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Occurrence, composition and dew point of tars produced during gasification of fuel cane bagasse in a downdraft gasifier

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ABSTRACT

Gasification of pelletised fuel cane bagasse a waste residue from an energy crop known as fuel cane was investigated to evaluate the potential of fuelling solid oxide fuel cells (SOFCs) with the raw fuel gas produced. Tars produced during gasification of the bagasse in a 50 kWe air-blown downdraft autothermal gasifier were collected, quantified and characterised and the tar dew point evaluated. The concentration of tar collected was 376 ± 27 mg m^{-3} of dry syngas (at 273 K, 101 kPa), emphasising the efficiency of the tar cracking reactions in the oxidation zone of the gasifier. However, although tar production was low, the typical mixture of tar compounds produced exhibited a high tar dew point of 90 ± 5 °C and was dominated by Class 2 and 5 tars which condense readily even at low concentrations. Additionally Class 1 tars had a mass fraction of 8% of the total tar produced. Therefore the calculated tar dew point underestimates the actual tar dew point and a high potential for fouling of SOFC anodes exists. Consequently primary or secondary gas cleaning treatment measures targeting the production or occurrence of Class 1, 2 and 5 tars will be essential for long term operation of SOFC power generating systems fuelled by raw fuel gas from fuel cane bagasse.

1. Introduction

The major contaminant contained in gasifier raw fuel gas is tar, a complex mixture of more than 10,000 organic compounds which is produced during gasification when solid carbonaceous fuels undergo pyrolysis [1]. Condensation of tars on downstream processes creates operational difficulties leading to clogged fuel lines, cracking in the pores of filters and damaged power conversion systems resulting in unacceptably high levels of maintenance for engines, turbines and fuel cells. Most raw fuel gas applications therefore require the removal of some or all of the tars before the gas can be used [2]. Moreover, they contain on a weight basis, approximately 10% of the total biomass high heating value (HHV) [3] which is lost to the raw fuel gas if they are not converted to H_2, CO and CH_4. The reduction and/or removal of tar from the raw fuel gas is therefore one of the major technical barriers to be overcome in the development of biomass gasification for the use of this gas in efficient and economic generation of power [4].

The occurrence, composition and concentration of tar formed during gasification are functions of the fuel used and the process variables employed. A large body of information on total tar mass production can be found in the literature, however little information has been reported on tar composition from downdraft gasifiers. Moreover since the quantity and type of tar produced can cause forced-outages in industrial operations due to blocking and fouling of downstream equipment, understanding tar formation and composition

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during gasification of biomass is fundamental to the efficient operation of commercial biomass gasification systems.

The term “fuel cane”, collectively describes three types of high fibre cane (mass fraction 26–28.3%) developed in Barbados for energy production by the West Indies Central Sugar Cane Breeding Station (WICSCB). These canes designated W179460, W179461 and W181456 were produced by genetic hybridisation of wild *Saccharum spontaneum* clones with very high levels of fibre, and noble and commercial clones of sugar cane [5]. Fuel cane has a low sucrose content (11–11.3%) [6] and is subjected to the same type of processing in sugar factories as sugar cane. Fuel cane bagasse (FCB), the residue from fuel cane processing has been identified as a potential feedstock for fuelling an air-blown downdraft gasifier coupled to a solid oxide fuel cell (SOFC). SOFCs offer the best opportunity to upgrade the low heating value of the raw fuel gas produced by gasification since coupling a gasifier with a fuel cell can potentially achieve fuel conversion efficiencies as high as 60% [7]. This paper discusses the composition and dew point of the tars produced during gasification of FCB in a pilot scale 50 kWe downdraft gasifier and evaluates the feasibility for operation of SOFCs on this biofuel.

2. Experimental

2.1. Preparation of fuel cane bagasse

Fuel cane, grown at various locations in Barbados (13° 10N, 59° 32W) and at elevations ranging from 60 to 90 m was harvested by mechanical harvesters in February during the dry season. They were cut approximately 15 cm above ground and the stalk, cane tops and trash were immediately loaded unto trailers and delivered to the Portvale sugar factory where sugar was extracted within 48 h of harvesting. To avoid changes in biomass structure caused by complete drying, the bagasse produced was then air dried outdoors in covered areas at ambient conditions (32 °C) to a moisture content of mass fraction 20–25%. After drying, the bagasse was sealed in 50 polypropylene bags each weighing 20 kg and shipped to the United Kingdom for use in this study. On arrival at the laboratory in the UK, the FCB was air dried indoors at laboratory-ambient conditions. During this time the heaps were mixed every two days to ensure even drying and the moisture content monitored periodically until equilibrium with the ambient atmosphere (mass fraction 9.4–10%, dry basis) was obtained. It was then shredded in a hammer mill and pelletised into 8 mm diameter pellets using a Swedish Power Chippers AB commercial pellet press PP300, the final moisture content of the pellets ranged from mass fraction 6.0 to 7.4% (dry basis).

2.2. Characterisation of fuel cane bagasse

Sampling of FCB was carried out according to Ref. [8]. Each bag of bagasse was emptied into a heap, the heap was visually divided into three layers and a shovel was used to sample each layer. These samples were mixed to form a composite sample after which subsamples of 100 g each were removed. The subsamples were mixed and samples from this mixture were then used for determination of the mesh size, bulk density, proximate and ultimate analysis using CEN/TS methods [9–12]. Mesh size of the bagasse was determined by hand sieving using Endecott laboratory test sieves. Starting with the largest aperture which retained bagasse, the particles were collected quantitatively through successively smaller sieves until the smallest particles could be retained. Each portion retained in the sieve was weighed to establish the particle size composition. The results of these analyses are presented in Table 1.

2.3. 50 kW(e) air-blown downdraft gasifier

A schematic of the downdraft gasifier system used in this work is shown in Fig. 1. Gasification of the bagasse was carried out at atmospheric pressure in an intensified autothermal air-blown 50 kW(e) throated downdraft gasifier. The system mainly comprises an Imbert type reactor with a throat near the base, an air blower, a gas clean up system consisting of two cyclones, a water scrubber and an ash collector. The basic gasification system was described in Refs. [13,14]. The reactor has a double wall and heat loss is further reduced by fibreglass lagging which covers the outer shell.

Fuel cane bagasse was batch fed manually into the reactor through the hopper at the top; after loading the gasifier the induced draft fan was switched on and the reactor started by manually lighting the air inlet ports with a butane torch. Air, the gasifying agent was then sucked into the gasifier through the main air inlet valve at a controlled flow rate and into the chamber surrounding the throat by the induced draft fan. From there the air then flowed into the oxidation zone through a plane of air nozzles. The raw fuel gas generated in the gasifier was then extracted from the reactor by the suction effect of the induced draft fan. As the solid fuel was converted to raw fuel gas, the fuel bed moved down through the reactor under gravity. The ash and residues of char produced during gasification were emptied into the ash box manually by periodically turning the ash box handle during gasification.

Table 1 – Proximate and ultimate analysis of fuel cane bagasse.

Ultimate analysis	
Carbon, w_C (%)	49.4 ± 0.03
Hydrogen, w_H (%)	6.3 ± 0.3
Oxygen,[a] w_O (%)	53.9 ± 0.5
Nitrogen, w_N (%)	0.30 ± 0.06
Sulphur, w_S (%)	0.07 ± 0.01
Chlorine, w_{Cl} (%)	0.05 ± 0.01
High heating value, HHV (MJ kg^{-1})	18.9 ± 0.3
Low heating value, LHV (MJ kg^{-1})	17.6 ± 0.2
Proximate analysis	
Moisture, $w_{moisture}$ (%)	9.4 ± 0.8
Volatile matter, $w_{volatile\ matter}$ (% db)	65 ± 5
Fixed carbon, $w_{fixed\ carbon}$ (% db)	31 ± 4
Ash, w_{ash} (% db)	3.6 ± 0.7

db – dry basis.
a Calculated by difference.