so the end user of the SRF would understand the specifications of each batch of SRF prior to delivery and use.

An example set-up of the image analysis system is shown in Figure 3.

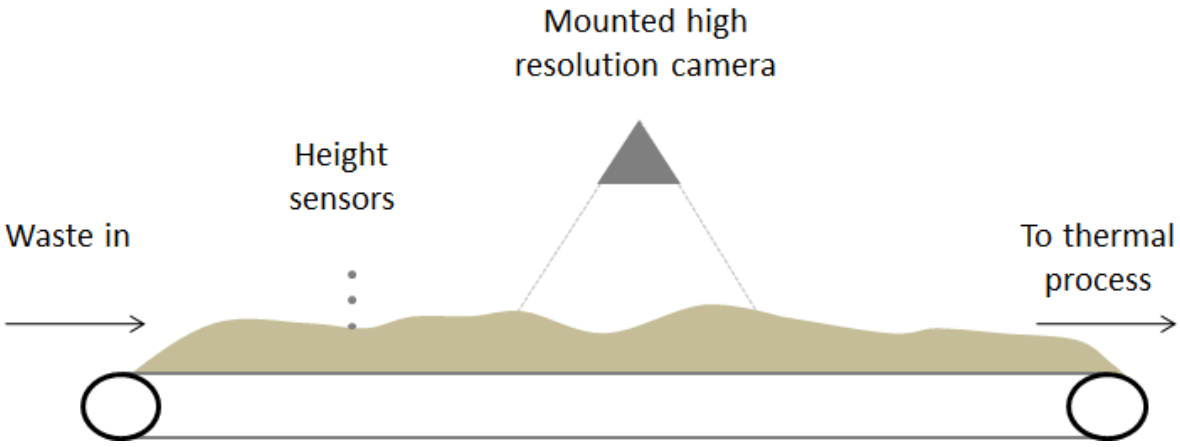


Figure 3. Example set-up of the image analysis process in a typical waste processing facility

The calculation steps from initial waste reception through to the combustion of the waste are shown in Figure 4.

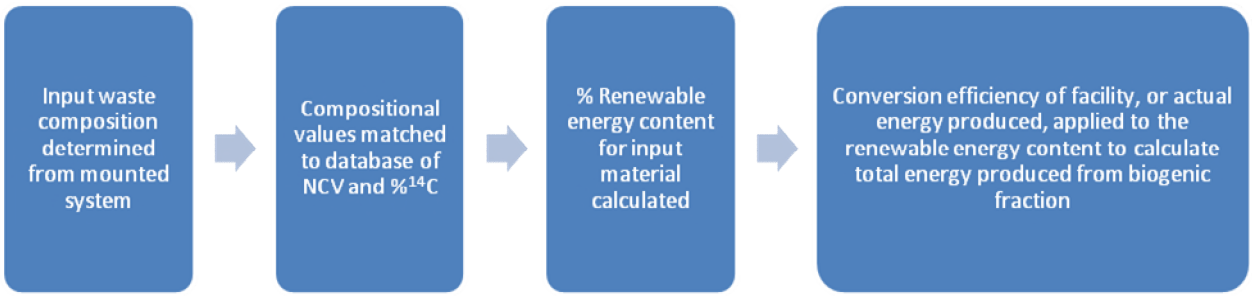


Figure 4. Calculation stages for the determination of renewable energy produced from a heterogeneous waste material.

Further work is required to improve the accuracy of the image analysis tool, and also to improve the time taken to analyse each image (currently 6-7 minutes in total). The required image processing can be set up so that the most labour intensive steps (image cropping and geometrical correction) would not be necessary. This would mean that each image could be analysed in 3 minutes or less by a competent operator.

5. CONCLUSIONS

From the work presented it can be concluded that the image analysis tool has demonstrated potential in the application of renewable energy from waste monitoring. Further work has been identified, and is currently ongoing. This work is aimed at further automation of the method, improved transfer of a 2D image to mass (to prevent component mass over-estimation) and to demonstrate the suitability to other applications.

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