Contemporary Engineering Sciences, Vol. 9, 2016, no. 27, 1339 - 1348
HIKARI Ltd, www.m-hikari.com
http://dx.doi.org/10.12988/ces.2016.68142

Pyro-Gasification of Hazelnut Pruning Using a Downdraft Gasifier for Concurrent Production of Syngas and Biochar

Andrea Colantoni [1], Leonardo Longo [1], Francesco Gallucci [2] and Danilo Monarca [1]

[1] Department of Agricultural and Forestry sciences (DAFNE)
Università degli Studi della Tuscia
01100 Viterbo, Italy

[2] Department of agricultural engineering (CREA-ING)
Consiglio per la ricerca in agricoltura e l'analisi dell'economia agraria
00015 Monterotondo (Roma), Italy

Abstract

Hazelnut pruning constitute a waste management problem with critical environmental consequences, in fact the most common solution taken into account by farmers for hazelnut pruning management consists in an uncontrolled outdoors combustion in field that causes toxic gaseous emissions. The aim of this work is to provide an alternative solution represented by use of pruning as feedstock in a downdraft air gasifier, working with low values of equivalence ratio (ER), in order to obtain syngas and biochar. In this study, chips of shredded hazelnut pruning with a lower heating value (LHV) of about 15,3 MJ/kg and a moisture of 15% have been used. Syngas obtained shows an LHV increasing from 3,84 to 4,45 MJ/Nm^3 with the rise of airflow introduced. Char coming from the pyrolysis of biomass shows an high carbon content of about 75% while the solid residue, that is the biochar resulting from the partial gasification of char of pyrolysis, is characterized by a carbon content ranging from about 32% up to 47% for the higher and lower airflow values respectively. Results show that the energetic value of syngas is suitable for heat and power production while biochar can be used as soil improver and carbon sink.

Keywords: Pyro-gasification; Downdraft; Biomass waste; Hazelnut; Syngas; Biochar

1. Introduction

Renewable energy is an important instrument for world energy demand satisfaction, it has been estimated that percentage of renewable sources in total world power generation will reach about 33% in 2040, starting from 12% of 2012 [1]. In Italy, the energy plants fueled by renewable sources reached, in 2014, an amount slightly higher than 40% of the total plants, corresponding to a level of renewable energy production of about 43% of the gross total power production. In this contest, the bioenergy sector covers about 15% of the total renewable energy production [2]. Biomass for renewable energy production can be divided in energy crops, such as poplar, and waste biomass obtained from the management of agro-forestry sector. Beyond the origin of biomass, its use for energy production is related to an integrated evaluation of economic, environmental and energy aspects, paying attention to the biomass characteristics, such as moisture content, its availability in time and necessary pre-treatments such as drying [3,4]. The agricultural sector is an important resource of biomass, including the residues from the pruning of fruit or nut trees, such as hazel (Corylus avellana L.). The usual management practice for pruning is to allow natural decomposition or combustion in the fields; this practice is no longer acceptable according to the latest EC Directives and Kyoto Protocol obligations. Hazelnut is one of the most important and investigated crops in the Viterbo area (central Italy) because it represents with Cuneo, Roma, Avellino, Napoli and Messina the 80% of the national production [5, 6, 7, 8]. From this perspective the hazelnut pruning can be seen as a significant biomass resource. Biomass production arising from the management of the hazelnut crops is equivalent to about 1,4 t/ha [9].

Thermo-chemical processes are the most suitable energetic conversion methods for lignocellulosic biomass such as hazelnut pruning. Gasification permits to obtain a syngas, that is mixture of gases such as CO, H_2, CO_2, CH_4 and N_2, in case of use of air as oxidant. Composition of syngas depends on the biomass, in terms of lower heating value and moisture, type of oxidant, technologies and operational conditions such as the equivalence ratio (ER), temperature and pressure. Use of air, as oxidizing agent, determines a LHV of syngas less than 6 MJ/Nm^3, that increase up to 15 MJ/Nm^3 in case of oxygen and 20 MJ/Nm^3 with use of steam, the latter is usually connected to use of fluidized bed gasifier and provides a syngas with high hydrogen content [10,11,12,13,14]. The composition of syngas is also affected by the presence of impurities including particulate, TAR and other elements, such as sulfur based compounds, that require a cleaning up of syngas before its use [15, 16, 17]. Several experiments on gasification of biomass with air, by means of downdraft gasifier, have been realized and different kind of vegetable biomasses have been used, such as wood sawdust and sunflower seeds, rice husk, empty fruit bunches from palm-oil production, corn cobs, vine pruning

[18, 19, 20, 21, 22]. Results of these studies shown that syngas composition is usually characterized by an amount of CO slightly higher than H_2 and variable between 15-20% for both of compounds. The amount of CH_4 and N_2 are usually less than 3% and more than 45% respectively.
Biochar is a feasible and interesting additional output of thermo-chemical processes, its quantitative and qualitative characteristics depend on the biomass and the type of process in terms of temperature and use of oxidizing agent. Pyrolysis determines higher biochar yield than gasification, reaching values of solid fraction up to 35-40% respect to the initial amount of biomass [23, 24, 25].
Obviously, concurrent production of biochar and syngas affects the gasification process of biomass: increase of yield and carbon content of biochar is strongly linked to the reduction of flow and LHV of syngas.

2. Material and methods

2.1 Biomass
After harvesting the hazelnut pruning, biomass have been subjected to treatments of shredding and drying, in order to reduce the size and the moisture. Chips used for pyro-gasification tests are characterized by an elongated shape, ranging from about 1 to more than 10 cm. Results of characterization is shown in Tab.1.

Table 1. Characteristics of shredded hazelnut pruning.

Parameter	Value	U.M	According to
Moisture	15,0	%	UNI-EN 14774-2010
$LHV_{M=15}$	15,3	MJ/kg	UNI-EN 14918:2010
$LHV_{M=0}$	18,4	MJ/kg	
C	46,73	% db	UNI-EN 15104:2011
H	6,80	% db	
N	0,59	% db	
Ash	1,97	% db	UNI-EN 14775:2010

2.2 Downdraft gasifier
The scheme of fixed bed downdraft reactor used with flows of air, biomass and syngas are shown in Fig.1. Airflow inside the reactor is sucked by means of the intake fan system while biomass falls down from the top of the reactor. In the throat zone, corresponding to the air inlet point, occurs a biomass partial combustion which provides heating to the gasification reactions. Biochar, produced during pyrolysis phase, is collected on the inner grid and partially converted into syngas. The latter is sucked by the pump up to the torch. The remaining part of unconverted biochar is collected below the grid.

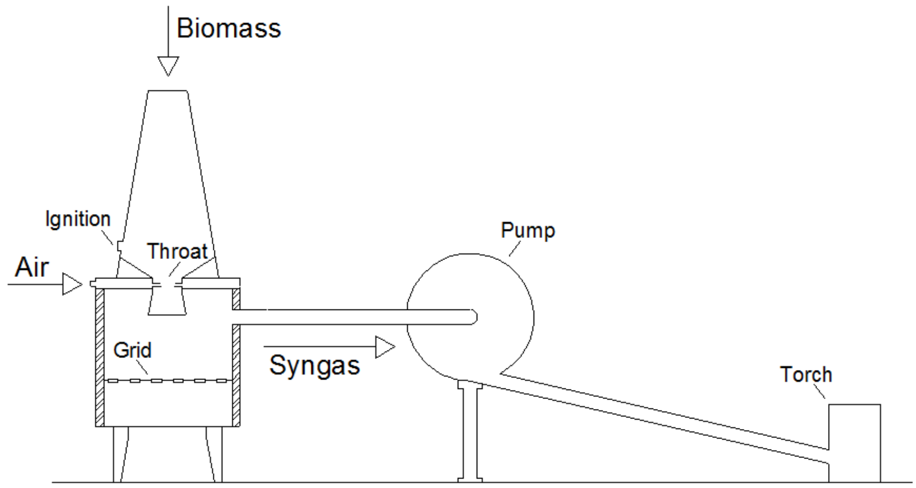

Figure 1. Downdraft gasifier system.

2.3 Test procedure

After filling the reactor, biomass have been ignited to provide heating for initiating the process. During biomass gasification, syngas has been sampled through an opening in the pipeline between the pump and torch, using Tedlar bags and hence analyzed by means of gas chromatograph analyzer. Once all biomass has been consumed and gasification process ends, the remaining biochar has been collected and subsequently characterized.

Gasification tests for different conditions of airflows and biomass consumption have been carried out (Tab.2). Considering the amount of stoichiometric air for complete combustion of shredding pruning, which is equal to 5,84 $kg_{air}/kg_{biomass}$, the equivalence ratio (ER) has been evaluated using Eq.1:

$$ER = \frac{\left[\frac{kg_{\ air}}{kg_{\ biomass}}\right]_{real}}{\left[\frac{kg_{\ air}}{kg_{\ biomass}}\right]_{stoichiometric}} \quad (1)$$

Table 2. Operating condition of gasification tests.

Test condition	Airflow (m^3/s)	Biomass consumption (kg/s)	ER (-)
1	0,0013	0,0041	0,069
2	0,0021	0,0049	0,088
3	0,0025	0,0055	0,094

During tests, the operating temperature of gasification zone, between the inner grid and throat point, reaches up 900°C while ER values have been closed between the pyrolysis value of 0 and the minimum gasification value of 0,2.

3. Results and discussion

Syngas composition (Tab.3) is strongly affected by airflow: increase of ER, that means increase of oxidizing agent, causes the rise of combustion reaction rate that means higher thermal energy for endothermic gasification reactions with consequence of increase in carbon monoxide and hydrogen contents that, during experimentation, have risen from 14% to 17% in volume and from 13% to nearly 17% respectively.

Table 3: Syngas composition.

Test condition	ER (-)	CO (% vol.)	H_2 (% vol.)	CH_4 (% vol.)	N_2 (% vol.)	O_2 (% vol.)	CO_2 (% vol.)
1	0,069	14,00	13,23	1,82	55,09	1,57	13,37
2	0,088	15,11	15,47	1,49	51,86	0,83	14,15
3	0,094	17,06	16,68	1,40	49,91	0,84	13,22

Lower heating value of syngas (Fig.2) has been evaluated depending on carbon monoxide, hydrogen and methane contents as shown in following formula [26]:

$$LHV_{syngas} = \frac{1}{100} \cdot (12{,}622 \cdot \%CO + 10{,}788 \cdot \%H_2 + 35{,}814 \cdot \%CH_4) \quad (2)$$

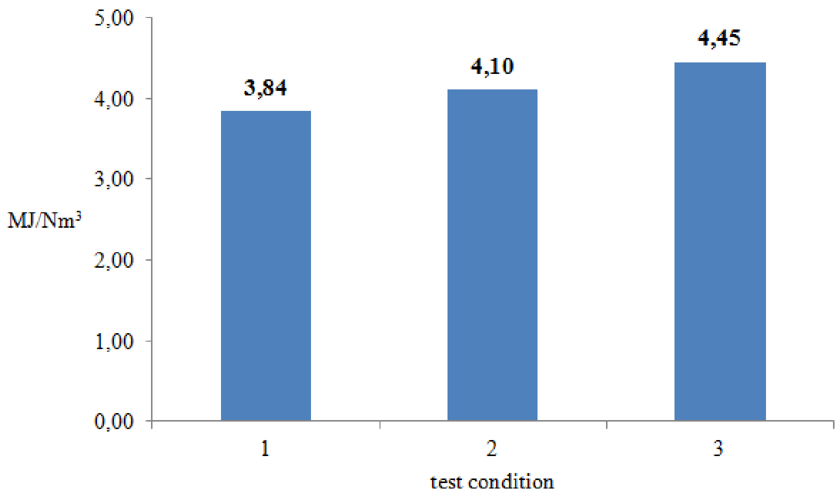

Figure 2. Lower heating value of syngas.

Increasing airflow causes higher biomass-syngas conversion rate that means reduction of carbon content in biochar resulting from gasification of char coming from pyrolysis phase of biomass. Composition of biochar obtained for low airflow values is characterized by high carbon content and low ash content, conversely for high airflow values (Fig.2).

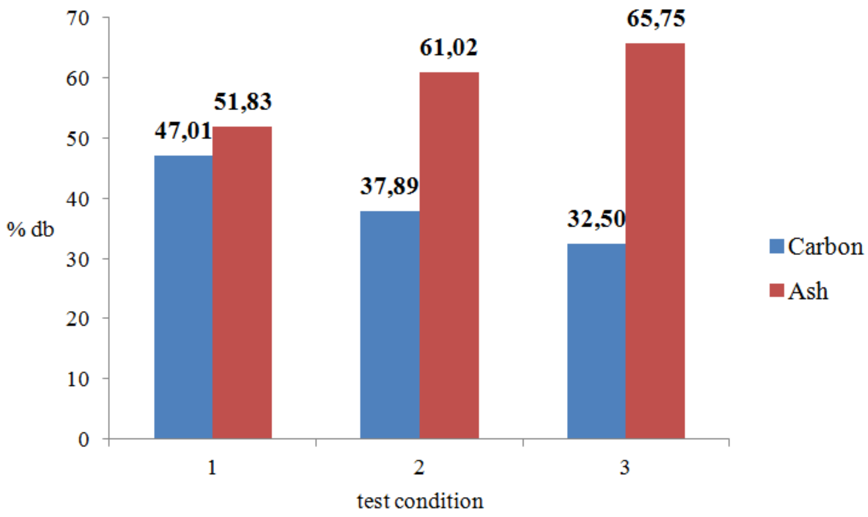

Figure 3: Trend of carbon and ash contents in biochar.

Char of pyrolysis, produced during tests, represents biochar obtained before its gasification and it is related to the ER value of 0. It is characterized by a carbon content of 75,73% on dry basis with a corresponding LHV of 25,78 MJ/kg. Experiment shows that values of ER less than 0,2 allow to obtain incomplete char gasification. Lower airflows determine an increase of carbon content in the remaining biochar with a subsequent reduction of LHV in syngas, that is strongly linked to the presence of carbon-based elements such as carbon monoxide and methane. Conversely high airflows cause an increase in carbon conversion rate of char into syngas (Fig.4) providing the rise of LHV in syngas.

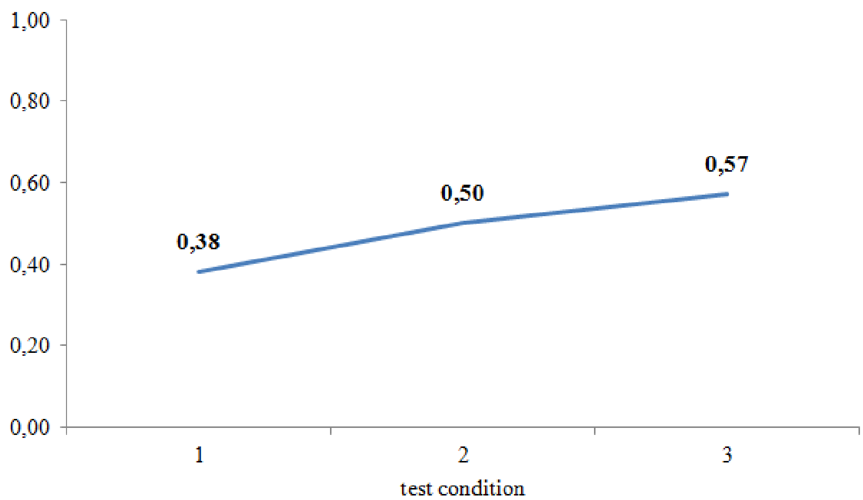

Figure 4. Carbon conversion rate of char into syngas.

Comparing results with those of literature, lower heating value reached by syngas is in agreement with the range of 4-6 MJ/Nm^3 which is typical for gasification of biomass using air [11,18,20,21,27] and with minimum value of 4,2 MJ/Nm^3 required

to use as fuel in a gas engine [16]. In addition to calorific value, that represents the most important aspect for power production, syngas for internal gas engine requires also low TAR and particulate contents. Generally syngas obtained from downdraft gasifiers is characterized by a TAR content ranging from 0,01 g/Nm^3 up to 6 g/Nm^3 while particulate content ranges from 0,1 g/Nm^3 to 8 g/Nm^3 [12].
The carbon content of pyrolysis char is in the range from 60% to 80% which represents the typical range for biochars obtained from thermo-chemical conversion of biomass [28], obviously carbon content decreases in case of increasing airflows towards to stoichiometric value. As consequence of carbon content, biochar is useful as carbon sink and soil improver. Biochar can also be used as catalyst for chemical reactions or adsorbent for cleaning of gaseous flows [25, 29, 30].

4. Conclusions

Pyro-gasification of hazelnut pruning has been studied, using a downdraft gasifier, to obtain co-production of syngas and biochar. Syngas shows an LHV, with increasing of airflows and hence ER values, ranging from 3,84 MJ/Nm^3 up to 4,46 MJ/Nm^3 that is related to the increase of carbon monoxide from 14% to 17% in volume and from 13% to nearly 17% for hydrogen. Conversely carbon content of biochar shows a downward trend from 47% to about 32% on dry basis, in case of airflow increase. It is hence evident that the carbon conversion rate of char in syngas increases with the rise of airflow value. This experimentation shows that co-production of syngas and biochar is a difficult balancing between two contrasting outputs: syngas and biochar. The objective of the downdraft system proposed is to develop a method for proper agro-forestry wastes management that is able to provide energy in terms of syngas for satisfaction of energy demand of farms and at the same time to replace commercial fertilizer with use of biochar, obtained from waste biomasses, as soil improver.

References

[1] International Energy Agency IEA (2014). World Energy Outlook 2014 - Factsheet. www.worldenergyoutlook.org

[2] Gestore Servizi Energetici GSE (2015). Statistical report – Energy from renewable sources - 2014. www.gse.it

[3] A. Colantoni, L.M.P. Delfanti, F. Recanatesi, M. Tolli, R. Lord, Land use planning for utilizing biomass residues in Tuscia Romana (central Italy): Preliminary results of a multi criteria analysis to create an agro-energy district, *Land Use Policy*, **50** (2016), 125-133. http://dx.doi.org/10.1016/j.landusepol.2015.09.012

[4] V. Civitarese, R. Spinelli, M. Barontini, F. Gallucci, E. Santangelo, A. Acampora, A. Scarfone, A. del Giudice, L. Pari, Open-Air Drying of Cut and Windrowed Short-Rotation Poplar Stems, *BioEnergy Research*, **8** (2015), 1614-1620. http://dx.doi.org/10.1007/s12155-015-9612-3

[5] S. Franco, B. Pancino, V. Cristofori, Hazelnut production and local development in Italy, *Acta Horticulturae*, **1052** (2014), 347-352. http://dx.doi.org/10.17660/actahortic.2014.1052.48

[6] S. Speranza, D. Bucini, B. Paparatti, New observations on biology of European shot-hole borer [*Xyleborus dispar* (F.)] on hazelnut in Northern Latium (Central Italy), *Acta Horticulturae*, **845** (2009), 539-542. http://dx.doi.org/10.17660/actahortic.2009.845.84

[7] B. Paparatti, S. Speranza, Biological control of hazelnut weevil (*Curculio nucum* L., Coleoptera, Curculionidae) using the entomopathogenic fungus *Beauveria bassiana* (Balsamo) Vuill. (Deuteromycotina, Hyphomycetes), *Acta Horticulturae,* **686** (2005), 407-412. http://dx.doi.org/10.17660/actahortic.2005.686.56

[8] G.M. Balestra, D. Bucini, B. Paparatti, S. Speranza, C. Proietti Zolla, C. Pucci, L. Varvaro, Bio-etology of *Anisandrus dispar* F. and its possible involvment in dieback (Moria) diseases of hazelnut (*Corylus avellana* L.) plants in central Italy, *Acta Horticulturae*, **686** (2005), 435-444. http://dx.doi.org/10.17660/actahortic.2005.686.60

[9] S. Di Giacinto, L. Longo, G. Menghini, L.M.P. Delfanti, G. Egidi, L. De Benedictis, S. Riccioni, L. Salvati, A model for estimating pruned biomass obtained from Corylus avellana L, *Applied Mathematical Sciences*, **8** (2014), 6555-6564. http://dx.doi.org/10.12988/ams.2014.46441

[10] P. McKendry, Energy production from biomass (part 2): conversion technologies, *Bioresource Technology*, **83** (2002), 47-54. http://dx.doi.org/10.1016/s0960-8524(01)00119-5

[11] P. McKendry, Energy production from biomass (part 3): gasification technologies, *Bioresource Technology*, **83** (2002), 55-63. http://dx.doi.org/10.1016/s0960-8524(01)00120-1

[12] N. Couto, A. Ruoboa, V. Silva, E. Monteiro, K. Bouziane, Influence of the biomass gasification processes on the final composition of syngas, *Energy Procedia*, **36** (2013), 596-606. http://dx.doi.org/10.1016/j.egypro.2013.07.068

[13] A. Molino, S. Chianese, D. Musmarra, Biomass gasification technology: The state of the art overview, *Journal of Energy Chemistry*, **25** (2016), 10-25. http://dx.doi.org/10.1016/j.jechem.2015.11.005

[14] M. Moneti, L.M.P. Delfanti, A. Marucci, R. Bedini, F. Gambella, A.R. Proto, F. Gallucci, Simulations of a Plant with a Fluidized Bed Gasifier WGS and PSA, *Contemporary Engineering Sciences*, **8** (2015), 1461-1473. http://dx.doi.org/10.12988/ces.2015.56191

[15] A. Kumar, D.D. Jones, M.A. Hanna, Thermochemical Biomass Gasification: A Review of the Current Status of the Technology, *Energies*, **3** (2009), 556-581. http://dx.doi.org/10.3390/en20300556

[16] Y.I. Son, S.J. Yoon, Y.K. Kim, J.G. Lee, Gasification and power generation characteristics of woody biomass utilizing a downdraft gasifier, *Biomass and Bioenergy*, **35** (2011), 4215-4220. http://dx.doi.org/10.1016/j.biombioe.2011.07.008

[17] N. Abdoulmoumine, S. Adhikari, A Kulkarni , S. Chattanathan, A review on biomass gasification syngas cleanup, *Applied Energy*, **155** (2015), 294-307. http://dx.doi.org/10.1016/j.apenergy.2015.05.095

[18] M. Simone, F. Barontini, C. Nicolella, L. Tognotti, Gasification of pelletized biomass in a pilot scale downdraft gasifier, *Bioresource Technology*, **116** (2012), 403-412. http://dx.doi.org/10.1016/j.biortech.2012.03.119

[19] S.J. Yoon, Y.I. Son, Y.K. Kim, J.G. Lee, Gasification and power generation characteristics of rice husk and rice husk pellet using a downdraft fixed-bed gasifier, *Renewable Energy*, **42** (2012), 163-167. http://dx.doi.org/10.1016/j.renene.2011.08.028

[20] C. Erlich, T.H. Fransson, Downdraft gasification of pellets made of wood, palm-oil residues respective bagasse: experimental study, *Applied Energy*, **88** (2011), 899-908. http://dx.doi.org/10.1016/j.apenergy.2010.08.028

[21] E. Biagini, F. Barontini, L. Tognotti, Gasification of agricultural residues in a demonstrative plant: Corn cobs, *Bioresource Technology*, **173** (2014), 110-116. http://dx.doi.org/10.1016/j.biortech.2014.09.086

[22] E. Biagini, F. Barontini, L. Tognotti, Gasification of agricultural residues in a demonstrative plant: Vine pruning and rice husks, *Bioresource Technology*, **194** (2015), 36-42. http://dx.doi.org/10.1016/j.biortech.2015.07.016

[23] S.P. Sohi, E. Krull, E. Lopez-Capel, R. Bol, A review of biochar and its use and function in soil, *Advances in Agronomy*, **105** (2010), 47-82. http://dx.doi.org/10.1016/s0065-2113(10)05002-9

[24] Mu. Balat, Me. Balat, E. Kirtay, H. Balat, Main routes for the thermo-conversion of biomass into fuels and chemicals. Part 1: pyrolysis system, *Energy Conversion and Management*, **50** (2009), 3147-3157. http://dx.doi.org/10.1016/j.enconman.2009.08.014

[25] K. Qian, A. Kumar, H. Zhang, D. Bellmer, R. Huhnke, Recent advances in utilization of biochar, *Renewable and Sustainable Energy Reviews*, **42** (2015), 1055-1064. http://dx.doi.org/10.1016/j.rser.2014.10.074

[26] L. Wei, L.O. Pordesimo, A. Haryanto, J. Wooten, Co-gasification of hardwood chips and crude glycerol in a pilot scale downdraft gasifier, *Bioresource Technology*, **102** (2011), 6266–6272. http://dx.doi.org/10.1016/j.biortech.2011.02.109

[27] A.V. Bridgwater, Renewable fuels and chemicals by thermal processing of biomass, *Chemical Engineering Journal*, **91** (2003), 87-102. http://dx.doi.org/10.1016/s1385-8947(02)00142-0

[28] L. Luo, C. Xu, Z. Chen, S. Zhang, Properties of biomass-derived biochars: Combined effects of operating conditions and biomass types, *Bioresource Technology*, **192** (2015), 83-89. http://dx.doi.org/10.1016/j.biortech.2015.05.054

[29] J. Veres, J. Kolonicny, T. Ochodek, Biochar status under international law and regulatory issues for the practical application, *Chemical Engineering Transactions*, **37** (2014), 799-804.

[30] D. Monarca, M. Cecchini, A. Colantoni, Plant for the production of chips and pellet: technical and economic aspects of a case study in the central Italy, Chapter in *Computational Science and Its Applications*, Springer-Verlag Berlin Heidelberg, 2011, 296-306. http://dx.doi.org/10.1007/978-3-642-21898-9_26

Received: August 3, 2016; Published: October 3, 2016