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Fluid bed gasification – Plasma converter process generating energy from solid waste: Experimental assessment of sulphur species

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ABSTRACT

Often perceived as a Cinderella material, there is growing appreciation for solid waste as a renewable content thermal process feed. Nonetheless, research on solid waste gasification and sulphur mechanisms in particular is lacking. This paper presents results from two related experiments on a novel two stage gasification process, at demonstration scale, using a sulphur-enriched wood pellet feed.

Notable SO_2 and relatively low COS levels (before gas cleaning) were interesting features of the trials, and not normally expected under reducing gasification conditions. Analysis suggests that localised oxygen rich regions within the fluid bed played a role in SO_2's generation. The response of COS to sulphur in the feed was quite prompt, whereas SO_2 was more delayed. It is proposed that the bed material sequestered sulphur from the feed, later aiding SO_2 generation. The more reducing gas phase regions above the bed would have facilitated COS – hence its faster response. These results provide a useful insight, with further analysis on a suite of performed experiments underway, along with thermodynamic modelling.

1. Introduction

Although gasification capacity to date has focused on fossil fuels (Childress, 2008), the use of solid waste feedstocks has significant potential (Knoef, 2005). Annually, some 3.4–4.0 bn tonnes of waste are produced worldwide from commercial, industrial and municipal sectors (Chalmin and Gaillochet, 2009). Huge growth in arisings can be expected as developing countries catch up (for example, ca. 10% for China in 2005) (He et al., 2009). Recent policy to tackle resource conservation and climate change has given gasification renewed impetus. Nonetheless, this remains dependent on evolving global economic and political factors, as epitomised at the United Nations (UN) Climate Conference, Copenhagen, 2009.

Research on municipal solid waste (MSW) gasification has been quite lacking (He et al., 2009). Moreover, understanding of sulphur partitioning and speciation is limited, with most research on coal and then biomass (Kuramochi et al., 2005). This represents a significant gap since the release of sulphur compounds may lead to process equipment issues, thus necessitating costly abatement measures. Nonetheless, it is reported that most feed-bound sulphur is released as H_2S under reducing gasification conditions, both for coal (Álvarez and Clemente, 2008; Jazbec et al., 2004; and Nakazato et al., 2003) and biomass (Kuramochi et al., 2005). As well as understanding the feed and its sulphur content, in order to predict partitioning and emissions, the interplay with other constituents (metals and chlorides, for instance) must be appreciated (Zevenhoven-Onderwater et al., 2001; Kuramochi et al., 2005; and Morrin et al., 2012).

Our research focuses on a novel two stage fluidbed gasification – plasma converter technology developed by Advanced Plasma Power (APP) to transform solid waste into energy at a commercial scale. The overall aim of our research is to investigate pollutant removal from the hot syngas, focusing on the partitioning and chemistry of sulphur along with other relevant components. Analysis, including thermodynamic modelling, is supported by experimental data.

Key stages to the APP Gasplasma™ process include: fuel preparation; fluid bed gasifier; plasma converter (PC); heat recovery; gas cleaning; and power generation. A summary of the commercial scale specifications are provided in Fig. 1 (detailed description provided in Morrin et al. (2012) and Materazzi et al. (2013)).

Abbreviations: UN, United Nations; MSW, municipal solid waste; APP, Advanced Plasma Power Ltd.; BFB, bubbling fluidised bed; PC, plasma converter; ID, induced draft; RDF, refuse derived fuel; SCADA, Supervisory Control and Data Acquisition; Exp., experiment; W, wood pellets; WA, sulphuric acid treated wood pellets; EPSRC, UK Engineering and Physical Sciences Research Council; EngD, Engineering Doctorate.

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As part of ongoing research and development, APP operates a demonstration plant incorporating the main process units described above (Fig. 2). Central to the process are the bubbling fluidised bed (BFB) gasifier and single carbon electrode plasma converter (PC). In this case, the enhanced syngas is cooled using a thermal fluid heat exchanger (from ca. 1000 to 200 °C), before passing through dry and wet scrubbing stages for the removal of chloride and sulphur gas species (exiting at ca. 40 °C). Slightly negative pressure (5–10 mbar) is maintained within the process using an induced draft (ID) fan located after the wet scrubber (APP, 2010a; 2010b). The syngas is then directed to either the gas engine or thermal oxidiser. Depending on feed properties, the plant may handle 20–100 kg/h of RDF, or 2–60 kg/h of wood pellets. The bed material in the BFB may be decanted and replenished during operation. Each process item is centrally controlled and monitored (for temperature, pressure, flow rates, electrical input, feed supply and gaseous species amongst others) by way of a Supervisory Control and Data Acquisition (SCADA) computer interface.

This paper focuses on two related experiments preformed recently on APP's demonstration plant. Wood pellet feedstock augmented with sulphur was used with a view to understanding sulphur release during gasification. After detailing the materials and methods employed, the results are presented, analysed and discussed, followed by summary conclusions.

Fig. 2. APP demonstration plant, Swindon, UK.

2. Materials

Along with the actual process, the feedstock (composition detailed in Table 1) and fluid bed material (Table 2) are integral to this research. Although the plant routinely handles RDF, the experiments reviewed in this paper focus on a wood pellet feed. The pellets were sourced locally and comply with the European standard CEN/TS 14691 (Big Barn, 2012). They are cylindrical in shape, with a diameter of 6–8 mm and varying length ($\geqslant$3 mm). Virgin sawdust is used in their manufacture, derived from a mix of spruce (ca. 50%) and pine with Douglas fir (ca. 50%) (Rowley, 2013). Compositional analysis results are presented in Table 1. Generally pellets are manufactured by compressing dry sawdust or wood shreds under high pressure until the lignin softens and binds the material together (Forestry Commission, 2007). This, combined with a low moisture and ash content, makes them a clean, high energy density fuel (typically two thirds that of coal). They also have a consistent composition and flow easily, making them an ideal experimental feed. By contrast, RDF has a less consistent composition and feedrate, thus introducing more variables to experiments. This can complicate analysis as well as the reproduction of and comparison between experiments.

Table 1
Composition and calorific value of wood pellets used in experiments.[a]

Composition	(wt.%)	Calorific value	(kJ/kg)
Carbon	46.55	Gross	24.075
Hydrogen	5.26	DAF	26.337
Nitrogen	0.26	Net	22.730
Sulphur	0.01		
Chlorine	0.01		
Volatile matter	78.3		
DAF volatile matter	85.6		
Total moisture	8.1		
Ash	0.5		

[a] APP (2011b).

Table 2
Composition data for BFB material used in experiments.[a]

Species	mg/kg	Species	mg/kg
Antimony	5.5	Thallium	<0.1
Arsenic	0.9	Tin	17.8
Cadmium	<0.1	Phosphorus	125.0
Chromium	11.1		
Cobalt	1.9	Total carbon (%)[b]	<0.01
Copper	329.3	Total sulphur (%)[b]	0.022
Lead	21.3		
Manganese	114.2	SO_4^{2-} (acid sol)	390.0
Mercury	<0.1	SO_4^{2-} (H_2O sol) (mg/l)[b]	191.0
Nickel	7.9	Chloride (2:1) (mg/l)[b]	215.0

[a] APP (2012).
[b] Other units.

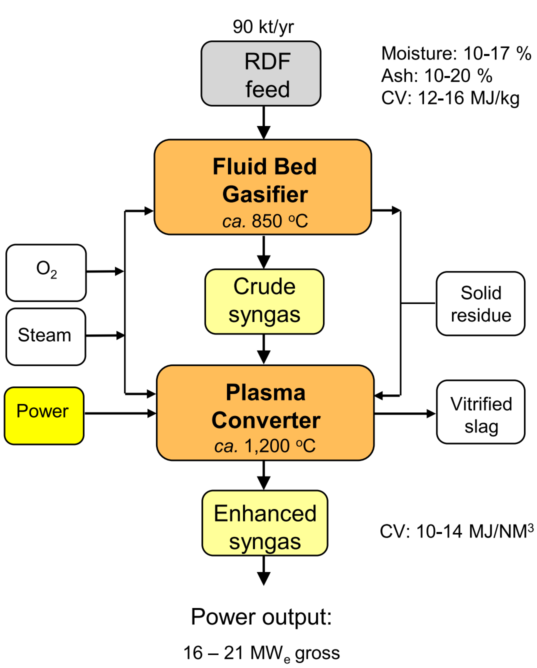

Fig. 1. APP commercial process, key parameters.