Preliminary study of gasification of Argan's nutshells in a fluidized bed gasifier

Zainab Afailal[1], Noemí Gil-Lalaguna[1,2], Isabel Fonts[1,2]

[1] Grupo de Procesos Termoquímicos (GPT)
Instituto de Investigación en Ingeniería de Aragón (I3A)
Universidad de Zaragoza, Mariano Esquillor s/n, 50018, Zaragoza, Spain.
Tel. +34-976762224, e-mail: 770905@posta.unizar.es
[2] Centro Universitario de la Defensa de Zaragoza

Abstract

The main objective of this study is to assess the performance of the gasification of Argan's nutshells with pure oxygen as gasification agent. The results of the experiments gave an important percentage of hydrogen produced, around 20%, and point to this agricultural waste as an interesting material to be gasified.

Key words: Gasification; Argan's nutshells; Pine forest residue; Syngas

Introduction

The present work deals with the gasification of shells of Argan (AS), waste coming from argan nuts, the fruit of Argania Spinosa (L.) Skeels, which is an endemic tree to Morocco. This tree covers an area of about 870000 hectares of southwest of the country [1]. Its importance consists of the fight against soil erosion, fodder for goats, as well as the production of the famous argan nut oil [1]. Morocco produces annually over than 4000 tons of argan's oil, fact that leaves behind around of 20 tons of waste (Argan's nutshells) for each ton of oil produced [2]. Local people use this waste as alimentation of traditional furnaces for heating, but its hardness and rigidity hinder its use as fuel for heating.

Up to date, bibliographic resources in terms of any other type of valorization of the AS are scarce and, from the best of our knowledge, no research has been carried out on, for example, the gasification of this waste. Therefore, gasification of AS has been preliminary studied in this work aiming to compare the results with the use of other lignocellulosic materials.

Gasification is a process that can rapidly transform a solid feedstock into a gaseous fuel rich in hydrogen, carbon monoxide and methane, using a gasifying agent as air, oxygen, steam or carbon dioxide. This treatment takes place in a temperature usually ranging between 800 and 1100°C [3].

This study will be divided into three parts: (i) Characterization of the raw material; (ii) Establishment of an adequate theoretical model based on non-stoichiometry equilibrium for gasification; (iii) Gasification of this raw material according to the operational conditions of temperature and equivalence ratio (ER) defined by the thermodynamic model. As final step, the results obtained for AS gasification will be compared with the gasification's results of a most typical lignocellulosic material, such as forest residues of pine.

Material and Methods

1- Materials

Before the gasification experiments, a complete characterization of the raw material was required. The Argan's nutshells were crushed before characterization in order to obtain a homogenous sample. The results of higher hating value (HHV), ultimate and proximate analyses are grouped in Table 1. Elemental analysis was determined using LECO CHN628 Analyzer combined with the sulfur add-on module 628-S, higher heating value by means of calorific Bomb IKA model C2000 basic, ash content according to EN 14775:2010, moisture content according to EN 14774-3:2010 and volatile matter according to EN 15148-2010.

As can be seen in Table 1, where characterization results of AS are compared with those of forest residues of pine (P), differences between both materials are not significant neither in terms of elemental composition nor in the calorific value.

2- Theoretical model

The AS gasification process has been theoretically modeled through the study of the chemical equilibrium using HSC 6.1 software add-in in Excel. Calculation in this model is based on three main conditions: i) minimization of the Gibbs free energy of the system; ii) compliance with the atomic balance of the reaction; and iii) establishment of an auto-thermal process by filling the energy balance. The model takes into account heat losses of 5%. In order to obtain the ER required to reach certain temperature for gasification, it is sufficient to enter the characteristics of the raw material in the model while varying the temperature and/or the S/C (steam to carbon mass ratio) if steam is also used as gasifying agent in addition to O_2. Gas yield and composition are also the results of this model.

3- Experimental system

Gasification experiments of nutshells of Argan (AS) were conducted in a fluidized bed reactor operating at atmospheric conditions in a laboratory scale plant [4]. The biomass was introduced to the reactor semi-continuously from the upper entrance by means of a manual valves system (3.5g/min). The reactor is composed of two parts: bed zone and free-board zone with inners diameters of 40 mm and 63 mm, respectively. The gasification agent was pure oxygen, which was introduced from the bottom of the bed. In the bed, composed of 100 g of calcined dolomite (particle size between 150 and 250 µm), partial oxidation of the biomass and gasification reactions take place. Heating of the reactor was operated by an electric furnace with different and controlled heating parts (bed, free-board and cyclone). The bed and free-board temperatures were set at 850°C, while the cyclone and the subsequent hot filter were heated to 450°C. Ash and char produced in the reaction left the bed by overflow to a solid vessel, while vapors and gases passed through a cyclone and a hot filter, where solid particles were removed. Then condensable vapors (water and organic compounds) were collected in two water cooled condensers, and a cotton filter was used to retain humidity and small aerosols of tar. The volume of gas was measured using a volumetric gas meter. As final step, gas composition was analyzed by an online micro-chromatograph (Agilent 3000A).

Results and discussion

Table 2 shows the results of the theoretical study of gasification equilibrium for both materials, Argan's nutshells and pine, at different ratios of steam in the gasification medium and at a temperature of 850ºC. The slight differences in the composition of both materials lead to a higher requirement of O_2 (higher ER) in the case of AS gasification to mantain 850ºC.

As first step of the AS gasification experiments, the work was firstly focused on studying the gasification process with only O_2 as gasification agent. Additional steam was not added to the reaction medium, but only the material moisture took part in the gasification reactions (S/C=0.184). Therefore, operational conditions in AS gasification were 25.2% as ER (pure oxygen) in a temperature around of 850ºC. Two replicates of this experiment were conducted in order to evaluate the experimental error.

The most relevant results of AS gasification are summarized in Table 3. For the sake of comparison, results of pine gasification (previously studied at similar operating conditions in the GPT) are also included in Table 3. Results of char yield, tar content in the gas and heating value of the gas were almost the same for both materials, while data of H_2/CO ratio and gas production were slightly better in the case of pine gasification. Regarding gas composition from AS gasification (Figure 1), H_2 content reached 20%, while CO and CO_2 were 32 and 35%, respectively. A significant percentage of CH_4 was also obtained (8.5%).

Conclusions

As the results of this preliminary study shown, gasification can be a promising technology for the valorization of nutshells of Argan in syngas. Further work under different operating conditions is required to optimize the AS gasification performance.

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FIGURES / TABLES

Table 1: Characterization results of Argan's shells (AS) in comparison with forest residues of pine (P).

Proximate analysis	AS (wt. %, wet basis)	P (wt. %, wet basis)
Ash	0.20±0.04	1.8±0.2
Moisture	8.74±0.03	7.7±0.2
Volatiles	74.6±0.3	77±2
Ultimate analysis	AS (wt. %, wet basis)	P (wt. %, wet basis)
C	47.5±0.1	46.74±0.02
H	6.55±0.08	6.28±0.04
N	0.177±0.003	0.093±0.001
S	0.044±0.001	0.050±0.001
*O**	45.5±0.2	45.04±0.02
HHV(kJ/kg)	18613±44	18513±89

**Calculated by difference (wt.%): 100-C-H-N-S-Ash.*

Table 2: Results of theoretical study for Argan's shells (AS) and forest residues of pine (P) at T=850°C.

AS			P		
S/C	ER (%)	H_2/CO	S/C	ER(%)	H_2/CO
0.184*	25.2	0.806	0.165*	23.4	0.787
0.5	26.0	1.002	0.5	24.2	0.995
0.7	26.6	1.125	0.7	24.8	1.118
0.9	27.2	1.247	0.9	25.4	1.240
1.1	27.8	1.369	1.1	26.0	1.362
1.3	28.4	1.490	1.3	26.6	1.483
1.5	29.1	1.610	1.5	27.3	1.604

****Without adding steam. Steam in the gasification medium is just coming from the own moisture content of the material.***

Table 3: Gasification results of Argan's shells (AS) in comparison with pine gasification.

	AS	P
Char yield (%)	3±1	4
g tar / m^3N (gravimetric)	6±3	6
H_2/CO ratio	0.64±0.01	0.84
Gas production (m^3N / kg)	0.82±0.09	1.16
Gas LHV (MJ / m^3N)	10.7±0.1	10.5

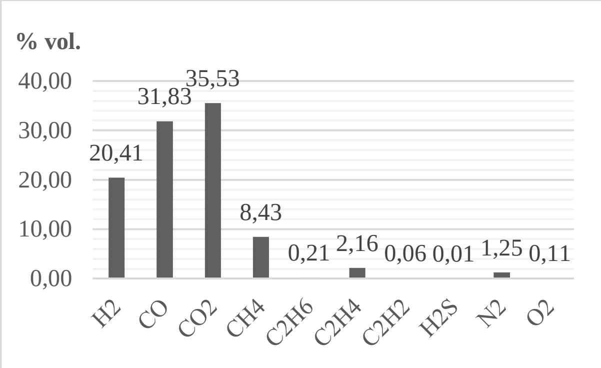

Figure 1: Gas composition (% vol.) from AS gasification at 850ºC and ER=25.2%.