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Production of BioSNG from waste derived syngas: Pilot plant operation and preliminary assessment

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ABSTRACT

Bio-substitute natural gas (or BioSNG) produced from gasification of waste fuels and subsequent methanation of the product gas could play a crucial role in the decarbonisation of heating and transportation, and could be a vital part of the energy mix in the coming decades. The BioSNG demonstration plant described in this paper seeks to prove the technical feasibility of the thermal gasification of waste to renewable gas, through a preliminary experimental programme to take an existing stream of syngas, methanate it and show that it can be upgraded to gas grid quality requirements. The syngas used in the project is a waste-derived syngas from a two-stage fluidised bed - plasma pilot facility, which is then converted and upgraded in a new, dedicated conversion and clean up plant. Extensive trials were undertaken on methanation and gas upgrading units for over 60 h of continuous operation. The fundamentals of a once-through methanation process train have been established on the demonstration facility and a model built to extend the analysis over different operational parameters. Over the trials, methane outputs of greater than 50 kW_{th} output were routinely produced from three methanation reactors in series, with a total CO conversion exceeding 90% at pressures as low as atmospheric, in line with kinetic model predictions. Retention of CO_2 as well as adequate partial pressure of H_2O in the process stream was important for process control. The plant provided demonstration of the efficacy of a PSA system for separation of CO_2 (99% removal efficiency) as well as the potential to remove a proportion of residual H_2, N_2 and CO, although this was associated with appreciable CH_4 slip. The process can be optimized primarily by reducing inlet temperature to methanation reactors, controlling syngas composition and using adequate steam to carbon ratio, depending on the type of waste. This information can be used to inform the design and economics of subsequent planned commercial plants that could significantly increase the potential of renewable gas in the UK and elsewhere in Europe, providing a low cost route to low carbon heat and transport.

1. Introduction

Methane is an attractive heat and transport fuel vector. It is a clean and relatively low carbon intensity fuel, which can be utilised efficiently in the well-established infrastructure and demand-side technologies, such as gas boilers for heating and an increasingly wide range of gas vehicles (Uusitalo et al., 2014). Bio-methane produced from biomass or waste materials retains all the attributes of natural gas, with the crucial advantage that the fuel is renewable, offering substantial CO_2 emission savings. Biomethane is historically being produced via the upgrading of biogas from Anaerobic Digestion (Ardolino et al., 2018; Mao et al., 2015; Mata-Alvarez et al., 2000). However, in order to achieve a step change in production capacity, alternative approaches such as via thermo-chemical routes (termed bio-substitute natural gas, or BioSNG) are necessary (Li et al., 2015; Seadi et al., 2008). Whilst technically feasible, this approach is less mature than anaerobic digestion. Transition from aspiration, to widespread operating facilities and infrastructure requires a detailed understanding of the technical and commercial attributes of the full chain, from feedstock supply through to delivery of grid quality gas, as well as the development of the first crucial operating facility which provides the tangible proof of concept for roll out (Cozens and Manson-Whitton, 2010; E4tech, 2014).

The demand for low carbon solutions for heat and transport through BioSNG is receiving increased international attention,

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especially in Europe with Gobigas project in Gothenburg and the Engie BioSNG research facility in Lyon (Arvidsson et al., 2012; Li et al., 2015; Rönsch et al., 2016). Both these facilities are focused on pure biomass feedstocks.

In light of the dominance of waste in the Europe bioenergy landscape as well as the wider economic and environmental attributes, the focus is rapidly shifting to waste-derived biomass. The production of Solid Recovered Fuel (SRF) or Refuse Derived Fuel (RDF) from non-hazardous wastes creates the opportunity to utilise wastes in thermal applications that are more sophisticated than the classical waste disposal route via incineration; in particular RDF, which contains up to 60–70% fraction (energy basis) of biomass (Iacovidou et al., 2018), is being regarded increasingly by a number of producers and users as a potential feedstock in gasification (Caputo and Pelagagge, 2002). Hence, there is the potential for the transformation of combustible wastes into syngas and its products – including BioSNG, notwithstanding that new technical challenges associated to the heterogeneous composition of the waste materials are inevitably introduced. Whilst the production of substitute natural gas from coal is a well-established process, being practiced for example at the Dakota synfuels plant for over 30 years (Kopyscinski et al., 2010; Li et al., 2014), production of BioSNG presents a number of issues demanding specific design choices and technical solutions. BioSNG plants must be at significantly smaller operational scale than coal to SNG plants (10–100 MWth output compared with 1000 MWth) due to the distributed nature of biomass and waste arising and lower energy density of the feedstock (Kopyscinski et al., 2010; Rönsch and Kaltschmitt, 2012). This has important implications for many aspects of the plant design, specifically the gas processing and methanation approach. The chemistry and form of the feedstock, as well as scale of operation, means that unlike coal, it cannot be processed using established high intensity, high pressure entrained flow gasification (Gassner and Maréchal, 2012). The available gasification technologies for this service tend to produce a syngas that contains a range of complex hydrocarbons ('tars') and other organic and inorganic contaminants (e.g. olefins, thiophenes, chlorides, etc.), whose presence and detrimental effects are not always appreciated (Kaufman-Rechulski et al., 2011). For example, at the modest commercial scale associated with waste fuelled facilities it would be economically impractical to use conventional energy intensive syngas scrubbing techniques (e.g. Rectisol or Selexol) to handle the entire range of sulphur contaminants found in the syngas (Rönsch and Kaltschmitt, 2012).

The approach taken in this work is the use of a prepared syngas produced from a primary fluidised bed gasification unit, ideally suited to the conversion of heterogeneous feedstock with low melting point components (Arena and Di Gregorio, 2014; Arena et al., 2015), and a second, high temperature syngas treatment stage, comprising an electric arc plasma converter (Materazzi et al., 2014). The advantage of splitting the waste conversion process in two separate stages, is that the combined process is reasonably agnostic to changes in fuel composition, and can easily cope with the high ash loading produced by RDF gasification, which can be recovered as an environmentally stable, vitrified product from the second stage (Materazzi et al., 2015a). Furthermore, the high temperature in the second stage breaks down tars and sulphur bearing species such as thiophenes, delivering a carbon monoxide and hydrogen-rich intermediary gas which can be treated by conventional and readily scalable dry or wet gas processing/polishing techniques to remove contaminant components to the parts per billion levels required for methanation catalysis (Materazzi et al., 2015b). Indirect (or allothermal) gasification, an alternative approach taken in other BioSNG processes which physically separates char combustion from biomass steam (or CO_2) gasification, offers the potential efficiency advantages of a syngas containing up to 15% methane, as well as low inherent nitrogen levels without the need of an air separation unit (van der Meijden et al., 2010). However, this high methane content in this pyrolysis gas represents the gaseous end of a spectrum of complex and condensable hydrocarbons, including cyclic, polycyclic and sulphur containing organic species. Removal of large quantities of complex organics down to levels which can be tolerated by a catalyst is particularly challenging (Heidenreich and Foscolo, 2015).

The design approach described in this paper is to produce syngas inherently free of any hydrocarbon, and rely on catalytic stages to selectively recombine atoms to the desired product. Furthermore, it is well known that methanation reaction rates can generate very high heat fluxes, which can lead to thermal degradation, localized coking and catalyst sintering (Bartholomew, 1982). In coal-scale SNG facilities this is typically addressed by complex reactor design and recycling of product gas to minimise reactant concentration and remove reaction heat (Rönsch and Kaltschmitt, 2012). In light of the scale of waste facilities, the strategic approach here is for a simplified once-through reactor system with the retention of carbon dioxide and use of steam as diluents to provide thermal buffering and moderation of the reactions.

In this paper, the thermodynamics and kinetics of the involved reactions are analysed through operation of a pilot plant with real syngas derived from wastes. This information would be key to properly design and optimize such reactors and, more importantly, to limit the risks during up-scaling from laboratory over pilot to commercial scale. For this purpose, a model is also developed in Aspen Plus to evaluate any differences in operating conditions, and to some extent, how different parameters affect the BioSNG efficiency of the systems. The systems will comprise water–gas shift reactor, methanation reactors, heat recovery, and product separation.

2. Experimental

2.1. Feedstock and materials

The approach used in the BioSNG technology is inherently flexible in terms of feedstocks; the two-stage gasification system has demonstrated operation on a large range of feedstocks and, because of a separate shift reaction stage which provides means for H_2:CO ratio adjustment, the downstream methanation process is able to cope with a wide variety of syngas compositions from the gasifier. The experimental programme presented in this work has focused on waste feedstocks, primarily municipal solid waste (MSW), as this represents the most technically challenging feedstock with the highest treatment costs, and will be the focus of early plants in the future. Feedstocks such as waste wood would require minimal process adjustments.

This section provides the specification for the baseline feedstock utilised in experiments. The design point for the waste composition for the pilot facility is derived from a number of datasets for representative residual municipal, commercial and trade waste collected nationally as well as locally. The design point specification is as shown in Table 1.

Mass balance figures assume such waste is input to the facility in the form of wet RDF (i.e. shredded municipal waste with metals, glass, incombustibles and large objects removed), which is then dried on-site; the data presented on Table 2 gives an indicative specification for the RDF, based on the waste described above. As all emerging technologies, implementation of BioSNG from MSW can only take place at this time with the appropriate tax, incentive and legislative environment. For example, the Renewable Obligation (RO) is the most established instrument in the UK to incentivise the use of biogenic resource (in this specific definition for