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INFLUENCE OF STEM DIAMETER AND BARK RATIO OF EVERGREEN HARDWOODS ON THE FUEL CHARACTERISTICS OF THE PRODUCED PELLETS

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Abstract

Forest biomass originating from Mediterranean forest vegetation could be a potential source of renewable energy in the form of pellets, butdue to its diversity there is a need for better understanding and detailed examination of its main fuel characteristics. The aim of this work was the evaluation of the impact that bark percentage and barked stem diameter have on the ash content and heating value of thefollowing evergreen Mediterranean hardwood species: Arbutus unedo, Erica arborea, Quercus coccifera, Quercus ilex and Phillyrea latifolia. For all the above species, the barked diameter, bark thickness, bark percentage as well as the ash content and higher heating value of bark and wood have been determined. In all cases the ash content of bark was higher than that of wood and also higher than the requirement of the related EN standard. Therefore the bark of tested species could be used in the production of pellets provided that its ratio would be in a level corresponding to the maximum allowed ash content values. Taking into account the results of the determinations, the equations and graphs were used in order to calculate the minimum of the stem diameter requirements in order to meet with the ash content restrictions. The effect of stem diameter on the HHV (higher heating value) was also evaluated. Among the tested species, Erica arborea proved to be the most appropriate for the production of pellets showing the highest HHV and the lowest ash content.

Key words: *evergreen hardwoods; bark; ash; heating value; pellets.*

INTRODUCTION

Woody biomass is a considerable source of renewable energy not only because there are many streams of such raw materials but also because there is the potential of converting them to standard shapes (e.g. pellets and briquettes) therefore increasing their energy density, improving their storability and reducing handling and transport costs while on the same time providing the possibility to be used in automated combustion facilities (Telmo and Lousada 2011). Various alternative biomasses are currently used as solid biofuels including sawdust, organic and agricultural waste, nonfood energy crops as well as forest biomass. (Haberl and Geissler 2000, Hoogwijk 2003, Perlack *et al*. 2005, Demirbas 2007, Filbakk *et al*. 2011).

The use of forest biomass originating from Mediterranean forest vegetation in particular has been acknowledged as a potential means to meet with the increasing energy demands while on the same time their removal from forest contributes to the prevention of forest fires (Viana *et al*. 2012). In the Mediterranean region, many forests are composed by evergreen hardwoods including short rotation (25-30 years) coppices. These forests include a number of different species of shrubs rather than trees, are growing at low altitudes and are mainly exploited with clear cuttings for the production of firewood and charcoal due to the fact that their wood do not posses the adequate quality characteristics for the production of sawn wood (Voulgaridis and Passialis 1995, Barboutis 1991). The assessment of the potential for these raw materials to be used as solid biofuels in pellet form, requires better understanding and detailed examination of their main fuel characteristics. The effect of their bark content on the fuel characteristics is very important since these species develop small diameter stems resulting in high bark:wood ratios. Furthermore, the bark usually presents higher ash content levels than wood. This fact could under terms inhibit the use of such biofuels.

Various papers have been published about the use of Mediterranean hardwood species as fuels (Voulgaridis and Passialis 1995, Dimitrakopoulos and Panov 2001, Siafaca *et al*. 1980) but not much information about the individual thermal characteristics of bark and wood of these species exist. Concerning the influence of bark on the quality of biofuels, Filbakk *et al*. (2011) as well as Lehtikangas (2001) reported that it is related to the increase of sintering effect during combustion. The later also reported that high ash content is connected to low heating value of the biofuel, and general have a negative impact on the pellet and briquette production equipment. For this reason, the recent related European standard for the quality characteristics of pellets for non-industrial use set a maximum ash content value of 3% (EN 14961-2:2011, European Pellet Council 2013).

OBJECTIVE

The aim of this work was the evaluation of the impact that bark percentage and barked stem diameter have on the ash content and heating value of pellets produced of some evergreen Mediterranean hardwood species, and to theoretically estimate the minimum barked stem of the species that meet the requirements of EN 14961-2 for ash content of pellets. Part of these results concerning the assessment of calorific value and ash content for bark and wood of some Mediterranean hardwood species was presented in a previous conference (Barboutis and Lykidis 2014)

MATERIAL, METHOD, EQUIPMENT

For the purposes of this work, stems from evergreen Mediterranean hardwood forest species was used namely: Arbutus unedo, Quercus ilex, Quercus coccifera, Erica arborea and Phillyrea latifolia. Each sample consisted of 15 stems having a mean diameter not larger than 10 cm and was collected from a firewood yard of East Chalkidiki forests, (Greece). For each stem the barked diameter and bark thickness was measured at both ends of the stems. The proportion of bark was calculated as the ratio of bark area in a transverse section to the total stem area of this section according to equation (1):

$$Z = 100\frac{f(2R-f)}{R^2} \qquad (1)$$

where:
Z= Bark percentage (%)
f= Bark thickness (cm)
R= Barked stem radius (cm)

For the determination of bark percentage it was considered that the transverse surfaces were circular. 30 measurements were carried out for each species. Consequently, bark and wood were separated and the materials were ground by means of a portable chipper.

The bulk samples were reduced by coning and quartering to a representative sample of about 0.5 kg. The samples were subsequently air-dried and ground using a rotating-blade Wiley mill with a 0.7 mm sieve. All materials were gently dried for at least two weeks in a ventilated oven at 60 ± 1 °C until steady mass was achieved.

For the determination of ash, the methodology described in EN 14775:2004 was used. The samples with mass of at least 1g were weighed to the nearest 0.1mg in the pre-weighed porcelain crucibles and transferred in a cold muffle furnace (Heraeus MR 170) with a ventilation rate of about 5 changes per minute. The samples were then heated to 250 °C within 50 min and the temperature was kept constant for 60 min. In the next step, the temperature was increased to 550 °C within 60 min and was maintained at that level for 3 h. Consequently the crucibles were transferred to an empty desiccator without lid for 5 min followed by 15 min with closed lid and then weighed. To ensure complete incineration the samples were reloaded in the hot furnace for 30 min intervals and were reweighed according to the above procedure until the mass changes were lower than 0.2 mg. The ash content on dry basis was calculated according to equation (2):

$$Ad = \frac{m_3 - m_1}{m_2 - m_1} \times 100 \qquad (2)$$

where:
Ad= Ash content (%)
m_1= Mass of the empty crucible (g)
m_2= Mass of the crucible plus the dried test sample (g)
m_3= Mass of the crucible plus ash (g)

The ash measurements were carried out in 3 replicates for each material. Moisture content was determined according to CEN/TS 14774-3. The calorific value was expressed with Higher Heating Value (HHV) which is the absolute value of the specific energy combustion, in calories per unit mass of a solid biofuel burned in oxygen in a calorimetric bomb under specified conditions. HHV was determined in a Parr 1261 isoperibol bomb calorimeter according to the method described in the European Standard CEN/TS 14918:2005. Sample pellets with mass of 1.0 ± 0.1 g and diameter of 13 mm were produced using a hydraulic pellet press applying a load of about 7t for 1min. The pellets were weighed to the nearest 0.0001 g in a crucible and then placed inside a Paar 1108 oxygen combustion bomb in contact with 10 cm of pre-weighed platinum ignition wire. The bomb was subsequently charged with oxygen (purity of 99.7 %) at 30 ± 2 bar and submerged in a stainless steel bucket containing 2000.0 ml of distilled water. Prior to filling the bucket, the water was conditioned in a waterbath at 33 ± 0.5 °C. The calorimeter jacket was maintained at constant temperature by circulating water at 35 °C to maintain slightly higher temperature than the final temperature of the calorimeter and assure that evaporation losses were minimized. The HHV measurements were carried out in 6 replicates for each material. Prior to starting the above measurements, the calorimeter was calibrated and validated with 6 individual calibration runs using benzoic acid pellets. HHV values were expressed in cal/g. Sulphur and chlorine adjustments were not carried out because they are present in low concentrations in wood fuels (Lehtikangas 2001).

Afterwards, a theoretical estimation of the fuel characteristics of pellets produced from the selected species was implemented. This was based on the bark and wood ash content as well as the calorific values that had been determined, taking into account the various barked stem diameters of the raw materials. Hence, the following equations (3, 4) were used:

$$ASH = a_1 \frac{z}{100} + a_2 \frac{100-z}{100} \quad (3)$$

$$HHV = b_1 \frac{z}{100} + b_2 \frac{100-z}{100} \quad (4)$$

where:
ASH= total ash content (%)
Z= Bark percentage (%)
a_1= Ash content of bark (%)
a_2= Ash content of wood (%)
HHV= total HHV (cal/g)
b_1= HHV of bark (cal/g)
b_2= HHV of wood (cal/g)

Mean values were compared with ANOVA (α = 0.95, LSD) using SPSS, the graphs were created in MATLAB program.

RESULTS AND DISCUSSION

The mean barked stem radii varied between 2.1 and 3.8 cm, while the mean bark thicknesses from 0.13 to 0.20 cm (Table 1). The differences between the mean values were not significant, except for the mean radius of Erica arborea, as well as the bark thickness of Arbutus unedo which were both significantly lower than the other species. Furthermore, the low standard deviations of bark thicknesses indicate that it does not vary significantly within the measured radii (which include the usual range of fuelwood radii) of the selected species. Consequently, the bark percentage values increase, as the barked stem radius decreases (Fig. 1).

According to Figure 1, it could be indicatively referred that concerning the bark thickness of 0.15 cm, the bark content would be 38 % in the case of barked stem of 2 cm diameter, while in the case of barked steam diameter of 10 cm this percentage would decrease to 6.38 %,.

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Table 1

Stem radius and bark thickness of the tested species

Species	Stem radius[a] (cm)		Bark thickness[a] (cm)	
Arbutus unedo	3.2	(1.1)	0.13	(0.015)
Erica arborea	2.1	(0.5)	0.17	(0.022)
Phillyrea latifolia	3.4	(0.7)	0.20	(0.028)
Quercus coccifera	3.1	(1.2)	0.17	(0.020)
Quercus ilex	3.8	(0.8)	0.15	(0.019)

[a] : Average of 30 measurements (S.D. in parentheses)

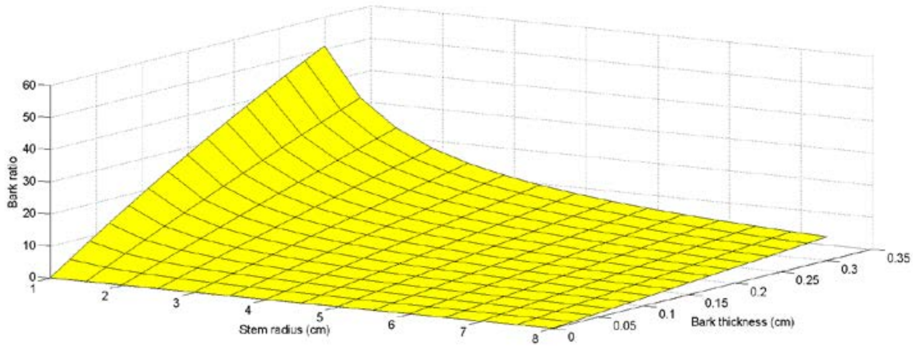

Fig. 1.
Theoretical bark percent according to bark thickness and barked stem radius

As it can be observed in Table 2, all the tested species showed lower ash content for wood than for bark. Among all species that were tested, the highest ash content values were both recorded by the bark (12.18 %) and wood (1.62 %) of Quercus coccifera, while the lowest values were presented by Erica arborea wood (0.39 %). Ash content values of wood ranged between 0.39 and 1.62 %, while the content of bark percentage fluctuated in the range of 4.97 to 12.18 %. It should be noted, that for all the tested species the ash content of bark was higher than the requirement of 3 % max. (referred for pellets), which should be met in order to comply with EN 14961-2 standard. Therefore, the tested species can be used for the production of pellets, provided that their barked stem diameter is in a range which corresponds to total ash content values (wood and bark) lower than the above limit (Fig. 2). Pellets produced with the material used in this research (within the range of the respective mean diameters) could present total ash content values below 3% and therefore could be appropriate for non-industrial use, even though none of them could fulfill the requirements of ENplus-A1 class. Furthermore, within the range of the diameters measured for Quercus coccifera and Quercus ilex, the produced pellets, could only be classified in Class EN-B concerning the ash content percentage. Moreover, if the material of Quercus coccifera had an average diameter of less than 5 cm, as the Erica material did, it would present ash percentages above 3% and therefore, it would not be suitable for such a use (Table 3).

Table 2

Mean and standard deviation of ash and higher heating values of the samples

		Arbutus unedo		Erica arborea		Phyllirea latifolia		Quercus coccifera		Quercus ilex	
		wood	bark	wood	bark	wood	bark	wood	bark	wood	bark
Ash[a] (%)	mean	0.83	7.16	0.39	5.24	0.67	4.97	1.62	12.18	1.14	9.15
	SD	0.06	0.14	0.04	0.13	0.05	0.12	0.06	0.09	0.03	0.11
HHV[b] (cal/g)	mean	4575	4335	4751	4764	4583	4957	4455	4228	4468	4122
	SD	14.5	2.9	15.0	21.6	7.8	30.8	18.3	10.2	10.8	15.2
MC[a] (%)	mean	7.1	11.5	8.0	1.2	7.9	7.7	7.4	9.3	7.1	9.9

[a] :Average of 3 measurements.
[b] :Average of 6 measurements

Theoretically, the only case, among the ones of the present work, that the requirements of ENplus-A1 class for ash content would be fullfilled is the use of Erica arborea stems with a diameter of more than 10 cm, but such stem diameters are not usually encountered in practice.

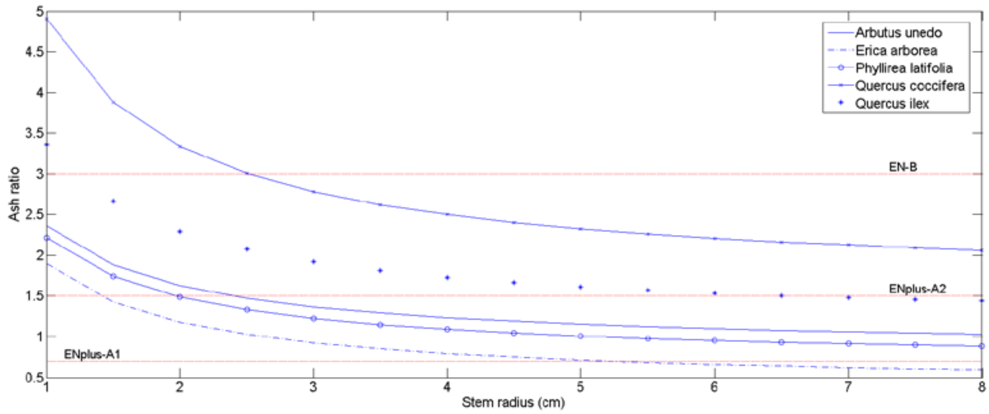

Fig. 2.
Total Ash content as function of stem radius of the tested species and the comparison with EN 14961-2 requirements

HHV of the tested species varied between 4122 and 4957 cal/g (Table 2). The highest HHV among them was presented by Phyllirea latifolia bark (4957 cal/g) which was 8.2 % higher than its respective value for wood. The lowest HHV was presented by Quercus ilex bark being 7.7 % lower than its wood. With the exception of Phyllirea latifolia, all tested species showed higher HHV for wood than for bark. It is worth mentioning that Erica arborea, even though presented the lowest diameter and the largest bark percentage, showed the highest HHV for wood (4751 cal/g) and the second highest for bark (4764 cal/g) among all tested species. The HHV differences between bark and wood for Erica arborea were not statistically significant (a = 0.05) and lead to a stable overall ash content regardless of the stem diameter. (Fig. 3). Furthermore, taking into account the ash content of Erica arborea (Fig. 2) showed that stem diameters larger than 2.8 cm would provide pellets of ENplus-A2 class, presenting HHV values higher than 4750 cal/g.

Table 3 contains the marginal values for the classification of pellets to the classes of EN 14961-2 but also the minimum barked stem diameters that corresponds to total ash content value that meets the respective requirement. In addition to the above, the respective HHV for the specific barked stem diameters are also included in the same Table.

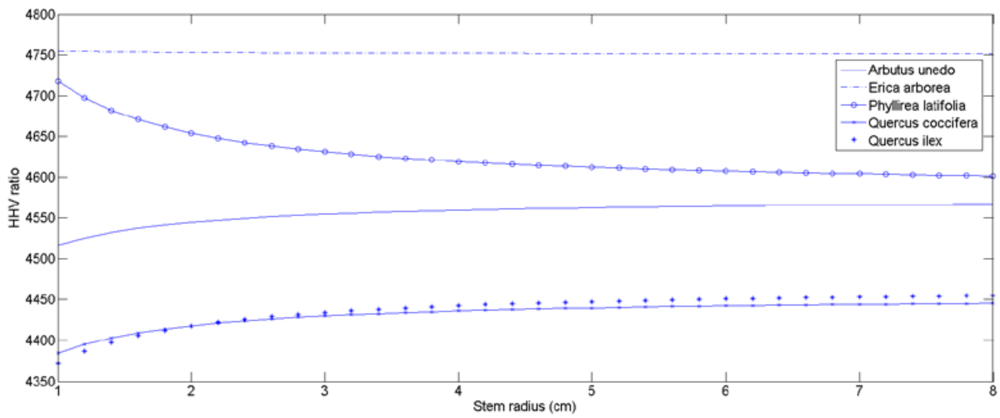

Fig. 3.
Higher Heating Values as function of the stem radius of tested species

The calorific value that the pellets of Phyllirea latifolia would provide, unlike the other species, would present a decreasing tendency as the stems diameter increases, but still it would be the second highest calorific value among the tested materials. In terms of the ash content values, the Phyllirea latifolia stems having a diameter of 4cm would produce pellets that meet the requirements for ENplus-A2 class (Table 3).

Table 3
Minimum barked diameter to meet the requirements of EN 14961-2 for ash content of pellets and the respective HHV result

Species	Diameter (cm)	Ash (%)	EN class	HHV (cal/g)
Arbutus unedo	4.80	1.50	ENplus-A2	4550
Erica arborea	2.80	1.50	ENplus-A2	4754
Phyllirea latifolia	3.94	1.50	ENplus-A2	4640
Quercus coccifera	5.04	3.00	EN-B	4425
Quercus ilex	2.42	3.00	EN-B	4388

CONCLUSIONS

One of the basic requirements of current European standards concerning biofuels in the form of pellets for non industrial use is the ash content maximum limit of 3 %. Ash content is significantly influenced by the bark percentage of the biofuel.

From the results of this paper it can be drawn that Arbutus unedo, Erica arborea, Phillyrea latifolia, Quercus coccifera and Quercus ilex stems cannot be used for the production of pellets of ENplus-A1 class, since the requirements of relevant standard, in terms of ash content limits, can not be fulfilled. On the contrary, all the above species could be used in the production of pellets that could be classified in ENplus-A2 for certain stem diameters.

Quercus coccifera with a barked diameter lower than 5 cm did not meet the requirements of EN 14961-2. The above species presented the worst fuel properties among all the tested ones.

On the contrary, Erica arborea proved to be the most appropriate, among the tested species, for the production of pellets. Erica demonstrated the highest HHV and the lowest ash content. As it was shown, Erica stems with diameter of 2.8 cm would produce pellets of ENplus-A2 class.

For the investigation of the suitability of a material to be included in pellet production process, except for the calorific value and ash content, of great significance is also the determination of other characteristics such as mechanical durability, amounts of fines and any other important property defined by the related standards.

REFERENCES

Barboutis I (1991) Utilization of wood of evergreen hardwoods in the production of composite boards (in Greek). PhD thesis, Aristotle University, Faculty of Forestry and Natural Environment, Thessaloniki, Greece.

Barboutis I, Lykidis C (2014) The Effects of Bark on Fuel Characteristics of Some Mediterranean Forest Species. Proceedings of the 57th SWST International Convention in conjunction with the 7th Wood Structure and Properties and the 6th European Hardwood Conference: "Sustainable Resources and Technology for Forest Products", June 23-27, 2014, Zvolen, Slovakia.

CEN/TS 14918 (2005) Solid biofuels. Method for the determination of calorific value.

Demirbas A (2007) Modernization of biomass energy conversion facilities. Energy Sources Part B, 29:227-35.

Dimitrakopoulos A, Panov P (2001) Pyric properties of some dominant Mediterranean vegetation species. International Journal of Wildland Fire 10:23–27.

EN 14775 (2009) Solid biofuels. Determination of ash content.

EN 14961-2 (2011) Solid biofuels. Fuel specification and classes - Part 2: Wood pellets for non-industrial use.

CEN/TS 14774-3, Solid biofuels – Methods for the determination of moisture content – Oven dry method – Part 3: Moisture in general analysis sample.

European Pellet Council (2013) Handbook for the certification of wood pellets for heating purposes. http://www.enplus-pellets.eu (Last accessed on 26/04/2014).

Filbakk T, Jirjis R, Nurmi J, Høibø O (2011) The effect of bark content on quality parameters of Scots pine (Pinus sylvestris L.) pellets. Biomass and Bioenergy 35(8):3342-3349.

Haberl H, Geissler S (2000) Cascade utilization of biomass: strategies for a more efficient use of a scarce resource. Ecological Engineering 16:S111-21.

Hoogwijk M, Faaij A, van den Broek R, Berndes G, Gielen D, Turkenburg W (2003) Exploration of the ranges of the global potential of biomass for energy. Biomass Bioenergy 25:119-33.

Lehtikangas P (2001) Quality properties of pelletised sawdust, logging residues and bark. Biomass and Bioenergy 20:351–360.

Perlack R, Wright L, Turhollow A, Graham R, Stokes B, Erbach D (2005) Biomass as feedstock for a bioenergy and bioproducts industry: the technical feasibility of a billion-ton annual supply. US Department of Energy and US Department of Agriculture, p. 78.

Siafaca L, Adamandiadou S, Margaris N (1980) Caloric Content in Plants Dominating Maquis Ecosystems in Greece. Oecologia (Berl.) 44:276-280.

Telmo C, Lousada J (2011) Heating values of wood pellets from different species. Biomass and Bioenergy 35(7):2634-2639.

Viana H, Vega-Nieva D, Ortiz Torres L, Lousada J, Aranha J (2012) Fuel characterization and biomass combustion properties of selected native woody shrub species from central Portugal and NW Spain. Fuel 102:737-745.

Voulgaridis E, Passialis C (1995) Characteristics and technological properties of the wood of mediterranean evergreen hardwoods. Forêt Méditerranéenne, XVI, n° 1:3-12.