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Gasification of agricultural residues in a demonstrative plant: Vine pruning and rice husks

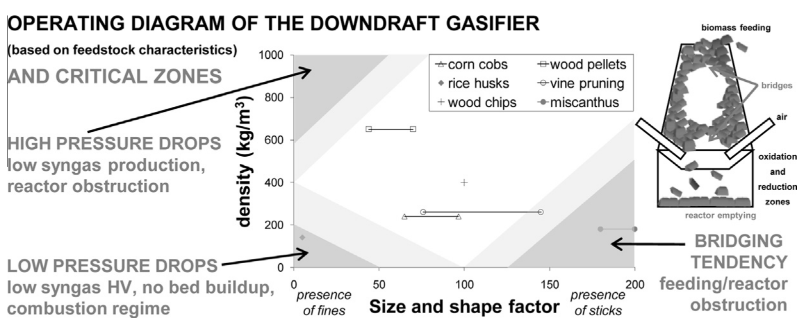
Enrico Biagini [a,*], Federica Barontini [a,b], Leonardo Tognotti [a,b]

[a] Dipartimento di Ingegneria Civile e Industriale (DICI), Università di Pisa, L. Lazzarino, 56126 Pisa, Italy
[b] Centro di Ricerca Interuniversitario Biomasse da Energia (CRIBE), Via vecchia di Marina, 6, 56122 Pisa, Italy

HIGHLIGHTS

- Experimental gasification tests are carried out with two biomass residues.
- The gasifier is a downdraft reactor at a demonstrative scale (350 kWth).
- Syngas composition, pressure drops, material and energy balances are provided.
- Plant operability and performance indexes are compared with previous results.
- A reactor diagram is defined considering density, size and shape of feedstocks.

GRAPHICAL ABSTRACT



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ABSTRACT

Tests with vine pruning and rice husks were carried out in a demonstrative downdraft gasifier (350 kW), to prove the reactor operability, quantify the plant efficiency, and thus extend the range of potential energy feedstocks. Pressure drops, syngas flow rate and composition were monitored to study the material and energy balances, and performance indexes. Interesting results were obtained for vine pruning (syngas heating value 5.7 MJ/m^3, equivalent ratio 0.26, cold gas efficiency 65%, power efficiency 21%), while poorer values were obtained for rice husks (syngas heating value 2.5–3.8 MJ/m^3, equivalent ratio 0.4, cold gas efficiency 31–42%, power efficiency 10–13%). The work contains also a comparison with previous results (wood pellets, corn cobs, *Miscanthus*) for defining an operating diagram, based on material density and particle size and shape, and the critical zones (reactor obstruction, bridging, no bed buildup, combustion regime).

1. Introduction

Gasification with air in a downdraft reactor coupled to an internal combustion engine is one of the most attracting biomass-to-energy applications on a small scale, because of the higher power efficiency with respect to any direct combustion based system, the possibility of utilizing the by-products (biochar as a soil amendment, recovery heat for cogeneration), the low emissions due to the combustion of a gas instead of a solid. The open issues concern the limitations on feedstock specifications (low moisture, narrow dimensional range, as discussed in Simone et al., 2009; Martinez et al., 2012), the high level required in the syngas cleaning (especially for tar and dust), and the disposal of waste water and/or filter media. Further drawbacks derive from issues related to biomass fuels, such as seasonal availability, logistics, low energy density.

* Corresponding author. Tel.: +39 050 2217840.
E-mail address: e.biagini@ing.unipi.it (E. Biagini).

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It is important to prove the operability of the gasifier with feedstocks other than the reference material (wood chips) in order to extend the diffusion of this technology to cheap and widespread agricultural by-products and food residues. The valorization of these lignocellulosic residues may increase the economic values of agricultural wastes and represent an opportunity for farmers. As a matter of fact, many of them represent out-of-specification fuels and are not suitable for the direct gasification, due to high moisture or ash content, presence of fines or long particles.

The work includes the results of the regional research project "Bio-Power in Tuscany" funded by Regione Toscana (Italy), aiming at proving the feasibility of a distributed energy generation in small plants that use biomass sources on a regional area. It is also part of the programmed activities on agricultural and forest biomasses to be tested in the gasification plant at CRIBE (Biomass-to-Energy Interuniversity Research Center).

Previous works with corn cobs revealed that good results (good operability, high plant efficiency) can be obtained, almost comparable with those obtained with wood chips (Biagini et al., 2014a). This work continues the investigation with out-of-specification agricultural residues and compares the results with previous ones in the same plant to extend the range of potential energy feedstocks and define an operability diagram of the gasifier (Biagini et al., 2014b). Vine pruning and rice husks were studied: the former derives from wine industry, which generates large amounts of residues on a regional scale and is a woody waste to be disposed; the latter derives from the cultivation of rice and is known to have a high ash content and low energy density. Potential availability of vine pruning is estimated to be 42 kt/y in Tuscany, and raises to 540 kt/y in Italy, while the availability of rice husks is around 280 kt/y in Italy (data from ENAMA, 2011).

Many studies can be found for the conversion of rice residues to energy (see for instance the review by Lim et al., 2012), dealing with thermochemical and biochemical processes. More limited investigations can be found for the utilization of vine pruning due to the smaller amounts and local availability. Data on such biofuels are rare for gasification in pilot/demonstrative scale plants (Natarajan et al., 1998; Yin et al., 2002; Ramírez Behainne and Martinez, 2014 for rice husks, Brito et al., 2014 for vine pruning), while some more frequent studies in laboratory scale apparatuses can be found (see for instance Gañán et al. (2006) for vine residues, Zhao et al., 2009 for rice husks). In this paper the results of the experimental campaigns in a downdraft demonstrative gasifier are provided and compared with previous data in the same plant.

2. Methods

2.1. Fuel characterization

The activities of the plant were supported by the laboratory at DICI (Department of Industrial and Civil Engineering of the University of Pisa – Italy), for the characterization of the solid fuels. The moisture content and bulk density was evaluated according to the European standard test methods EN 14774-1 and EN 15103, respectively. Volatile matter (VM), fixed carbon (FC) and ash content were determined by thermogravimetric (TG) analysis with a TA Q-500 thermobalance. Ultimate analysis was carried out with a LECO TruSpec CHN Elemental Analyzer, according to EN 15104 test method. A LECO AC-500 Isoperibol Calorimeter was used for determining the heating value (HV), according to EN 14918 test method. The particle size distribution was obtained according to EN 15149-1.

The results of material characterization are listed in Table 1. It can be noted that the moisture content is relatively low for both feedstocks (below 20% wt, which is the recommended specification). The ash content of rice husks is very high (16.6% wt on a dry basis), with repercussion on the heating value (15.6 against 18.1 MJ/kg on a dry basis for rice husks and vine pruning, respectively). The bulk density is low for vine pruning (260 kg/m^3) and very low for rice husks (140 kg/m^3). The particle size distributions of both feedstocks are compared in Fig. 1 with specifications recommended for an optimal operability of the feeding lines and gasifier. As can be seen, vine pruning is formed of a certain amounts of out-of-specification particles, both too large (a difference of 4.5% with respect to the recommended size fraction above 63 mm) and too fine (a difference of 24% for the range 3.15–8 mm, a difference of 11% for the range below 3.15 mm). Rice husks are formed of out-of-specification particles, almost exclusively below 3.15 mm.

2.2. Description of the gasification facility

The Gastone gasification plant is sited at CRIBE center (Pisa – Italy) and has a maximum thermal input of 350 kW, corresponding to 80 kg/h of biomass with a moisture content of 15%. The reactor is a downdraft type, with air entering just above the internal restriction for the depression caused by the blower at the end of the plant. During gasification tests, the amount of material inside the reactor was maintained constant by means of a level control (Reed and Das, 1988). Biochar was removed from the bottom of the reduction zone and samples were collected for offline analysis. Particulate, tar and most water were removed from the syngas in the cleanup line. Differential manometers gave the pressure drops across the gasifier bed and clean-up units to monitor the plant operability. The syngas temperature was continuously measured at the exit of the gasifier. A flow-meter at the end of the cleanup line measured the syngas production. A Gas Chromatograph (micro-GC Agilent 3000) and a Fourier Transformed Infrared Spectrometer (Bruker Tensor 37 FTIR spectrometer), positioned at the end of the cleanup line, was used for online gas analysis. More details on the equipment, diagnostics and analysis procedures can be found elsewhere (Simone et al., 2012, 2013; Biagini et al., 2014a).

3. Results and discussion

Four experimental tests were carried out (tests 1 and 2 with vine pruning, tests 3 and 4 with rice husks) by regulating the blower head at different levels, and thus obtaining different pressure drops across the gasification bed (DP) and different air and biomass flow rates. The measurements of the syngas flow rate, DP and syngas temperature at the gasifier exit are shown in Fig. 2, where results for all tests are plotted consecutively, excluding the transitory periods required for achieving stationary conditions.

Tests 1 and 2 with vine pruning differed in the syngas flow rate, 87 and 112 m^3/h (mean values of the stationary period, as following reported data), respectively. Correspondingly, the pressure drops were relatively low (14 mbar) for test 1 and relatively high (20 mbar) for test 2, respectively. These values are indeed acceptable and comparable with typical operation of the gasifier (generally DP are in the range 10–40 mbar). However, it can be noted that pressure drops are more irregular for test 2, i.e. for relatively high biomass feeding rate.

Tests 3 and 4 with rice husks differed in the syngas flow rate, 87 and 119 m^3/h, respectively. In both cases, the pressure drops were extremely low (1–3 mbar). These values are judged too small for typical operation of the gasifier, and imputable to the difficulty in building the fixed bed on the bottom grid of the reactor. This