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# Energetic characteristics of syngas obtained from gasification of hazelnut prunings

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**Abstract**

The aim of the study concerns the energy recovery of chips, derived from hazelnut prunings, by means of gasification through air. The gasifier is a downdraft fixed bed reactor, the biomass used is characterized by a moisture of about 16% and a LHV of 15 MJ/kg. The composition of syngas is characterized by a high amount of nitrogen, more than 50% in volume, that is due to use of air as oxidant agent. Results of syngas analysis show that the increase of air flow causes a decrease in hydrogen content but a more marked increase in carbon monoxide and methane contents. The LHV of syngas obtained ranges from 3.2 to 3.6 MJ/Nm$^3$ and it is suitable to obtain thermal energy that can be used to provide heat for small farms, especially for greenhouses. The gasification system presented is also able to obtain as output flow, in addition to syngas, a solid residue or biochar which can be used in agronomic sector to improve soil characteristics.


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*Keywords:* Biomass;Gasification; Downdraft gasifier; Syngas; Hazelnut prunings.

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## 1. Introduction

Biomass is a renewable resource and its correct use is related to an integrated assessment of economic, environmental and energy aspects. Bioenergy can contribute to satisfy, in a sustainable way, the future energy request and it represents the most important renewable energy source (Moneti, Delfanti, Marucci, Bedini, Gambella, Proto & Gallucci, 2015).

In particular is important the biomass availability and referring to this aspect the area of Tuscia (Viterbo) devoted to hazelnut cultivation represents more than a quarter of the national area devoted to hazelnuts. This situation allows to consider Tuscia like a possible agro-energetic district based on energetic recovery of biomass derived from the hazelnut management (Barontini, Proietti Silvestri, Nardi, Crisante, Pepe, Pari, Gallucci, Bovicelli &Righi, 2013; Colantoni A., Delfanti, Recanatesi, Tolli, &Lord, 2016; Di Giacinto,Longo, Menghini, Delfanti,Egidi, De Benedictis, Riccioni&Salvati, 2014).

Hazelnut cultivation provides lignocellulosic biomass such as prunings and hazelnut shells with characteristics that are suitable for thermo-chemical processes. The gasification process is useful to obtain a fuel gas (syngas) to use for heating and power production by means of cogeneration systems based on internal combustion engine or, to avoid the problems connected to the presence of TAR, external combustion engine such as Stirling engine (Monarca, Cecchini, Guerrieri &Colantoni,2009; McKendry,2002; Boubaker, De Franchi, Colantoni, Monarca, Cecchini, Longo, Allegrini, Di Giacinto, Biondi &Menghini,2014; Monarca, Colantoni, Cecchini, Longo, Vecchione, Carlini, &Manzo, 2012; Monarca, Cecchini, Colantoni &Marucci, 2011).The characteristics of syngas depend on the types of inlet flows, the technologies and the operational conditions. Referring to the first aspect it is important to consider the biomass used, in terms of heating value and moisture, and the oxidizing agent which influences strongly the heating value of syngas that can reach up to 20 MJ/Nm$^3$ in case of use steam and up to 15 MJ/Nm$^3$ with oxygen in contrast with air which determines a LHV less than 6 MJ/Nm$^3$. Furthermore the type of gasifiers and the operational conditions, such as the equivalence ratio, temperature and pressure, influence the gasification process (Couto, Ruoboa, Silva, Monteiro&Bouziane,2013; McKendry, 2002).To use syngas for power production in a gas engine is necessary to reaches a LHV not less than 4.2 MJ/Nm$^3$ combined with a limited TAR content to avoid todamage the engine. Referring to this second aspect it is important to highlight that in downdraft fixed bed the content of TAR is very low contrary to what happens with the other technologies used for biomass gasification(Boubaker, Colantoni, Longo, Menghini, Baciotti, Allegrini&Cecchini, 2013; Kumar, Jones&Hanna, 2009).

## 2. Material and methods

### *2.1 Biomass*

Biomass used during experimentation consists of chips which derive from mechanical grinding of hazelnut prunings. Before the mechanical treatment, the biomass has been dried outdoors to reduce the high average moisture content equal to 47%, with a range between 35% and 60%, until to a lower and more uniform value of about 16%. This phase has been necessary in order to shred the biomass and to achieve characteristics suitable for gasification process in terms of moisture and lower heating value (LHV). The increase of LHV caused by the reduction of moisture of hazelnut prunings is shown in Figure 1.

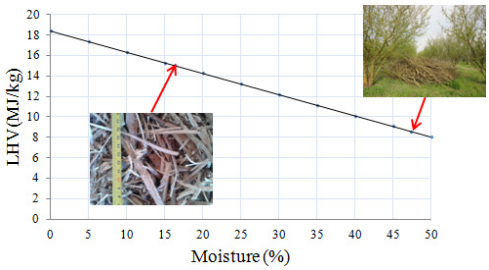


Fig.1. Trend of LHV of hazelnut prunings.

The chips obtainedfrom mechanical treatment are characterized by an elongated shape with different thicknesses and sizes. The chemical characteristics of chipsare shown in Table 1.

Table 1.Biomass characteristics.

| Parameter | Value | Unit |
|---|---|---|
| Moisture | 16.3 | % |
| LHV | 15.04 | MJ/kg |
| Carbon | 46.36 | % on dry basis |
| Hydrogen | 6.79 | % on dry basis |
| Nitrogen | 0.49 | % on dry basis |
| Ash | 1.68 | % on dry basis |

*2.2 Gasification system*

The gasification system is composed by a downdraft reactor with a suction system for the air. The reactor is characterized by an internal throat zone in which the biomass, falling from the top, mixes up with the air. As a result of this mixing, there is a partial combustion of biomass connected with the production of biochar.

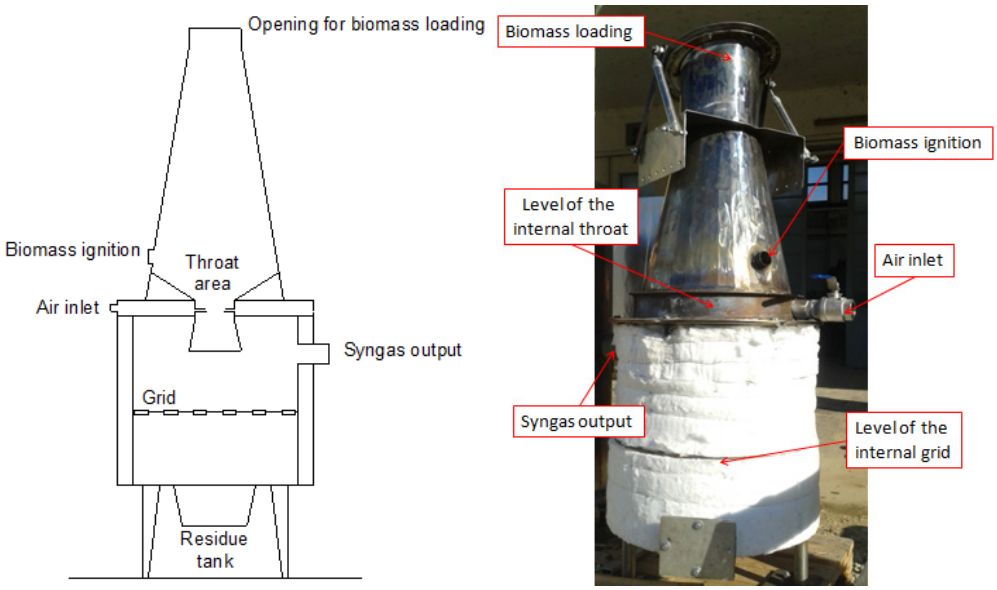


Fig.2. Downdraft reactor.

During the process, the biochar falls down on the grid: one part is gasified while the other one part is collected in a tank which is placed at the bottom of the gasifier. An electric engine allows the shaking of the grid in order to achieve a complete and uniform biochar conversion.

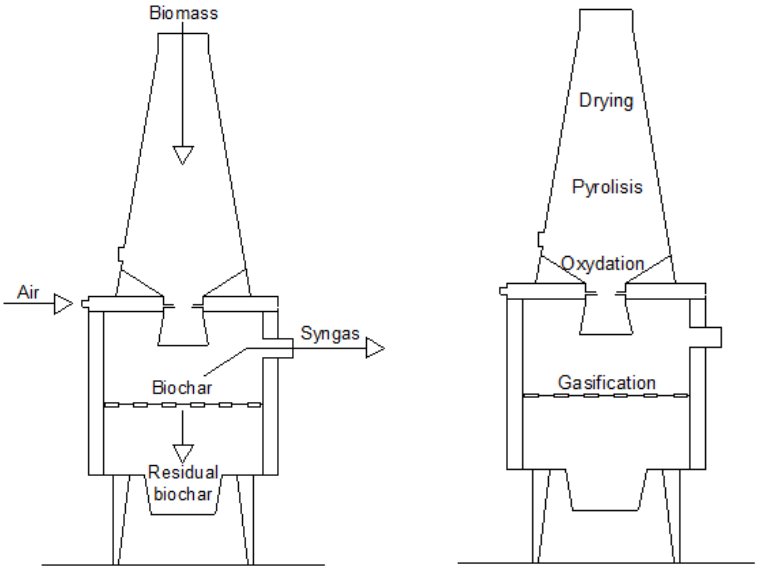


Fig.3. Flows and phases of the gasification process.

*2.3Test procedure*

The gasification tests are batch tests, with a discontinuous biomass supply: the reactor is filled from the upper part with biomass and, after the biomass loading, the fan suction system is started and simultaneously the biomass is ignited.

The first step of the process is characterized by the production of a smoke rich in water vapor as a consequence of the biomass moisture. After the drying of biomass and with the reaching of a temperature inside the reactor of about 900°C, there is the production of a fuel gas that is sampled by means of use of Tedlar bags and subsequently characterized by gas-chromatography.

The syngasproduced is conducted by the suction system to the torch and it is burnt.For the gasification tests, two different air flows have been used:$f_1$ = 0,0024 $m^3/s$ and $f_2$ = 0,0027 $m^3/s$. For lower air flows, there were problems to obtain a fuel gas, while for higher values there were problems connected to a high biomass consumption that made it difficult the stabilization and control of the process.

## 3. Results and discussion

The composition of syngas is characterized by a high amount of nitrogen, more than 50% in volume, that is due the use of air as oxidant agent. Results of syngas analysis show that the increase of air flow causesa decrease in hydrogen content buta more marked increasein carbon monoxide and methane contents (Table 2).

Table 2. Syngas composition.

| Element | Value ($f_1$) | Value ($f_2$) | Unit |
|---|---|---|---|
| $N_2$ | 57.64 | 54.67 | % volume |
| $O_2$ | 2.49 | 2.57 | % volume |
| $H_2$ | 11.93 | 11.29 | % volume |
| CO | 10.77 | 12.16 | % volume |
| $CH_4$ | 1.45 | 2.40 | % volume |
| $CO_2$ | 15.73 | 16.92 | % volume |

The lower heating value (LHV) of syngas depends on the percentage by volume of carbon monoxide, hydrogen and methane and is calculated by the following formula with LHV expressed in MJ/Nm$^3$ and CO, $H_2$ and $CH_4$expressed in % on volume(Son, Yoon, Kim,&Lee, 2011):

$$LHV = \frac{12.622 \cdot \mathrm{CO} + 10.788 \cdot \mathrm{H_2} + 35.814 \cdot \mathrm{CH_4}}{100} \quad (1)$$

The LHV of syngas ranges from 3.2 MJ/Nm$^3$ to 3.6 MJ/Nm$^3$ for the lower air flow (f1) and the higher air flow (f2) respectively. The increase of air flow causes an growth of the biomass conversion rate that means a higher percentage of carbon monoxide and methane contents with the consequence of an increase of LHV. Comparing these results with other similar experiments it is possible to notice that the LHV of syngas is slightly lower compared to the typical values of biomass gasification with air which usually ranges from 4 to 6 MJ/Nm$^3$(Couto, Ruoboa, Silva, Monteiro &Bouziane, 2013; Biagini, Barontini, &Tognotti, 2014; Machin, Pedroso, Proenza, Silveira, Conti, Braga&Machin, 2015).Obviously this mainly depends on the composition of syngas in terms of hydrogen and monoxide carbon content. Similar studies, regarding the gasification of agro-forestry residues, show values of monoxide carbon content in a range from 13% up to almost 18% in volume while hydrogen content ranges from 12% up to almost 14% in volume. Methane content is typical less than 3%. Results show that it is necessary to increase the carbon monoxide content of syngas and it is possible through the reduction of the thermal losses from the reactor with the advantage of an increase and stabilization of temperature in the gasification zone. The increase of temperature also determines the reduction of TAR content by means of thermal cracking process. The increase of LHV is also connected to the decrease of the biomass moisture: a reduction of moisture allows to avoid to subtract heat to the gasification reactions.

## 4. Conclusion

Renewable wastes such as biomass agricultural residues derived, are increasingly being recognized as valuable feedstock because of their rich carbon composition (Proto, Zimbalatti, Abenavoli, Bernardi & Benalia, 2014; Abenavoli & Proto, 2015).This study shows that is possible to achieve an energy recovery of hazelnut prunings by means of gasification process. The energetic content of syngas obtained, up to 3.6 MJ/Nm$^3$,is slightly low to beused in gas engines for power production that typically require syngas with LHV not less than 4.2 MJ/Nm$^3$, so it is necessary operate with suitable biomass pretreatments such as drying and to improve the gasification system.

It is also necessary to make additional syngas analysis in order to better aspects such asthe TAR and the particulate contents and to provide for a cleaning system of syngas. Regarding on the impurities contained in syngas, qualitative characterizationof TAR has been carried out: washing syngas through water shows the presence of phenol, furanmethanol and cresol mainly.

The characteristics of syngas are suitable to obtain thermal energy that can be used to provide heat for small farms, especially for greenhouses. The gasification system presented is also able to obtain as output flow, in

additionto syngas, a solid residue or biochar which can be used in agronomic sector:on one side to improve soil characteristics on the other as a carbon sink, in consequence of its high carbon content.

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