Effect of Temperature on the Gasification of Olive Bagasse Particles

A. F. Almeida(1), M. S. Vieira(1), M. P. Neto(1), I. M. Pereira(1), A. M. Ribeiro(1), A. C. Ribeiro(1), R. M. Pilão (1)

(1) CIETI, Instituto Superior de Engenharia do Porto, Instituto Politécnico do Porto, Rua Dr. António Bernardino de Almeida 431, 4200-072 Porto, Portugal
afdsa@isep.ipp.pt

Abstract: *In this experimental study the evolution of gas characteristics during the gasification of olive bagasse particles was investigated using a semi-batch fluidized-bed gasifier. Sand particles with a mean diameter of 375 µm were used as bed material and an air flow was used as the fluidizing agent. Experimental tests were conducted with particles of diameter ranging from in 1.25 to 2 mm. The material was characterised through elemental and proximate analysis, and the higher heating value was also measured. In each run, the major components of the gas phase were identified as CO, CO_2, H_2, CH_4, O_2 and N_2. Gaseous samples were collected and analysed by gas chromatography. The effect of bed temperature on gasification performance was studied. The tests were conducted at bed temperatures in the range of 700ºC to 900ºC Experimental results showed that gasification with air at higher temperatures favoured gas production, Results also showed increases in the gasification performance parameters as the bed temperature is increased.*

1. Introduction

Gasification processes provide the opportunity to convert renewable biomass feedstock into clean fuel gases generally involves pyrolysis as well as combustion. This thermochemical process allows the conversion of the biomass into a combustible gas mixture through its partial oxidation at high temperatures, usually in the range of 800 to 900°C. Char, tar and non-condensable gas are representative by-products from gasification. Char is a residual solid material from devolatilization or pyrolysis of carbonaceous in biomass. Tars are variable mixture of phenols, polycyclic aromatic hydrocarbons and heterocyclic compounds. The resulting gas, known as producer gas, mainly contains carbon monoxide, hydrogen, and methane along with carbon dioxide and nitrogen [1].

Portugal holds a worldwide dominant position in the Olive Oil industry. The possibility of using residues from this industry for energy production is very important for this activity sector.

In this experimental study, the evolution of gas characteristics during the gasification of olive bagasse particles was investigated. The influence of temperature on gasification performance parameters was evaluated.

2. Experimental

Olive bagasse particles with particle size ranging from 1.25 to 2 mm were used as biomass feedstock for performing the experiments. The proximate and ultimate analyses are reported in Table I. The high level of volatile content is an indication of the raw material's ability to be used in gasification processes.

The semi-batch fluidized-bed reactor (Image 1) is made of stainless steel tube with an internal diameter of 54 mm and a height of 800 mm. The reactor is surrounded by a 3 kW electrical resistance which allows the temperature to be raised to the desired level. The gas distributor, at the bottom of the fluidizing column, is a uniformly perforated plate with holes of 0.6 mm diameter. Sand particles with diameters in the range of 250 µm to 500 µm were used as bed material. Air was used as a fluidising agent and the gas flow was measured with a rotameter. The reactor was equipped with an external condenser and a cyclone. A thermocouple and a pressure probe were used to monitor the fluidising conditions in the reactor.

The gasification performance was studied by performing tests at a fixed air flow rate of 0.25 kg/h and using 3 g of biomass. The biomass batch load was fed in through a pipe ending near the bed surface. The tests were conducted at five different bed temperatures: 750ºC, 800ºC, 850ºC, 885ºC and 900ºC.

During the gasification process, several samples of dry and clean gas were collected and analysed in a gas chromatograph (Dani 1000 DPC). The GC is fitted with an injector OPT333 suitable for packed columns and a thermal conductivity detector (TCD OPT266). A 60/80 Carboxen 1000 column was used with argon as carrier gas. The gases detected and quantified in the gasification process were H_2, O_2, N_2, CO, CH_4 and CO_2.

Table I . Proximate and ultimate analyses of biomass

Moisture (w/w%)	8.7
HHV$_c$ [(1)] (kJ/kg *a.r*)	20830
Proximate analysis (*wt/w% a.r*)	
Volatiles	84.0
Fixed carbon	3.9
Asch	3.4
Ultimate analysis (*w/w% a.r*)	
Carbon	52.5
Hydrogen	7.3
Nitrogen	1.5
Oxygen, *diff.*	30.0

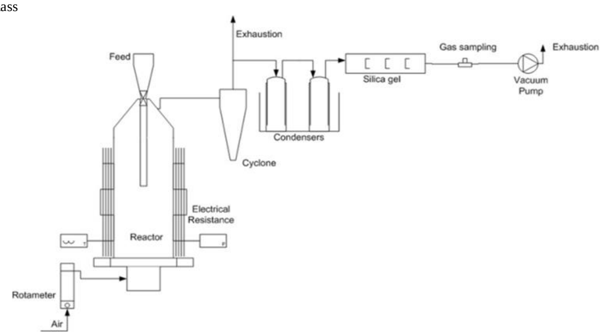

Image 1. Experimental configuration.

3. Results and Discussion

Temperature is crucial for the overall biomass gasification as it is a parameter that affects the chemical reactions involved in the gasification process. Image 2 summaries the influence of temperature on the average composition of the producer gas. These mean compositions were estimated by the integration of composition vs. time evolution curves.

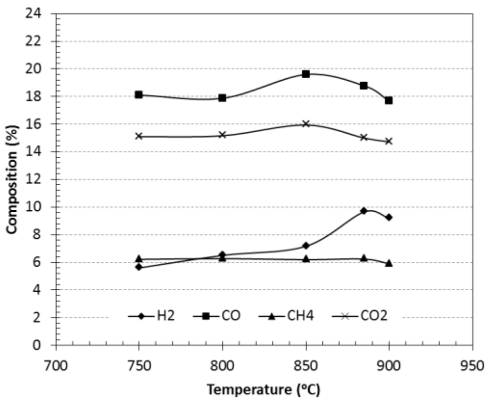

Image 2. Effect of bed temperature on the average producer gas composition.

The results show that increasing the bed temperature from 750ºC to 850ºC increase H_2 production from 5.6% to 7.2%, while CO increases from 18.1% to 19.6%. Over the temperature range of 850 to 900ºC it can be observed that there is a substantial increase in H_2, from 7.2 to 9.7%, while a smaller decrease from 19.6 to 17.7%, was detected in CO concentration. Concerning to CO_2 content in the producer gas, it was found that it is released around an overall value of 15% with a small peak of 15.9% near the 850ºC. No significant changes were detected in CH_4 production, which was around a constant value of 6%, over all the range of temperatures tested.

The gasification process is the result of the combination of a series of complex and competing reactions. The mechanism of biomass gasification depends upon individual processes involved and can be represented by the following major gasification reactions [2, 3, 4], with corresponding reaction heat values:

Boudouard: $C + CO_2 \leftrightarrow 2CO$ $\quad - 172.58\ kJ/molC$ (1)

Water-gas: $C + H_2O \leftrightarrow CO + H_2$ $\quad - 131.38\ kJ/molC$ (2)

Water-gas Shift: $CO + H_2O \leftrightarrow CO_2 + H_2$ $\quad + 41.98\ kJ/mol$ (3)

Methanation: $C + 2H_2 \leftrightarrow CH_4$ $+74.9\ kJ/molC$ (4)

Methane steam reforming:

$$CH_4 + H_2O \leftrightarrow CO + 3H_2 \quad -206\ kJ/mol \quad (5)$$

$$CH_4 + 2H_2O \leftrightarrow 4H_2 + CO_2 \quad -165\ kJ/mol \quad (6)$$

Methane dry reforming: $CH_4 + CO_2 \leftrightarrow 2H_2 + 2CO$ $-165\ kJ/mol$ (7)

The increase of temperature promotes the exothermic Boudouard (1) and Water-gas (2) gasification reactions and contributes to a high content of H_2 and CO in the producer gas. As the result shows, there is a large quantity of CO in the gas, from which it can be supposed that those reactions happen simultaneously in the gasification process. However, according to Basu [2], the rate of production of CO through these reactions decreases for higher temperatures.

If the Water–gas shift reaction (3) has some importance at the range of temperatures tested, as reported by C. Franco [5], it was found that the moisture content in the presence of CO favoured that reaction leading to a decrease in CO content with the rise of temperature.

The increase of H_2 content in the producer gas at high temperatures may be explained by the promotion of endothermic Methane steam reforming (5, 6) and Methane dry reforming (7) reactions [3]. The remarkable increase in the H_2 concentration of the producer gas at high temperatures may also be related to the promotion of Tar reforming and cracking reactions [3, 5].

The methane evolution at high temperature can be related to the cracking of tar, but it can be consumed through the improvement of Steam reforming (5, 6) and Methane dry reforming (7) reactions in the gasification process. This behaviour and the affinity of the Methanation reaction (4) with low temperatures may be the reasons behind the constant value observed in the production of CH_4.

The air gasification process produces high CO_2 content [5]. At elevated temperatures its evolution is promoted via Methane steam reforming (6) which can probably overlap the reaction (5) contributing to the reduction in the rate of CO production at high temperatures. The CO_2 released was probably consumed through Methane dry reforming, Tar cracking and Boudouard reactions, leading to a decrease in CO_2 content for the highest temperatures tested [3, 6].

To assess the gasification performance, the following four parameters [3, 4, 7] were defined:

Carbon conversion efficiency (%):

$$\eta_c = \frac{12 \times A}{\%C \times m_c} \times 100 \quad (1)$$

where A is the total number of moles of carbon-bearing components (CO_2, CO and CH_4) present in the producer gas during the gasification time, m_c is the mass of biomass fed to the reactor (kg) and %C is the carbon content in the ultimate analysis of biomass.

Dry gas yield (Nm^3/kg):

$$Y = \frac{V_g}{(1 - \%h) \times m_c} \quad (2)$$

where V_g is the total volume (Nm^3) of gas produced during gasification, calculated from the nitrogen balance considering that nitrogen in biomass is negligible (%h is the biomass moisture).

Cold gas efficiency (%):

$$\eta_g = \frac{V_g \times HHV_g}{m_c \times HHV_c} \times 100 \quad (3)$$

where HHV_c is the biomass higher heating value (kJ/kg) and HHV_g is the higher heating value (kJ/Nm^3) of the producer gas.

Dry producer gas high heating value (kJ/Nm^3):

$$HHV_g = (\%H_2 \times 30.52 + \%CO \times 30.18 + \%CH_4 \times 95) \times 4.2 \quad (4)$$

where % H_2, % CO and % CH_4 are the average calculated volumetric concentrations in the total producer gas during the gasification process.
The results obtained for the performance of gasification in the range of 750ºC to 900ºC are shown in Table II and the results show an increase in all the gasification parameters.

Table II – Effect of temperature on the gasification performance parameters.

Bed Temperature (ºC)	750	800	850	885	900
Carbon conversion efficiency (%)	60,0	67,5	70,6	74,7	69,2
Dry gas yield (Nm^3/kg)	1,62	1,88	1,86	2,01	1,92
Cold gas efficiency (%)	38,2	45,3	46,9	54,1	47,8
HHVg (MJ/Nm^3)	5,39	5,50	5,76	6,16	5,68

As expected, the results show an increase in the carbon conversion with the increase of temperature. Higher gasifier temperature increases the amount of volatile released and promotes the char oxidation reactions. The maximum value of 74.7% was obtained for 850ºC in accordance with one of the limitations pointed to the semi-batch fluidised bed gasifiers [2].
The gas yield represents the fraction of olive bagasse particles converted to producer~~t~~ gas and, for the tested conditions, an increase in this parameter was observed as the bed temperature increased. Values ranging from 1.62 to 2.01 Nm^3/kg were obtained. Such increase may result from both the promotion of initial pyrolysis and devolatilization rate at high temperatures, and from the improvement at high temperatures of steam cracking tar reforming and endothermal char reactions [5, 6].

Formatada: Não Realce

The fraction of the energy content in olive bagasse particles transferred to the producer gas is represented by the cold gas efficiency. This parameter increases with the increase of temperature and values in the range of 38.9 to 54.1% were obtained. This behaviour can be related to both, the high dry gas yield and the increase of HHV_g resulting from the rise of combustible gases amount in the producer gas, especially H_2 and CO, with the increase of bed temperature.
Values in the range of 5.49 to 6.19 MJ/Nm^3 were obtained for the HHV of the producer gas. These values are within the range of data reported by several authors for biomass gasification [8, 9].

4. Conclusions

The gasification characteristics of olive bagasse particles were found to be affected by the bed temperature. Overall results indicate that olive bagasse particles are suitable to be used as raw material for gasification processes.
Best results were obtained at a bed temperature of 885°C. Values of 74.7% and 54.1% were obtained for carbon conversion efficiency and cold gas efficiency, respectively. For dry gas yield the value of 2.01 Nm^3/kg was obtained and the HHV_g of the producer gas was 6.16 MJ/Nm^3.

5. References

[1] Taylor & Francis Group, 2009, *Handbook of Plant-based Biofuels*, Ashok Pandey editor, New Yo~~u~~rk.
[2] Basu P., 2006, *Combustion and gasification in Fluidized beds*, Taylor& Francis Group.
[3] Pooya L., Zainal A., Gasification of palm empty fruit bunch in a bubbling fluidized bed: A performance and agglomeration study, 2011, *Bioresource Technology*, 102, 2068 – 2076.
[4] P. M. Lv, Xiong Z. H., Chang J., Wu C. Z., Chen, Y., Zhu J. X., An experimental study on biomass air-steam gasification in fluidized bed, Bioresource Technology, 95, 95-101
[5 [C.Franco, F. Pinto, I. Gulyanth, I. Cabrita, 2003, The study of reactions influencing the biomass steam gasification process, Fuel 82, 835-842.
[6] Rui Neto Andre, Filomena Pinto, Carlos Franco, M. Dias, I. Gulyurtlu, M.A.A. Matos, I. Cabrita, 2005, Fluidised bed co-gasification of coal and olive oil industry wastes, Fuel, 84, 1635–1644
[7] Shayan K., Regan G., Rajender G., Raymond J. S., 2013, Study of factors affecting syngas quality and their interactions in fluidized bed gasification of lignite coal, *Fuel*, 103, 308-320
[8] Ganan J., Abdulla A. A., Miranda A. B., Turegano J., Correia S., Cuerda E. M., 2005, Energy production by means of gasification process of residuals sourced in Extremadura (Spain), *Renewable Energy*, 30, 1759-1769
[9[Pengmei Lv, Jie Chang, Zuhong Xiong, Haitao Huang, Chuangzhi Wu, and Yong Chen, 2003, Biomass Air-Steam Gasification in a Fluidized Bed to Produce Hydrogen-Rich Gas , Energy and Fuel, 17, 677-682