Applied Thermal Engineering xxx (2014) 1–8

Contents lists available at ScienceDirect

Applied Thermal Engineering

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

The Sotacarbo gasification pilot platform: Plant overview, recent experimental results and potential future integrations

Alberto Pettinau*, Gabriele Calì, Eusebio Loria, Paolo Miraglia, Francesca Ferrara

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

HIGHLIGHTS

- The Sotacarbo pilot platform for electrical energy and H_2 production is described.
- Main results from gasification of different coals and biomass are summarized.
- Lignite presents the best performance, with a syngas production of 73 Nm^3/h.
- Clean syngas with less than 1 ppm of H_2S and COS can be directly fed to MCFC stack.
- Syngas-fed MCFC can allow an electrical efficiency up to 32–33%.

ARTICLE INFO

Article history:
Received 25 July 2013
Accepted 30 December 2013
Available online xxx

Keywords:
Coal and biomass gasification
Pilot plant
Hydrogen production
Molten carbonate fuel cell

ABSTRACT

Sotacarbo is currently developing several research projects to optimize a coal-to-hydrogen process configuration within the field of hydrogen production through coal gasification for distributed power generation. To achieve this goal, between 2007 and 2008, Sotacarbo built a flexible pilot platform within its Research Centre in the Serbariu former coal mine (Sardinia, Italy), which is still very much into operation. The platform includes a demonstration plant and a pilot air-blown fixed-bed gasifier, the latter equipped with a flexible syngas treatment line for combined power generation and CO_2-free hydrogen production.

This paper aims to give a brief description of the whole experimental equipment and to summarize the main results obtained during more than 1700 h of experimental tests in the pilot unit.

It is also reported the gasification performance under different operating conditions. A number of different fuels and fuel blends were tested, including South African sub bituminous coal, Sardinian high sulfur coal, lignite from Alaska and wood chips from local forests. Alaska's lignite reached the best gasification performance due to the high reactivity. There is also a quick examination of the syngas cleaning process's main performance.

Finally, the very high efficiency of sulfur compounds removal through a zinc oxide-based hot gas desulphurization process suggested to evaluate the possibility to integrate the plant with a fuel cell system for a high efficiency combined heat and power (CHP) generation. The main results of this theoretical assessment, reached through a properly developed simulation model, are also reported in this work.

1. Introduction

Coal and the other fossil fuels will remain a significant source of energy all along the transition phase (it will last several decades) towards a sustainable worldwide energy system, mainly based on renewables and nuclear sources [1–3].

Among clean coal technologies, coal gasification could represent a competitive option for power generation and also for the production of chemicals or clean fuels, with particular reference to hydrogen. Hydrogen is universally considered one of the most promising energy carriers [4,5] and characterized by a worldwide production (18% from coal) greater than one billion of cubic meters per day [6,7]. Gasification processes have the distinctive advantage to be easily integrated with pre-combustion CO_2 capture systems, typically more efficient and less expensive than the post-combustion processes [8–11].

* Corresponding author. Tel.: +39 0781 670 444; fax: +39 0781 670 552.
E-mail address: apettinau@sotacarbo.it (A. Pettinau).

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http://dx.doi.org/10.1016/j.applthermaleng.2013.12.079

In this context, Sotacarbo is engaged in a series of research projects in order to develop and to optimize a gasification process and an integrated syngas treatment line for CO_2-free power generation and hydrogen production from coal and biomass. To achieve this goal, in a flexible pilot platform located in the Sotacarbo Research Centre, in Carbonia (South-West Sardinia, Italy) more than 1700 h of experimental tests had been performed since June 2008. The platform includes a 1.3 m diameter demonstration unit and a 0.3 m diameter pilot unit, the latter equipped with a complete syngas treatment line for both power generation and hydrogen production.

The choice of a pilot platform configuration is the compromise between the need to develop a gasification process for medium and small-scale industrial applications and the interest in the development of coal-to-hydrogen integrated processes to be applied in large-scale power plants. The target of the gasification process (medium and small scale, up to 10–15 MW_{th}) brought with itself the choice of a fixed-bed, air-blown gasifier. These processes handling is easier [12,13] and it is well known that the counter current fluid dynamics ensures a higher efficiency than other gasification technologies [14].

The Sotacarbo gasification technology allows to gasify different kinds of coal (including high sulfur low rank coals) and also biomass. The flexible configuration of the pilot syngas treatment line allows to test and characterize some gas treatment processes and materials (solvents, sorbents and catalysts) for syngas desulphurization, water-gas shift, CO_2 removal, hydrogen purification and so on. These specific properties of the pilot unit allow Sotacarbo to provide technical support to third Companies for testing activities on specific fuels, materials and processes.

This paper reports a short description of the pilot unit, together with an overview of the main experimental results obtained with the most representative tested fuels, which represents the core of the overall work. Moreover, a preliminary theoretical assessment on the potential integration of the pilot plant with an advanced syngas-feed molten carbonate fuel cell (MCFC) system is also presented.

2. An overview of the Sotacarbo pilot plant

The Sotacarbo pilot platform (Fig. 1) was built up to test different plant solutions at different operating conditions; therefore, it is characterized by a very flexible and simple layout. Both demonstration and pilot plants are based on a fixed-bed, up-draft and air-blown gasification process, suitable to be fed with both coal and biomass.

2.1. Pilot gasification process

The Sotacarbo pilot unit is based on a 0.3 m internal diameter gasifier (Fig. 2), equipped with a manual coal charging system, and a flexible syngas treatment system for both power generation and hydrogen production.

For the feeding of the gasifier, fuel is provided in big bags; every bag is drown out from the storage area by a heaver and, through a tackle, it is charged in a proper hopper in order to empty the bag itself. Then, fuel is drown out from this hopper and charged into the gasifier.

Fuel bed (which operates at about 0.11–0.14 MPa) is characterized by different operating zones, where the coal drying, devolatilization, pyrolisis, gasification and combustion processes take place. As fuel flows downwards, it is heated by the hot raw gas that moves upwards, coming from the gasification and combustion zones [15,16]. The gasification agents (air, if necessary enriched with oxygen, and steam) are introduced into the reactor near the bottom, below the fuel grate, so that they are pre-heated by cooling the bottom ash, which are removed through the grate itself (an electrical pre-heating up to 250 °C can be operated in order to avoid steam condensation before the injection into the gasifier).

Fig. 1. The overall Sotacarbo platform.

Temperature profile into the reactor can be determined through a probe, located near the reactor vertical axis and equipped with a series of 11 K-type thermocouples (with a measure range between 0 and 1200 °C), and through a series of other 34 thermocouples located near the reactor's wall and in the grate.

The start-up of the gasifier is carried out by using a series of three ceramic lamps, located near the bottom of the fuel bed, which heat the fuel (initially wood pellets, usually mixed with a small amount of paraffinic material to promote the ignition) in an inert atmosphere.

2.2. Dust and tar removal system

As shown by Fig. 3 [17], raw syngas from the gasification process is sent to an integrated skid which includes a wet scrubber, a first

Fig. 2. Pilot gasifier.

Please cite this article in press as: A. Pettinau, et al., The Sotacarbo gasification pilot platform: Plant overview, recent experimental results and potential future integrations, Applied Thermal Engineering (2014), http://dx.doi.org/10.1016/j.applthermaleng.2013.12.079