Fuel 195 (2017) 182–189

Contents lists available at ScienceDirect

Fuel

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

Full Length Article

Biomass sources for thermal conversion. Techno-economical overview

Roberto García [a], Consuelo Pizarro [b,*], Antonio G. Lavín [b], Julio L. Bueno [b]

[a] Instituto Nacional del Carbón, INCAR-CSIC, Apartado 73, 33080 Oviedo, Spain
[b] Department of Chemical and Environmental Engineering, Faculty of Chemistry, University of Oviedo, Julián Clavería s/n, 33006 Oviedo, Spain

HIGHLIGHTS

- Thirteen alternative biomass fuels were analyzed and compared with wood pellets.
- Some of them present characteristics that make then not adequated for combustion.
- Almond Shell and olive Stone proved to be technical and economically competitive.
- Some other samples characteristics may be improved due to pretreatment.

ARTICLE INFO

Article history:
Received 13 May 2016
Received in revised form 11 January 2017
Accepted 15 January 2017
Available online 24 January 2017

Keywords:
Biomass
Alternative fuels
Combustion properties
Green-house emissions
Energy cost

ABSTRACT

The constant increase in the use of biomass fuels has raised prices of the most common commercial products and consequently seeking for new alternative biomass resources for thermal conversion, like some industrial and agricultural wastes, becomes an interesting issue. To this aim, thirteen alternative raw biomass samples were analyzed and compared with briquette, wood pellets, and charcoal. Their proximate, ultimate and calorimetric analysis and physical properties data have been considered. In the same way gaseous emissions, ash composition, deposition and corrosion tendencies were evaluated. In addition to these intrinsic and environmental parameters, a general economic study, based on our previously obtained data, has been developed. Some of the selected samples, like almond shell and especially olive stone, seem to be optimum biomass resources to use instead of wood pellets, charcoal or briquettes in grate boilers, while some others require pretreatment to improve their characteristics and make them suitable alternatives to be considered in a short term future.

1. Introduction

The interest on alternative energy sources has deeply increased during the last two decades due to the concerns about environmental impact of traditional fossil fuels, their longevity and the constant fluctuation of their prices [1]. In this context, biomass, due to its renewability and CO_2-neutral balance, appeared as a promising sustainable feedstock to partially replace fossil fuels by reducing CO_2 emissions and helping to mitigate anthropogenic contributions to a perceptible global warming [2]. Biomass is the fourth largest source of primary energy in the world (meaning 12% of the total energy consumption) and rising to nearly 40% of it in some developing countries [3].

European Union objective to reach about 20% total energy use coming from renewable sources by 2020 directly focuses on biomass, as its consumption is expected to have grown by 260% by that date [4]. The constant growth of biomass demand is gradually causing price increase of the most commonly commercialized biomass fuels, so other "low-cost" alternative sources are encouraged to be found. To this aim, different options among agricultural and forest wastes, food processing industry residues, human and animal wastes, energy crops, municipal solid wastes (MSW), sewage sludge or leachates [5] should be carefully studied, and their use-as-fuel needs to be evaluated. Special attention should be payed to their intrinsic behavior, their environmental impact as gaseous emissions and ash-forming species and their collateral technical effects (i.e. melting and corrosion behavior).

In this way Ozcan [6] evaluated alternative biomass resources available in Turkey (MSW, energy crops, animal manure, urban waste water and sludge) concluding that they present a high potential for energy conversion. Shao [7] and Kaynak [8] evaluated the gaseous emissions (CO, NO_x and SO_2) of alternative biomass fuels, like sludge and peach and apricot stones, during their combustion. Wang [9] found that the ash related problems (agglomeration, slagging and fouling) appeared when burning three types of

---

* Corresponding author.
E-mail address: pizarroconsuelo@uniovi.es (C. Pizarro).

http://dx.doi.org/10.1016/j.fuel.2017.01.063
0016-2361/

seaweed, due to their high levels of alkalis. Finally Vassilev reviewed the chemical composition of a large number biomass fuels [10] and ashes [11] studying their evolution during the combustion process, focusing in eight non-common samples, like beech wood chips, corn cobs, marine macroalgae, plum pits, rice husk, switchgrass, sunflower seed hulls and walnut shells and compared their behavior with the one of coal.

In this context, the aim of this work is to evaluate the combustion properties of a number of alternative biomass fuels, obtained as industrial, agricultural or food-processing industry wastes, forest residues and energy crops, and compare them with three commercial biomass fuels to determinate if they can be considered a suitable replacement to normalized biomass ones, particularly for thermal conversion in fixed bed grate combustion processes and partly for fluidized bed processes [12,13]. We have not considered here biomass gasification processes. The relevant effects of biomass properties and applied gasification technology on the process and possible problems can be found elsewhere [14,15].

To do that, this work is structured as a first evaluation of the considered fuels, using analysis and physical properties data, obtained in previous works [16,17] and provided in Table 1. In addition to this, their gaseous emissions (NO_x, SO_2) were measured in a laboratory-scale device assuring the same reaction conditions.

Once evaluated the fuel properties, their residues after combustion (ashes) were also studied, with focus on their possible impacts in three fields: on human health due to emission of breathable particles; on combustion equipment due to deposition and corrosion tendency and on environment due to rewarding or damaging elements presence.

Finally, a brief economic study was developed, including energy generation, transport, store, constructive elements or maintenance costs, all of them highly influenced by fuels properties, trying to confirm if the evaluated fuels with the most promising properties, are nowadays economically competitive with the ones most commonly used in thermal conversion.

2. Materials and methods

Thirteen samples (almond shell – AS, beetroot pellets – BRP, coffee husk – CH, olive stone – OS, pine and pine cone leaf pellets – PPL, pine kernel shell – PKS, pine cone leaf – PCL, rice husk – RH, sorghum – SOR, straw pellets – SP, thistle – THI, vine orujillo – VO and wood chips – WCH) were chosen as possible alternatives to the currently most common biomass fuels used in combustion. They have been analyzed and their performance compared with a commercial brand of wood pellets – WP, commonly used in industrial or medium-sized domestic biomass burners, a commercial brand of briquettes – BRI often used in small-sized domestic boilers, and a sample of charcoal – CC. Some of the selected samples are already used as feedstock for biomass boilers, but usually just in a local and seasonal way, as soon as they are obtained as a waste or byproduct of concrete food-processing industries; so their study is interesting to determine their suitability for a wider use.

For that purpose, a more complete characterization is required. In this way, samples were studied "as received" after an initial air-drying step at room temperature, if external moisture is detected. Then, samples are grinded and sieved to accomplish the normative followed for each analysis.

Gaseous emissions of SO_2 and NO_x were also measured and compared for the selected samples, using an experimental device consisting in a Carbolite MTF 12/38/850 tubular furnace, programmed from 150 to 950 °C with a ramp of 5 °C/min. One gram of sample is put into a combustion cell in a quartz reactor and a flux of 3 l/min of air is supplied, with a Bronkhorst mass flow controller, until complete conversion is achieved. The gaseous emissions are measured using a Testo 350-XL 454 gas analyzer.

The chemical composition of the samples ashes was determined by energy dispersive X-ray analysis (EDXA), technique that works coupled with a *Scanning Electron Microscope* (SEM). In this case a JEOL-6100 SEM was used, coupled to an INCA Energy 200 EDX Analyzer that provides semi-quantitative elemental composition information of the selected samples. Since samples must be conductive, they are covered with a thin gold layer. Besides this, X-ray fluorescence (XRF) obtained data are also provided. This technique gives information about the elemental-oxides composition of ashes that allows predicting some common problems caused by ashes in biomass thermo-chemical conversion, like agglomeration, slagging, fouling and corrosion. For this purpose, a Phillips PW204 XRF analyzer was used joined to a PW2540 automatic sample loader.

As biomass is reported to be a major contributor to particulate matter emissions bellow 2.5 μm [25], particle size distribution (PSD) of the obtained ashes have been reported as well to determine the fraction bellow this value. Thus, laser diffraction (LD)

Table 1
Analysis data of the selected samples tested in this work.

Sample	Ultimate analysis					Proximate analysis				HHV	BD	Ash fusion temperatures				Cl	Cl/S
	C	H	O	N	S	M	A	VM	FC			IDT	ST	HT	FT		
AS	46.4	5.7	47.5	0.3	0.2	8.7	2.2	82.0	15.8	18,275	373	1080	–	1346	1389	0.01	0.0
BRP	38.9	5.2	54.1	1.2	0.5	12.5	9.0	76.0	15.0	15,095	539	1000	1200	1600	1670	0.05	0.1
CH	45.1	6.4	45.5	2.5	0.5	9.6	5.8	76.2	18.0	18,236	34	979	–	1242	1268	0.03	0.1
OS	46.6	6.3	45.2	1.8	0.1	11.0	1.4	78.3	20.3	17,884	742	1132	1265	1303	1328	0.06	0.5
PPL	42.3	4.8	52.3	0.4	0.3	8.2	3.2	75.0	21.8	18,147	676	1173	–	1298	1333	0.00	0.0
PKS	47.9	4.9	46.3	0.3	0.6	8.3	2.7	77.6	19.7	18,893	535	1099	–	1248	1282	0.04	0.1
PCL	47.7	6.3	45.6	0.3	0.1	9.1	1.3	80.0	18.7	18,633	392	979	–	1242	1268	0.15	1.2
RH	26.7	2.9	70.1	0.2	0.2	7.3	13.7	74.0	12.3	15,899	107	1269	1370	1402	1430	0.10	0.5
SOR	37.9	5.9	55.2	0.7	0.2	6.1	17.0	62.0	21.0	11,872	204	919	1030	1113	1156	0.30	2.8
SP	47.9	5.5	45.9	0.6	0.2	7.3	9.8	79.0	11.2	16,584	565	868	1061	1093	1193	0.46	2.5
THI	43.9	6.5	48.9	0.5	0.3	11.6	0.2	80.7	19.1	17,747	29	945	980	1240	>1300	0.70	2.3
VO	44.2	5.3	48.1	1.9	0.6	9.5	12.7	79.0	8.3	17,742	143	1173	–	1298	1333	0.05	0.1
WCH	42.2	5.5	51.9	0.1	0.3	25.6	1.5	68.6	29.9	15,162	149	1178	1198	1215	1300	0.01	0.0
BRI	46.7	6.4	45.5	1.2	0.1	5.8	0.8	85.0	14.2	18,498	559	–	1370	>1450	>1450	0.02	0.2
CC	79.3	2.7	17.0	0.7	0.3	5.3	5.9	26.0	68.1	29,712	350	1269	1273	1275	1281	0.04	0.1
WP	46.8	6.1	46.2	0.6	0.3	7.7	1.3	82.0	16.7	18,218	589	1129	1202	1251	1244	0.01	0.0

Where C, H, O, N, S, M, A, VM and FC are the carbon, hydrogen, oxygen, nitrogen, sulphur, chlorine, moisture, ash, volatile matter and fixed carbon contents in mass percentage measured on the samples "as received". HHV is the higher heating value in J/g. Most of these parameters were calculated according to the standard ASTM E870 [18], except O and FC that were obtained by difference, respectively as 100-Σ(C, N, H, S) [19] and 100-Σ(A, VM) [20]. BD is the bulk density in kg/m^3, obtained as suggested in [21]. IDT, ST, HT and FT are respectively the average initial deformation, softening, hemisphere and fluid temperatures of the sample's ashes measured in °C [22–24]. Cl is the average chlorine content of the selected samples [24]. Cl/S is the calculated molar Cl/S ratio.