Fuel 152 (2015) 138–145

Contents lists available at ScienceDirect

Fuel

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

Characterization of several kinds of coal and biomass for pyrolysis and gasification

Caterina Frau *, Francesca Ferrara, Alessandro Orsini, Alberto Pettinau

Sotacarbo S.p.A., c/o Grande Miniera di Serbariu, 09013 Carbonia, Italy

HIGHLIGHTS

- Pyrolysis and gasification of different fuels have been experimentally assessed.
- Wood chips and different coals have been considered as reference fuels.
- Thermogravimetric analysis allows to design the pilot-scale gasification tests.
- Lignites are more performing than other fuels for fixed-bed air-blown gasification.

ARTICLE INFO

Article history:
Received 12 June 2014
Received in revised form 12 September 2014
Accepted 18 September 2014
Available online 1 October 2014

Keywords:
Pyrolysis
Gasification
Thermogravimetric analysis
Low rank coal
Wood chips

ABSTRACT

Sotacarbo is currently developing several research projects to optimize a coal and biomass gasification process for small- and medium-scale power generation and hydrogen production. To achieve this goal, between 2007 and 2008, Sotacarbo built a flexible pilot platform in its Research Centre in the Serbariu former coal mine (Sardinia, Italy), which is still very much into operation. The platform includes a demonstration and a pilot air-blown fixed-bed gasifiers, the latter tested for more than 2200 h and equipped with a flexible syngas treatment line for combined power generation and CO_2-free hydrogen production.

This paper reports the characterization of several kinds of fuels in terms of pyrolysis and gasification performance. In particular, a number of different coal and biomass samples have been tested, including South African bituminous coal, Sardinian high sulphur Sulcis sub-bituminous coal, lignites from Alaska and Hungary and stone pine wood chips.

An improved understanding of coal and biomass pyrolysis may be useful to predict the reactor performance in a gasification process and also to optimize the experimental campaigns in the pilot plant. Therefore, before the tests in the pilot-scale gasification unit, fuels are typically characterized by a thermogravimetric analysis to evaluate the pyrolysis behavior.

Among all the tested coals, Usibelli lignite from Alaska is the most reactive one. Its derivative thermogravimetric (DTG) profile presents a clear pyrolysis peak at 478 °C. The pilot-scale experimental results show that the gasification of 24 kg/h of Usibelli lignite allows the production of 79.67 kg/h of raw syngas, characterized by a lower heating value of 5.14 MJ/kg. An opposite behavior is shown by the South African bituminous coal, which does not present a peak in the DTG curve, as a consequence of the low volatile content in the fuel structure. This is confirmed by the gasification tests in the atmospheric fixed-bed plant, which show a low coal consumption and, as a consequence, a low syngas production (46.83 kg/h). Wood chips presents a very significant peak in the DTG profile at the temperature of 318 °C but, due to the low energy density, its gasification involves a low syngas production (23.31 kg/h).

1. Introduction

Coal has the largest reservoir in the world, if compared to other fossil energy sources like oil and gas [1]. Due to the common availability of coal and its cost stability, most of the developed countries use it as fossil fuel for power generation [2]. The International Energy Agency (IEA) has estimated that coal will be available for over 110 years, with coal reserves of about 860 billion tons [1]; a global

Abbreviations: ASU, air separation unit; CCS, carbon capture and storage; CHP, combined heat and power; DTG, derivative thermogravimetric profile; ESP, electrostatic precipitator; GL, grate loading (kg/m^2 h); HHV, higher heating value (MJ/kg); IEA, International Energy Agency; IGCC, integrated gasification combined cycle; IGFC, integrated gasification fuel cell; LHV, lower heating value (MJ/kg); LPG, liquefied petroleum gas; PSA, pressure swing adsorption; SGR, specific gasification rate (kg/m^2 h); TG, thermogravimetric profile; TGA, thermogravimetric analysis.

* Corresponding author. Tel.: +39 0781 670444; fax: +39 0781 670552.
E-mail addresses: c.frau@sotacarbo.it (C. Frau), f.ferrara@sotacarbo.it (F. Ferrara), a.orsini@sotacarbo.it (A. Orsini), apettinau@sotacarbo.it (A. Pettinau).

http://dx.doi.org/10.1016/j.fuel.2014.09.054
0016-2361/

peak in coal production can be expected between 2020 and 2050 [3,4]. Low rank coals, including brown coals, lignites and sub-bituminous coals, account for nearly half of the coal reserve worldwide [5,6]. They are playing an increasingly important role in supplying primary energy to developing countries. Currently, low rank coals are used primarily for electricity generation, but their use for other applications (such as co-generation and liquid fuels production) will increase in the future because they have certain advantages over black coals [7]. These advantages include low mining cost, high reactivity, high amount of volatiles, and low pollution-forming impurities [5]. However, in view of the exhaustion of fossil fuel reserves and the more and more restrictive environmental regulations, the use of alternative fuels as partial substitutes for fossil fuels for combined heat and power (CHP) generation is of growing importance.

From this global perspective, after fossil fuels (coal, oil and natural gas), biomass is the most important source of energy, which can supply about 14% of the world's energy consumption [8]. In recent years, several studies have reported that the combination of both coal and biomass is more advantageous than their individual effects [9,10]. It allows to use biomass in commercial scale power plants and coal in an environmentally friendly way. Moreover, a diffusion of biomass as primary fuel for power generation can contribute, in combination with carbon capture and storage (CCS) technologies applied to fossil fuel power plants, to the reduction of CO_2 emissions, which is essential to fight the global warming [11,12].

Gasification has been identified as a key technology in enhancing the environmental tolerability of low quality carbonaceous fuels. In particular, gasification is the first step to convert solid fuel into a cleaner synthesis gas. Syngas can be used in high efficiency devices, such as gas turbines, internal combustion engines or fuel cells for electricity and heat production. Considering medium- and small-scale applications, up-draft fixed-bed gasification is an interesting solution for distributed combined heat and power generation. Although this technology is conceptually not innovative, it is still used for coal and biomass gasification because of features like simple geometry, easy management, high efficiency, feedstock flexibility and, last but not least, its relatively low costs [13]. Despite most of the research and demonstration projects on large-scale integrated gasification combined cycle (IGCC) plants are based on oxygen-blown gasifiers [14], air-blown gasification could also be considered as an option, because of the potentially higher plant efficiency, the typically high plant availability and simplicity [15] and the economic advantage related to the absence of the air separation unit (ASU). Therefore, large-scale (higher than 10 MW), fixed-bed reactors have lost a part of their industrial market [16]; yet, medium- and small-scale (up to 10 MW) fixed-bed gasifiers, that have high thermal efficiency and require minimal pretreatment of the supplied fuel, have maintained a commercial interest especially for locally based power generation.

In this scenario, Sotacarbo is investigating the best and more efficient use of several kinds of coal and biomass for a sustainable production of electrical energy, clean gaseous and liquids fuels and heat. This paper describes the experimental equipment and presents the main results of a characterization analysis of several fuels to evaluate their behavior during pyrolysis and gasification processes. In particular, the most representative fuels tested in the Sotacarbo pilot plant have been selected and characterized through a thermogravimetric analysis (TGA) in inert atmosphere to assess the pyrolysis behavior and through pilot-scale experimental tests to investigate the gasification performance.

2. Feedstock

In this study, five kinds of fuel (selected as the most representative among those tested in the Sotacarbo pilot plant) have been characterized: (i) a high ash South African bituminous coal; (ii) a high sulphur sub-bituminous coal from the Sulcis coal mine (South-West Sardinia, Italy); (iii) a lignite from Usibelli coal mine, near Fairbanks (Alaska, USA); (iv) a high sulphur brown coal from Miskolc basin (Northern Hungary); (v) a stone pine (*Pinus pinea*) wood chips.

Table 1 shows proximate, ultimate and thermal analyses of the considered fuels, carried out in the Sotacarbo laboratories according to the international standards.

It is interesting to underline the very high volatile content of Usibelli lignite from Alaska with respect to South African coal and the very low heating values (HHV and LHV, higher and lower heating value, respectively) of Hungarian lignite. Both these parameters have a strong impact on the gasification performance. Moreover, the very high sulphur content in both Hungarian and Sulcis coal can be observed.

3. Pyrolysis characterization

The knowledge of the thermal decomposition of fuels is essential to assess the performance of gasification processes [17]. In particular, the pyrolysis process can be considered as the initial stage of thermal conversion process of carbonaceous materials, including gasification. So, an improved understanding of coal and biomass pyrolysis may be useful to predict the reactor performance in a gasification process. TGA is the simplest and the most effective technique to observe the pyrolysis profiles of a fuel. This chapter reports the main results of the experimental TGA characterization of the five considered fuels.

3.1. Experimental apparatus and procedures

A LECO TGA-701 thermogravimeter has been used for the assessment of the pyrolysis performance of each sample. Actually, the instrument allows to house up to 19 crucibles, but a maximum of 4 samples have been loaded for each test, in order to allow the collection of a high number of weights for each sample.

Each fuel has been crashed into a cross beater mill (Retsch SK100) and sieved in order to obtain a particle size lower than 125 μm. A portion of the resulting material is used as "as received" samples (used for the general characterization reported on Table 1), whereas the remaining is dried into an oven with a constant temperature of 105 ± 2 °C for at least 24 h and then stored in desiccators to prevent moisture absorption from atmosphere [18,19].

Each sample (1 ± 0.05 g) is loaded into a clean ceramic crucible and placed into the thermogravimeter. The test procedure is composed by the following steps: (i) heating from ambient temperature (about 30 °C) to 105 °C at a constant rate of 10 °C/min; (ii) temperature is maintained constant for 10 min in order to assure a complete removal of free-water [18]; (iii) heating up to 1000 °C [18,20] at a constant rate of 20 °C/min [18,21,22], chosen to minimize systematic errors in temperature measurement due to thermal lag during pyrolysis [11]; (iv) temperature is maintained constant at 1000 °C for other 10 min, in order to eventually complete the pyrolysis process; (v) cooling of the instrument to ambient temperature. During all the tests, a constant nitrogen flow (3.5 dm^3/min) is sent to the thermogravimeter to ensure an inert atmosphere. Each test has been performed two times, in order to assure the complete repeatability of the analysis.

3.2. Pyrolysis results

The experimental results of the analyses of the considered fuels are represented and compared by using the thermogravimetric (TG) profiles (Fig. 1) and the differential thermogravimetric