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Thermochemical assessment of Nicotiana glauca, Panicum virgatum and Elytrigia elongata as fuels for energy recovery through gasification

Yarima Torreiro[a,*], Isabel Ortiz[a], Gregorio Molina[a], Marta Maroño[a], Virginia Pérez[b], J. María Murillo[b], Raquel Ramos[b], Miguel Fernández[b], Susana García[a], J. María Sánchez[a]

[a] CIEMAT, Madrid, Spain
[b] CEDER-CIEMAT, Soria, Spain

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ABSTRACT

Production of energy from renewable biomass resources would reduce atmospheric CO_2 increase associated with fossil fuels use. In this context, the objective of this study is to evaluate the energy potential of three herbaceous biomass crops (*Nicotiana glauca*, *Panicum virgatum* and *Elytrigia elongata*) grown on marginal lands. In order to do so, physicochemical and thermogravimetric characterization and gasification tests of each crop were performed. From the thermogravimetric analysis, it was estimated the activation energies of each energy crop using the Friedman method, obtaining values of 194.3, 224.9 and 220.6 kJ/mol for Nicotiana glauca, Elytrigia elongata and Panicum virgatum respectively. Then, in order to assess their potential as fuels for energy recovery, gasification tests were performed in a fluidized bed gasifier, using air and enriched air as gasifying agents. The ranges of experimental conditions used were the following: gasification temperature: 770–820 °C; ER: 0.15–0.20; oxygen content: 21 and 27% respectively. The gasification gas obtained from these experiments had a calorific value between 3.5 and 5.0 MJ/Nm^3, being always slightly higher for enriched air gasification. Besides, particle and tar contents were in the range of 4–17 g/Nm^3 and 4–12 g/Nm^3 respectively using air and 4–27 g/Nm^3 and 4–18 g/Nm^3 using enriched air. The results obtained showed that it is feasible to gasify the three selected crops grown on marginal lands with little differences in the gas produced offering an alternative to obtain a clean energy.

1. Introduction

The potential use of biomass for fuel and energy production has been researched extensively in recent years. In fact, biomass is currently the third largest primary energy resource in the world after coal and oil. In view of the increase in energy demand, the high costs of fossil fuels and disposal as well as the environmental concern about levels of CO_2 in the atmosphere, the use of biomass to provide partial substitution of fossil fuels for steam and power generation is of growing importance [1,2].

The use of specifically designed crops to obtain biomass, the so-called “energy crops”, allows the resource production to be planned [3]. However, the selection of suitable energy crops and the availability of land for their cultivation are the leading concerns. Although cellulosic feedstocks are believed to have a positive environmental impact and can make up a remarkable proportion of future energy, they cannot be produced yet on arable lands due to social, environmental and economic concerns. A promising alternative is to grow cellulosic crops (traditionally called energy crops) on “*marginal lands*”, which are unproductive or unsuitable lands for crop production and that, subsequently, have no or little potential or profitability for conventional food crops. Therefore, energy crops grown on marginal lands will not only provide cellulosic biomass without competition with food crops, but also help to reclaim those lands with a substantial mitigation of greenhouse gases (GHG) [4].

Recently perennial grasses have been chosen as promising energy crops in Europe because of their beneficial attributes over wood feedstocks for bioenergy applications. Those benefits include ease of establishment, high yields, fast growing, minimum environmental impact and low costs. However, despite there is a lot of information dealing with the cultivation, productivity and chemistry of these crops, there is a lack of information concerning to their quality as fuels and their thermal degradation behavior [1]. Therefore, the knowledge of its chemical composition and its thermal behavior and reactivity is very important for the effective design and operation of the thermochemical conversion units, since solid devolatilization is always a fundamental

* Corresponding author.
E-mail address: yarima.torreiro@gmail.com (Y. Torreiro).

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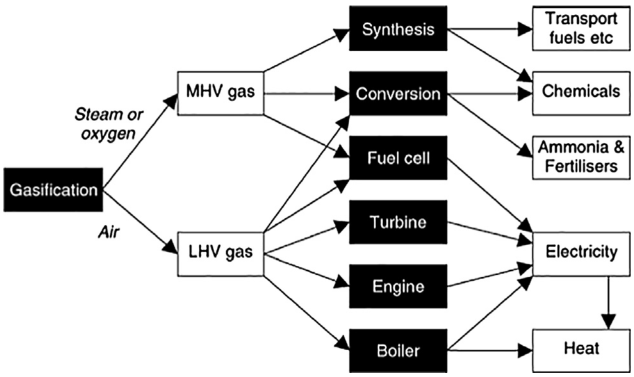

Fig. 1. Applications for gas from biomass gasification [9].

step during fuels thermal conversion [1,5,6].

Besides, the conversion of biomass by thermochemical processes such as pyrolysis, combustion and gasification is in volume the most important and efficient option to produce steam and power generation [1]. Particularly, gasification is one of the most promising and diversified technologies, due to its higher efficiency and its flexibility to use a wide range of feedstocks (biomass, coal, wastes, etc.) and to obtain a great variety of products, such as syngas, heat, power, bio-fuels, fertilizer and bio-char [7,8]. For example, Fig. 1 summarizes the range of fuel, electricity and chemical products that can be derived from the product gas obtained through biomass gasification. A medium heating value gas (MHV gas) obtained from steam or pyrolytic gasification is better suited to synthesis of transport fuels and commodity chemicals. On the other hand, a low heating value gas (LHV gas) obtained through air gasification is mainly used for electricity production [9].

In this context, three herbaceous biomass are considered as promising energy crops due to their high productivity, appropriateness for marginal land quality and their low water and nutritional requirements: *Nicotiana glauca* (NG) also known as tree tobacco; *Panicum virgatum* (PV) commonly known as switchgrass, and *Elytrigia elongata* (EE) or wheatgrass. Besides, they have allowed to obtain a high biomass production from which fuel and electricity can be generated [4,10]. Therefore, this study aims to investigate the potential of the three selected energy crops (NG, PV and EE) as fuels for energy recovery through gasification: In order to do so, this work can be divided in three parts: firstly, their thermochemical characterization by means of proximate, ultimate analysis, ash analysis, determination of calorific value and thermogravimetric analysis (TGA); secondly, the estimation of pyrolysis kinetics of biomass materials, necessary to understand their behavior during thermal processes. Finally, short series of tests using the three crops and two different gasifying agents, air and enriched air, were conducted in a pilot bubbling fluidized bed (BFB) gasifier in order to determine gasification feasibility in terms of syngas composition, energy content, carbon conversion and tar content.

2. Experimental section

2.1. Materials

Three energy crops have been studied in this research: *Nicotiana glauca* (NG), supplied by Azahar Management S.A, and *Panicum virgatum* (PV) and *Elytrigia elongata* (EE) supplied by CEDER. In all the cases, the raw biomasses were received from the suppliers and pelletized as cylindrical pellets, with an average size of 6 × 18 mm.

2.2. Characterization

2.2.1. Physicochemical characterization

The three herbaceous biomasses were exhaustively analyzed to obtain a thorough characterization of each one. All the analyses were carried out following the corresponding European norms for analysis and characterization of solid biofuels.

Characterization included the proximate analysis (for the determination of moisture content, ash content, volatile matter and fixed carbon), the ultimate analysis (to determine the total content of carbon, hydrogen, nitrogen, sulphur and oxygen of the sample), and the calorific value determination.

Furthermore, the ashes of the three biomasses (NG, EE, PV) were also analysed, and the content of the different elements present in the ashes were expressed as oxides. A theoretical method based on analyzing the ratio between alkaline earth oxides and alkaline oxides (Rake/ak) was carried out to predict the tendency to sintering of each sample. The relation for the estimation of sintering is the following [11]:

$$\mathrm{Rake/ak} = (\mathrm{CaO} + \mathrm{MgO})/(\mathrm{K_2O} + \mathrm{Na_2O}) \quad (1)$$

To complete the ash characterization, ash fusibility temperatures were also estimated using the corresponding standard method.

2.2.2. Thermogravimetric characterization

Thermogravimetric analysis (TGA) was done in an inert atmosphere of nitrogen in order to predict the behavior and thermal stability of different materials during a gasification process. TGA of different samples was performed in a thermobalance METTLER TOLEDO TGA/SDTA 851. The analyzer has a sensitive microbalance with an accuracy of ± 0.2 µg. Temperature measurements are expressed with an accuracy of ± 1 °C. In each test approximately 30 mg of sample was placed in a platinum basket and heated in N_2 flow (50 ml/min) from room temperature to up to 900–1000 °C at different heating rates of (5, 10 and 20 °C/min).

2.3. Kinetic study

Pyrolysis is the initial step in most thermochemical conversion processes. During that stage, large complex hydrocarbon molecules break down into smaller and simpler molecules of gas, liquid and char. Knowledge of pyrolysis therefore becomes relevant due to the fact that it is a key conversion step during gasification [12–14].

For a better understanding of the pyrolysis process, many researchers have studied thermal decomposition of biomass by thermogravimetric analyses. TGA is the technique most commonly used for kinetic analysis of devolatilization processes [5]. Two types of experimental studies can be done, isothermal and non-isothermal. The advantages of non-isothermal methods lie in the possibility to obtain results in a wide range of temperatures studying the influence of different heating rates on the thermal decomposition process [14].

There are many methods for analyzing non-isothermal solid-state kinetic data from TGA. These methods can be divided into two types: model fitting and model free (isoconversional) methods. Isoconversional methods are more frequently adopted because are flexible to allow for a change of mechanism during the course reaction (not necessary to choose a specific reaction model) and mass transfer limitations are reduced by the use of multiple heating rates [15].

The rate of decomposition of a determined material is a function of temperature and conversion. Conversion (α) may be described as follows:

$$\alpha = \frac{m_0 - m}{m_0 - m_f} \quad (2)$$

where m_0 is the initial mass of the sample, m is the mass of the pyrolyzed sample, and m_f is the final residual mass. The general conversion-time relationship is expressed in Eq. (3).

$$\frac{d\alpha}{dt} = k(T)f(\alpha) \quad (3)$$

where f(α) is the model function which describes the dependence of the