

Potential of Waste Wood as a Source of Bioenergy Fuel

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1 Introduction

Competition against agricultural food production and limited land availability reduces the security of future energy demands being met from bioenergy. Therefore, it is of great importance to increase sources of non-food feedstock and to investigate any potential from other sources, such as waste wood.

Waste wood generated in the UK was estimated at 4.1 MT in 2010 [1]. Around 2 MT were recovered or diverted from the waste stream for recycling, with the remaining continuing to be sent to landfill creating a potential source of fuel.

Diverse streams of waste wood produce an assortment of materials, forms and non-wood content, which gives rise to a range of qualities. Investigations of chemical compositions must be performed for the utilisation of waste wood through laboratory characterisation methods. This gives an understanding of its properties to allow predictions of the effects during conversion into energy. This project analysed the following waste wood materials;

Municipal: household collections, civic amenity sites, woodland management.

Commercial & Industry: furniture manufacturing, wood packaging, pallets, utility poles.

Construction & Demolition: panelboard, particleboard, plywood, railway sleepers.

Fibreboard, MDF, chipboard, plywood, light, dark and red wood [sourced from industry].

A sheet of chipboard, cut into thirteen blocks, then washed with distilled water for various temperatures and length of time.



2 Methodology

Experimental methods were used to investigate the potential of waste wood as a source of biomass. After shredding and sieving to desired size, the CHNOS (carbon, hydrogen, nitrogen, oxygen and sulphur), ash, moisture and volatile contents of all the samples were analysed. Specific advanced techniques were used for the different samples. This allows for further analysis to identify potential issues with the relevant waste woods. A domestic stove combustion test was also conducted to study the potential harm caused by the burning of chipboard in a real-world scenario. These methods are outlined below:

Proximate, Ultimate Analysis and Calorific Values

This analysis determines the moisture, ash and volatile content, CHNOS content and hence the HHV values of the samples respectively.

Pyrolysis Gas Chromatography Mass Spectrometry

Wood samples are burned at 500°C in a nitrogen atmosphere with a 1/20 split ratio. The gaseous products were then analysed via mass spectrometry.

Solid State Fourier Transform Infra-Red Spectroscopy

IR light shone through samples and spectra taken. Molecules that are present in samples are determined via studying their main absorption peaks.

Ion Chromatography Mass Spectrometry

IC-MS can determine the concentrations of anions and cations in ppm, possible via the separation of ions due to interactions with a resin.

Domestic Stove Combustion Test

A multi-fuel domestic stove, fitted with various apparatus to record various emissions, was used to burn a chipboard and hardwood mix.

3 Results and Analysis

3.1 Calorific Values, Proximate and Ultimate Analysis

	HHV _{db} (MJ/kg)	Ash _{db} (wt.%)	N _{daf} (wt.%)
Highest	23.22 [birch bark]	36.94 [crosshatched]	18.76 [CB 3 min 30°C]
	10.08 [ash bark]	5.85 [crosshatched]	1.21 [CB 5 min 20°C]
	1.85 [willow 1 stem wood]	7.43 [chipboard]	5.24 [CB 10 min 40°C]
Lowest	16.15 [hazel bark]	29.27 [dark wood]	17.78 [CB 10 min 40°C]
	0.31 [willow 2 stem wood]	0.75 [high processed]	0.61 [CB raw]
	0.15 [ash stem wood]	0.81 [lightwood]	2.29 [CB 10 min 20°C]

Table 1: Calorific values, in terms of HHV, and ash content, on a dry basis (db), and nitrogen content, on a dry ash free basis (daf), are shown to the left according to the highest and lowest figures found within each set of wood samples. Note that CB stands for chipboard. For comparison, the HHV_{db} of Polish coal is 33.69 MJ/kg².

All the samples were analysed for CHNOS content, ash, moisture and volatile matter contents via ultimate and proximate analysis. The key results in terms of highest and lowest values are noted in Table 1.

3.2 Pyrolysis Gas Chromatography Mass Spectrometry [Py-GC-MS]

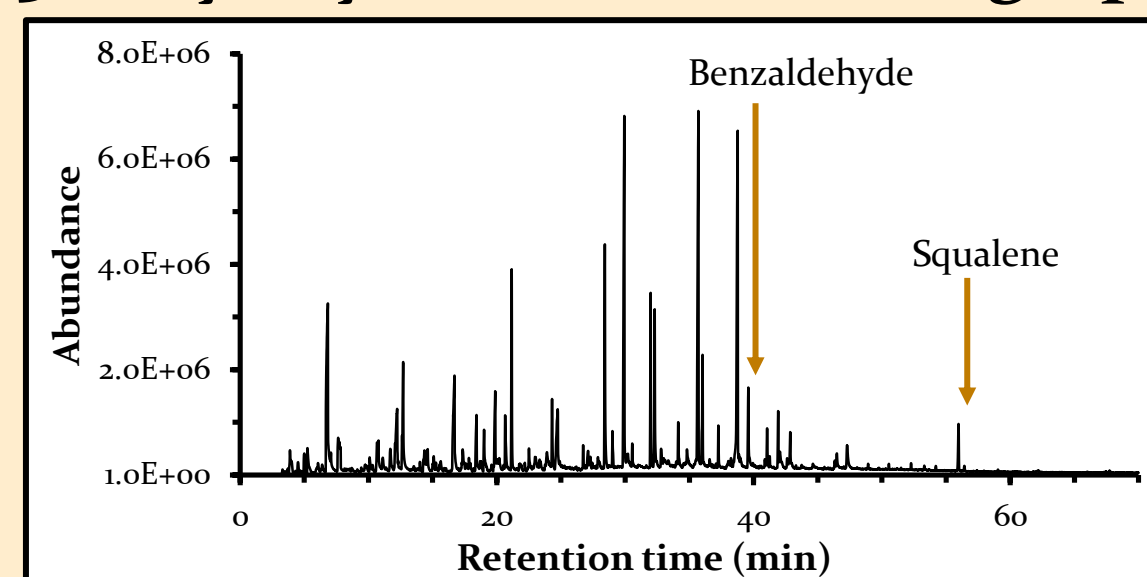


Figure 1: Py-GC-MS chromatogram of willow 1 stem wood

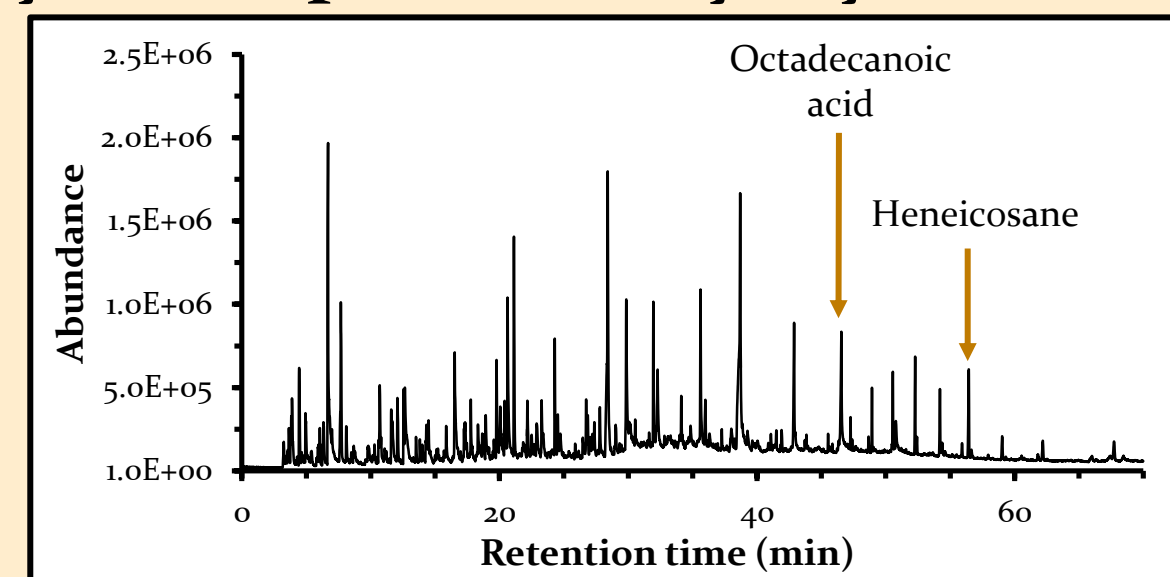


Figure 2: Py-GC-MS chromatogram of willow 2 bark.

Figures 1 and 2 show examples of stem wood and bark chromatograms respectively. Interesting exclusive compounds are also shown within their sample types. Benzaldehyde is an organic compound used to confer almond flavour. Squalene is also an organic compound used within skin moisturisers. Octadecanoic acid is a saturated fatty acid used as a softening agent in soaps. Heneicosane is an alkaloid used within both medicines and poisons and is found in bark, seeds, roots and leaves.

3.3 Solid State Fourier Transform Infrared Spectroscopy [FT-IR]

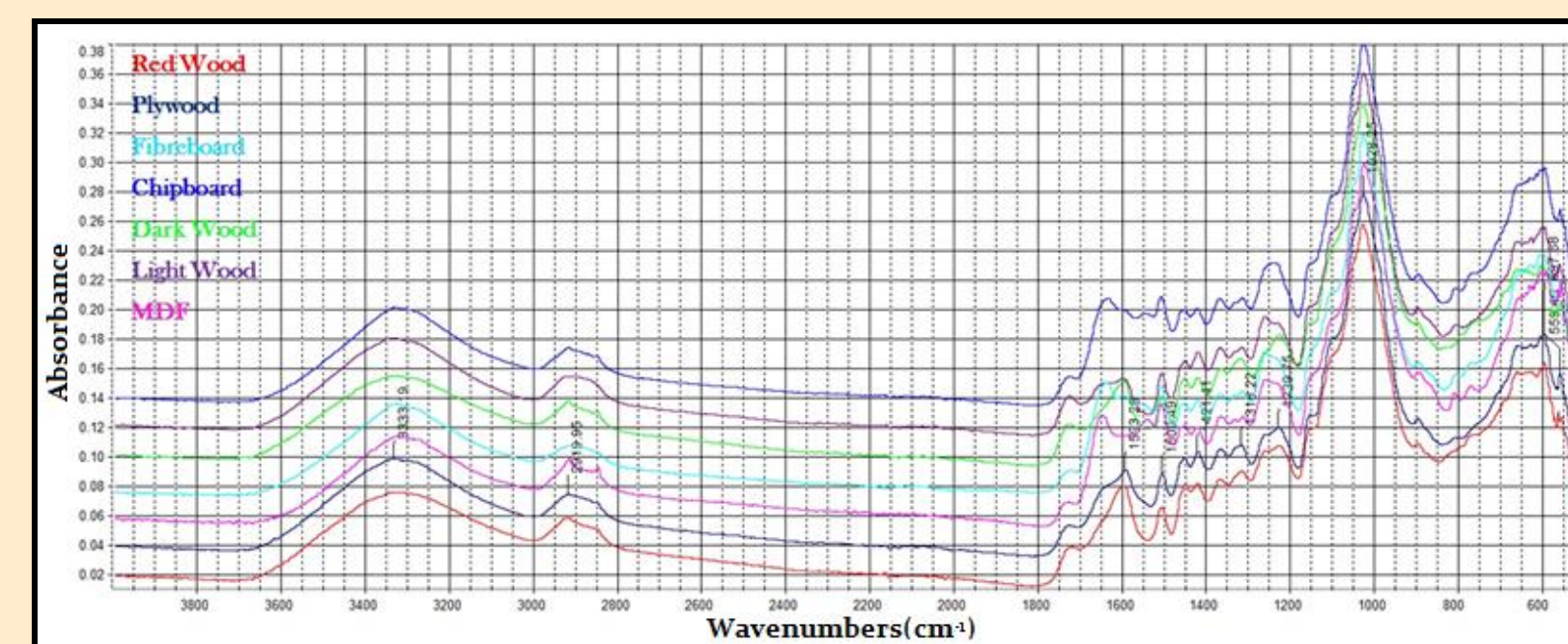


Figure 3: The FT-IR spectra for each of the samples from industrial waste wood, off-set for clarity.

Industry waste wood samples all have similar IR spectra, seen in Figure 3. The spectra is indicative of lignocellulosic biomass, as expected. Moisture in the samples accounts for the broad peak at 3300 cm⁻¹. Aliphatic hydrocarbons & inorganic phosphates were identified. Drying the samples beforehand would sharpen the signature peaks allowing determination of the cellulose to lignin ratio for each sample.

3.4 Ion Chromatography Mass Spectrometry [IC-MS]

After washing the thirteen chipboard samples in distilled water at varying temperatures (20, 30, 40°C), and for different durations (1, 5, 10 mins), the resultant leachate was analysed for trace metals using ion chromatography. The main findings are listed as follows:

- As the temperature and duration of wash increased, the amount of anions and cations leached from chipboard increased, especially for chloride, sulphate, sodium, magnesium, calcium and potassium. Nitrogen reduced by 41% on a dry basis.
- Certain temperatures and wash duration favoured particular chemical compounds (nitrate and acetate). Therefore there is a need to identify the most important trace metals for removal so pre-treatment techniques can be engineered accordingly.
- The volatile matter content of chipboard increased after pre-treatment, resulting in a reduced fixed carbon content, caused by the removal of potassium due to washing. This is because potassium has been found to influence the pyrolysis mechanism[3].
- The ash content of chipboard reduced by 58% due to pre-treatment with distilled water, compared to previous work[4]. Reduced ash content results in less fouling and slagging of the combustion chamber.

Less metals (chloride and sulphide especially) means less corrosive acid is formed inside the combustion chamber, which would increase the lifetime of the biorefinery. Hence, the use of other solvents and/or surfactants may improve pre-treatment methods.

References

- [1] WRAP, (2012). *Specification for the requirements and test methods for processing waste wood*. (PAS 111:2012) p.5.
- [2] E. Mitchell et al., (2014) *Combustion and Emissions Properties of RSPB Reed Briquettes*.
- [3] A. Saddawi et al., (2012). *Commodity Fuels from Biomass through Pretreatment and Torrefaction: Effects of Mineral Content on Torrefied Fuel Characteristics and Quality*.
- [4] ECN Phyllis Classification. (2014). Available: <https://www.ecn.nl/phyllis2/Browse/Standard/ECN-Phyllis#chipboard> [Accessed on 30/11/2014].
- [5] E. Mitchell, (2014). *Emissions from Domestic Biomass Combustion*. SUPERGEN Bioenergy Hub Conference, Aston University, 2014.

3.5 Domestic Stove Combustion Test

A 42:58% chipboard:hardwood mix was burned in a multi-fuel domestic stove to investigate the effect which the presence of the chipboard has on the particulate matter (PM) and gaseous emissions on household environments. This is important as high NO_x and CO emissions are known to cause various health problems, acid rain and smog. Four untreated slabs of chipboard were placed above the commercially available logs and then set alight. The stove during the combustion stages of interest are shown in Figure 4.



Figure 4: The chipboard/hardwood mix in the (a) volatile and (b) char combustion stages.

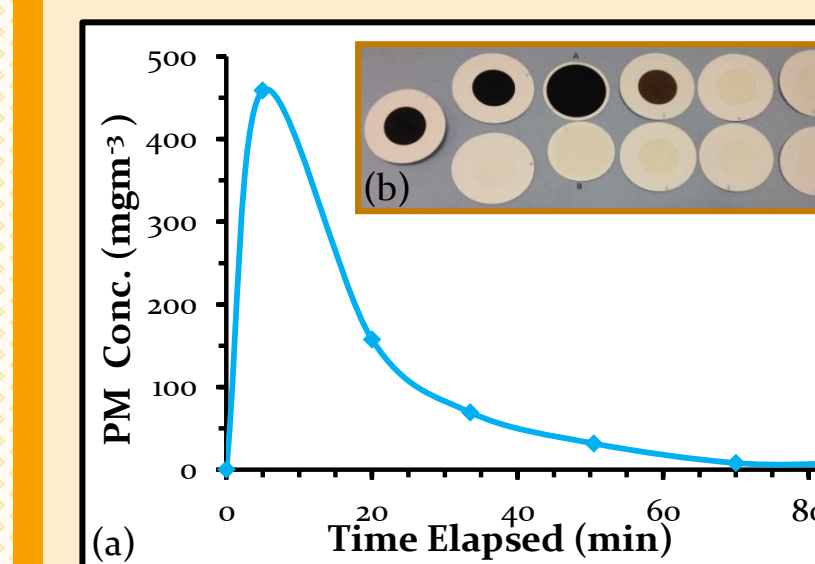


Figure 5: PM variation as a function of time (a), with filter papers shown in their pairs (b).

The amount of PM₁₀ and PM_{2.5} are important, as PM as small as 2.5 μm can get inside cells in the body, thus resulting in a various negative impacts on people's health. Figure 5 shows the exponential decrease in the levels of PM in the smoke captured by the filter papers after 10 mins. The PM₁₀ and PM_{2.5} concentrations were analysed and the total peak PM concentration was determined to be 458.7 mgm⁻³.

There are dangerously high levels of CO and NO_x emissions shown in Figure 6, with NO_x peaking at 248 ppm (corrected to 11% O₂). This is over triple the normal NO_x emissions of pure wood (72 ppm), and coal (225 ppm)[5]. This increase in NO_x must therefore be due to the chipboard, which has a nitrogen content of 7.43 wt.% on a dry ash free basis. Hence, it is recommended that raw chipboard should be avoided until suitable pre-treatment methods have been developed to combat these issues.

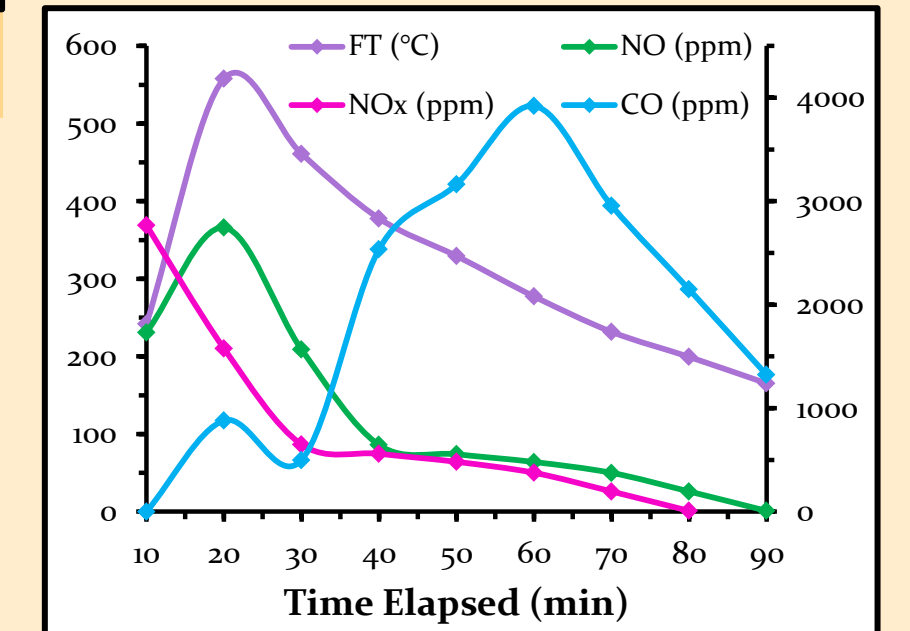


Figure 6: Emission profiles of NO_x and CO, alongside flue temperature (FT) during combustion. Note that the CO is the only value measured by the right hand side y-axis.

4 Conclusions and Future Research

Analysis of woodland management waste wood shows that birch bark is the most attractive for output energy owing to its high calorific value attributed to its high C, low O and low ash content, followed by willow 1 bark. Ash stem wood and willow 2 stem wood are most attractive for low emissions, owing to their relatively low N contents. Removal of bark material from stem wood may theoretically reduce overall moisture content and could improve slagging and fouling by a reduction of ash deposition.

It has been concluded that although many different types of waste wood from industry have similar compositions, the burning of raw chipboard should be avoided until pre-treatment methods have been sufficiently developed to reduce the high nitrogen content.

Pre-treatment methods using distilled water have shown that in general, a high temperature wash for at least ten minutes greatly reduces the harmful trace metals and ash content within the chipboard. Calorific values improved after pre-treatment by washing, this was due to the removal of catalytic metals; particularly potassium. Thus, pre-treatment by various washing temperatures are effective in making waste wood a viable fuel source.

There is scope for further work to develop the most effective pre-treatment methods for chipboard, such as using other solvents/surfactants, washing in higher temperatures (this may further reduce potassium content for example) and longer duration washes.