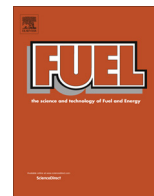




Contents lists available at ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel



Reactivity during bench-scale combustion of biomass fuels for carbon capture and storage applications

S. Pickard^a, S.S. Daood^b, M. Pourkashanian^c, W. Nimmo^{c,*}

^a Low Carbon Technologies Doctoral Training Centre, University of Leeds, Leeds LS2 9JT, UK

^b International Innovative Technologies Ltd., Gateshead NE11 0BU, UK

^c Energy Technology Innovation Institute, University of Leeds, Leeds LS2 9JT, UK

HIGHLIGHTS

- Combustion reactivity of 4 biomasses investigated with TGA.
- Conventional and CCS combustion environments analysed.
- Willow and grassy energy crops well characterised by modified Coats–Redfern method.
- Oxygen enrichment increases reactivity of volatiles and char.
- Substituting N₂ with CO₂ has complex effect on reactivity.

ARTICLE INFO

Article history:

Received 26 March 2014
Received in revised form 16 May 2014
Accepted 20 May 2014
Available online xxxxx

Keywords:

Biomass combustion
Oxyfuel
Oxygen-enrichment
Bio-CCS
TGA

ABSTRACT

Reactivities of four biomass samples were investigated in four combustion atmospheres using non-isothermal thermogravimetric analysis (TGA) under two heating rates. The chosen combustion atmospheres reflect carbon capture and storage (CCS) applications and include O₂ and CO₂-enrichment. Application of the Coats–Redfern method assessed changes in reactivity. Reactivity varied due to heating rate: the reactivity of char oxidation was lower at higher heating rates while devolatilisation reactions were less affected. In general, and particularly at the higher heating rate, increasing [O₂] increased combustion reactivity. A lesser effect was observed when substituting N₂ for CO₂ as the comburent; in unenriched conditions this tended to reduce char oxidation reactivity while in O₂-enriched conditions the reactivity marginally increased. Combustion in a typical, dry oxyfuel environment (30% O₂, 70% CO₂) was more reactive than in air in TGA experiments. These biomass results should interest researchers seeking to understand phenomena occurring in larger scale CCS-relevant experiments.

© 2014 Published by Elsevier Ltd.

1. Introduction

Combatting anthropogenic climate change and satisfying the forecast growth in global energy demand requires novel solutions for many established industries. Increasing pressure to limit and reduce greenhouse gas (GHG) emissions – particularly CO₂ – from power generation are widely understood to present a need to move away from unabated fossil fuel use. Reducing the emissions of CO₂ while maintaining a fleet of flexible thermal plant – required to balance and mitigate the variability of renewables generation against the inflexibility of nuclear generation – is seen as important by many nations. Two leading options to achieve this goal are to replace some or all of the fossil fuels with sustainably

sourced carbonaceous fuels such as biomass or to capture and permanently store the CO₂ resulting from the combustion process. While neither biomass cofiring nor carbon capture and storage (CCS) are truly sustainable in the long-term (only dedicated biomass firing without CCS could be envisioned as such) they represent one of the strongest options developed nations possess to reduce their GHG emissions while largely maintaining the quality of life of their citizens in the coming decades. Indeed, “[w]ithout CCS, overall costs to halve CO₂ emission levels by 2050 increase by 70%” [1]. Separately these processes could ideally offer substantial reductions in the emissions of CO₂ from electricity generation, but combined Bio-CCS projects could represent a net removal of CO₂ from the atmosphere. A net reduction of atmospheric CO₂ during Bio-CCS occurs as the CO₂ absorbed by plants during their photosynthetic growth stage is ultimately prevented from returning to the atmosphere being stored instead in deep geological formations.

* Corresponding author.

E-mail address: w.nimmo@leeds.ac.uk (W. Nimmo).

This is important since Bio-CCS is claimed to be “the only large-scale technology that can remove CO₂ from the atmosphere” [2] and with sustainably sourced fuels is able to produce power with lower GHG emissions than all other low-carbon generation technologies [3].

In the UK, early decarbonisation of the electricity system is seen as a priority in meeting the 2050 80% reduction targets since other sectors (e.g. transport and domestic heating) will require low-carbon electricity in order to reduce their sector’s carbon intensity [4]. Many technology roadmaps for the UK and globally strengthen the view that Bio-CCS is a necessary technology option for combatting climate change in the UK and around the world [1,2,5,6].

1.1. Knowledge to date

Conventional combustion of 100% biomass and cofiring with fossil fuels is widely practised on an industrial scale. However, CCS is still a developing technology which contains a wide range of configurational options and areas requiring further research [7]. A leading CCS technology option is oxyfuel combustion where, instead of selectively extracting CO₂ from a relatively dilute flue gas, the fuel is burnt in an environment that largely comprises of oxygen diluted by recycled flue gas (predominantly CO₂) which acts as a thermal diluent to match adiabatic flame temperatures to those seen in air-firing [8]. Through removing the largely inert nitrogen from the combustion process oxyfuel combustion is able to produce a flue gas far richer in CO₂ than conventional combustion processes requiring more conventional and economic gas clean up systems than envisioned for other CCS systems [9,10].

As well as new power stations, the current fleet will continue to emit CO₂ unless mitigating options are taken. While some plant will be suitable for total retrofitting of technologies such as oxyfuel, in other situations alternative CCS options such as post-combustion capture (PCC) may be preferred. PCC typically uses a chemical or physical agent to selectively remove CO₂ from the flue gas. However, one drawback to this method is the magnitude of the cost and size of a CO₂-scrubbing plant that is necessarily large due to the relatively dilute CO₂ in conventional flue gas (typically ~10%). One possibility for development in this area is to enrich the combustion air with oxygen, reducing the nitrogen content of the flue gas and hence concentrating CO₂ which could reduce the size and cost of PCC components, albeit at the extra cost of supplying oxygen. However, in addition to the potential logistical benefits, this technology option has been demonstrated to enhance combustion efficiency while simultaneously reduce nitrous oxide emissions when oxidant staging with over-fired air is used [11,12].

1.2. Experimental background

While bench-scale combustion techniques differ from full-scale plant in a number of ways, thermogravimetric analysis is a useful analogue for full-scale combustion that has been widely adopted to assess trends in fuel reactivity in both air and oxyfuel combustion scenarios, for example [13–15]. As standalone technologies biomass combustion and CCS have received much attention. However, a knowledge gap exists where little technical data has been published that concentrates on biomass combustion in situations applicable to CCS. In this work the behaviour of four biomass fuels in four combustion atmospheres which are useful to the development of CCS technologies are investigated to provide preliminary indications of their behaviour in novel combinations of fuel and combustion atmospheres. This work forms a part of a suite in which the fuels and combustion environments investigated at bench-scale are then used to inform the results of similar combustion tests carried out at pilot-scale [16].

Addressing climate change is a global challenge and the fuels tested in this study, while typical in the UK energy mix, are common outside of the UK so it is hoped the findings will be of wider interest.

2. Materials and methods

Three biomass resources – short rotation coppiced willow (SRC), miscanthus (MC) and reed canary grass (RCG) – were grown in the North of England by the BioReGen project [17]. Shea Meal (SM) supplied by RWE NPower was also included to compare with previous work [18]. Proximate analysis of the fuels was carried out by TGA analysis of mass loss in a nitrogen atmosphere with a temperature ramp rate of 20 K min⁻¹. Analysis of the lignocellulosic contents of biomass was conducted by several wet chemistry stages, as detailed in [19]. Results of analysis of the fuels are shown in Table 1. The negative value for lignin derived using the acid detergent lignin (ADL) method arises as the ADL measured value is less than the ash content of the fuel which suggests some of the ash components are solubilised by acid solutions. While this is less apparent for the samples containing lower amounts of ash, the negative value for RCG is thought to be due to the relatively high ash content (8.1%) acid solubility of particularly Ca and Na [20]. While the Klason and ADL methods for measuring lignin appear similar, differences of the magnitude observed inefuel:fuels are common, see for example [19].

2.1. Sample preparation

All of the UK-grown biomasses were harvested, dried and milled to pass through a sieve of 0.5 mm. In an attempt to separate experimental physical characteristics from those of a chemical nature and to ensure homogeneity in small sample sizes, it was necessary to further reduce the size of the particles. Mass transfer effects during thermal treatment have been shown to be largely mitigated once particle size is reduced to approximately 200 μm [21]. To avoid the escape of volatile species and/or waxy deposits, the biomass samples were milled using a SPEX 6770 Freezer Mill which uses liquid nitrogen to ensure samples remain solid during milling [22,23]. All samples were milled until they passed easily through a 212 μm sieve.

Table 1
Combined results of fuel characterisation studies.

Fuel	SRC	MC	RCG	SM
<i>Proximate analysis (%), ar</i>				
Moisture	6.0	5.5	5.8	7.5
Volatile matter (VM)	72.4	74	68.5	53.8
Fixed carbon (FC)	18.7	17.3	17.6	31.9
Ash	2.9	3.3	8.1	6.9
<i>Ultimate analysis (%), ar</i>				
C	47.7	46.4	42.2	48.6 ^a
H	6.0	5.8	5.4	5.9 ^a
N	0.4	0.3	1.4	2.9 ^a
S	0.0	0.0	0.0	0.2 ^a
O ^b	43.0	44.3	42.8	37.5 ^a
C:H	8.0	8.0	7.8	8.3 ^a
C:O	1.1	1.0	1.0	1.3 ^a
<i>Lignocellulosic content (%), ar</i>				
Hemicellulose	11.7	22.4	27.5	10.9
Cellulose	48.0	47.6	31.2	2.9
Lignin (ADL)	14.0	6.0	-2.0	24.4
Lignin (Klason)	27.2	23.0	20.0	41.6

^a Shea meal data from [11].

^b By difference.

Download English Version:

<https://daneshyari.com/en/article/6637001>

Download Persian Version:

<https://daneshyari.com/article/6637001>

[Daneshyari.com](https://daneshyari.com)