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Analysis of logging forest residues as an energy source

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<u>ABSTRACT</u>

Forest residue extraction levels in Greece are currently very low, but logging residues have the potential to be an important component of the wood energy supply chain. Forests are a major supplier of renewable energy. Exploring the possibilities of utilizing the biomass of logging residues for energy requires analysis and knowledge of its properties. In this research work the properties (ash, volatiles, fixed carbon, carbon, hydrogen, oxygen, nitrogen and calorific value) of the various constituents of the biomass of fir (Abies borisii - regis), pine (Pinus nigra), oak (Quercus frainetto) and beech (Fagus silvatica) logging residues were determined. Bark and ash content increased with decreasing diameter of branches. Ash content was higher in bark than in wood of branches in all species. Ash and nitrogen content was several times higher in bark and in foliage or needles than in wood of branches. Oak branches and twigs of all species had ash and nitrogen content higher than that required by the EN ISO 17225-2 standard for domestic pellets and they should not be used for energy, at least for pellets production. Volatile mater, fixed carbon, carbon and hydrogen content were in the range given by other researchers. Heating value is higher in softwood (fir and pine) than in hardwood (oak and beech) and ranged from 18.72 MJ/kg to 21.00 MJ/kg. In addition, Duncan's multiple range test was used to compare the means between the various constituents in all species.

1. Introduction

The growing global energy demand and concerns about the negative effects of growing greenhouse gas (GHG) emissions from fossil fuels call for alternative energy sources, which are low cost, renewable and non-polluting. One such renewable resource is biomass and especially forest biomass (European Commission 2005, Smeets and Faaij 2007, Becker et al. 2011). The remaining biomass in the forests after logging has attracted great interest as an energy source (Malinen et al. 2001, Gan and Smith 2006, Hu, Heitmann & Rojas 2008, Eker, Çoban & Acar 2009, Bouriaud, Ştefan & Flocea 2013, Järvinen and Agar 2014, Filippou et al. 2015a, Filippou et al. 2017a). Forest biomass consists of tops, branches, bark, foliage or needles and stumps (Giuntoli et al. 2015).

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In the past, logging residues were not exploited mainly because their harvest and transport was technically difficult and uneconomic. Currently new harvesting technologies and transportation systems have been developed and in conjunction with the increase in petroleum prices enable their extraction from the forest (Svanaes and Jungmeier 2010). Also, new and more efficient technologies enable conversion of biomass into energy in small units (mainly gasification) or conversion into compressed forms (wood pellets) that can be installed in or near the forests (Kauriinoja and Huuhtanen 2010, Filippou and Philippou 2014). These, further limit the transportation costs and give opportunities for local employment and rural development. Thus, logging residues from final harvest are expected to play an important role in meeting renewable energy goals in many countries (Gan and Smith 2006, Aguilar 2014). Their utilization for energy production could create business opportunities and employments in local populations, generate profit from residual material and provide energy self-sufficiency for rural communities (Philippou 2014). On the other hand, the literature on removal of logging residues from the forest and their exploitation also addresses various environmental and ecological issues and puts some constrains (Hesselink 2010, Abbas et al. 2011, Wall and Hytönen 2011).

The main material properties that affect conversion into energy as well the overall energy outcome are moisture content, ash content, volatile content, elemental composition, chemical components and calorific value (Obernberger, Brunner & Bärnthaler 2006, Vassilev et al. 2010, Filippou et al. 2017b). Biomass of logging residues, differ in chemical composition from stem wood (Zeng, Tang & Xiao 2014). There also exists variability in chemical composition between the various constituents of forest biomass (Werkelin et al. 2007, Wang and Dibdiakova 2014).

Ash content of biomass is known to vary between tree species and tree components (Rhén 2004, Filippou, Philippou & Sideras 2015b, Hytönen and Nurmi 2015). High ash content can decrease the heating value of biomass. In addition, ash content and its composition affect the proper functioning of the burners and gasifiers (Bryers 1996, Nielsen et al. 2000). The ash adheres to the heat transfer surfaces and cause corrosion. During combustion burning, the elements, mainly K, Na, S and Ca can melt, form sticky particles, adhere to the surfaces of the walls and create a burner malfunction (Raask 1969, Filbakk et al. 2011). The nitrogen content of biofuel is responsible for the formation of nitrogen oxides (NO_x) which have an environmental impact (Munalula and Meincken 2009). Biomass pellets, should have low ash and nitrogen content in order to meet quality standards requirements (EN ISO 17225-2:2015).

Calorific value of biomass is a function of its chemical composition (Shafizadeh, Chin & DeGroot 1977, McKendry 2002). Various researchers have determined the calorific value of various types of biomass from their elemental composition using proximity regression analysis models (Demirbaş 2003, Friedl et al. 2005, Telmo, Lousada & Moreira 2010, Singh, Singh & Gill 2015). Also, several researchers (Harris 1984, Nurmi 1997, Zeng, Tang & Xiao 2014, Singh, Singh & Gill 2015) have measured the heating value of various tree species and various tree components and found significant differences, both between species and tree biomass components.

The aim of this study is to examine the branches of fir, pine, oak and beech that remain in the forest after harvesting as an energy source, while also to determine their properties that influence the efficient conversion into energy. The properties studied included percentage of bark, ash, volatiles, fixed carbon, carbon, hydrogen, oxygen, nitrogen and calorific value. This work is a part of a research program, aiming at exploring the possibilities for the utilization of residues that remain in the forest after logging, for the production of solid biofuels. Within the framework of the program 5 research papers have been published (Filippou and Philippou 2014, Filippou et al. 2015a, Filippou, Philippou & Sideras 2015b, Filippou et al. 2017a, Filippou et al. 2017b).

2. Material and Methods

Logging residues of fir (*Abies borisii – regis*), pine (*Pinus nigra*), oak (*Quercus frainetto*) and beech (*Fagus silvatica*) were taken from forest stands, in northern Greece, during normal logging operations. Representative samples of branches with bark and foliage were taken from five trees of each species. For determining the percentage of bark in branches, transverse discs of different

diameters (from 2 to 9cm) were cut. The percentage of bark was calculated by measuring the diameter of the disc with the bark and after peeling the bark using the formula (1):

Where:

d₁=disk diameter with bark

 $d_{2=}$ disk diameter without bark

The branch samples were in total 127 and had diameter from 2 to 9 cm. Measurements were carried out in 4 discs (repetitions) of each branch.

For the determination of other properties, the branches were cut into three parts: thick branches (diameter > 5cm), thin branches (diameter of 2 - 5cm) and twigs (branches with a diameter < 2cm including the foliage or needles). Samples of thick and thin branches were debarked in order wood and bark to be tested separately. The samples were air-dried and milled first in a common hammer mill and then in a Willey mill to obtain particle size < 0.420mm (40 mesh). Ash content (% dry weight), the percentage of volatiles, fixed carbon, and the elemental analysis (C, H, N) were determined in accordance with CEN/TS 14775, CEN/TS 15148 and CEN/TS 15104 standards, respectively. The higher heating value (MJ/Kg dry) was determined in accordance with CEN/TS 14918 standard. Three samples of each material were used for the measurements of each property. Afterwards, Variable Analysis between different materials for each property in all species was executed. The Duncan's multiple range test was used to compare the means of chemical components between the various constituents in all species.

3. Results and Discussion

3.1 Bark percentage

Table 1 shows the average bark percentage of all branches measured, as well as the average percentage in each of the two class sizes of branches of fir, pine, oak and beech. Bark percentage ranged from 3.55% to 7.85% and it was higher in thin than in thick branches and varied between the species in a descending order: oak>fir>beech>pine. The differences in the percentage of bark between species was more evident when it was calculated at the same branch diameter (d = 5cm) for all species.

Tuble 1: Dark percentage of branches								
	Branches							
	d= 2-9cm		d= 2-5cm		d = >5 cm		d= 5cm	
Species	đ*	0/ hoult	đ a/a	%	đ	%	%	
-	a/a**	% Dark		bark	a/a	bark	bark++	
Fir	6.04*	6.87	4.01	7.85	8.07	6.05	6.97	
	32**	(1.19)+	16	(0.83)	16	(0.41)	0.87	
Pine	5.91	4.09	4.05	4.52	7.97	3.61	4.40	
	32	(0.71)	17	(0.83)	15	(0.55)	4.49	
Oak	5.86	6.89	4.02	7.85	7.97	5.85	7 20	
	32	(1.32)	16	(1.01)	16	(0.52)	7.50	
Beech	5.93	4.33	4.25	5.00	7.88	3.55	3.03	
	31	(1.19)	16	(1.27)	15	(0.22)	5.95	

Table 1. Bark percentage of branches

* Average diameter, **No of samples, +standard deviation, ++ calculated

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3.2 Proximate analysis

In Table 2, the ash content, volatile content (VC) and fixed carbon (FC) content of all branches and twigs is shown, as well as the wood and bark of thick (d=>5cm) and thin (d=2-5cm) branches of fir, pine, oak and beech. According to Duncan's multiple range test, the constituents in all species were categorized depending on their residues fraction. Tables 2, 3 and 4 illustrate the results, where each column is followed by figures in different letters (^S) that indicate the significant difference by Duncan's multiple range test (P<0.05).

3.3 Ash content

Ash content varied between the various parts of branches and between the species from 0.38% in the wood of thick branches of pine to 8.01% in the bark of thin branches of oak. It was multiple higher in bark than in wood of branches and higher in thin than in thick branches. It is obvious that ash content increases with decreasing branch diameter (see also Table 1). Twigs in all species had lower ash content than bark but higher than thick and thin branches. The ash content of the thick and thin branches (wood and bark) was in fir 0.76 to 0.86%, in pine 0.79 to 1.16%, in oak 2.53 to 3.81% and in beech 0.98 to 1.14%, respectively. The above variation of the ash content between the various materials is shown better in Figure 1. Werkelin et al. (2007) found big differences in ash content between wood and bark in branches of spruce, pine, poplar and birch. Zeng, Tang & Xiao (2014) also found significant differences in ash content of different parts of Scots pine tree and found that branch base has ash content of 0.48% and the branch twigs about 1.56%. The EN ISO 17225-2:2015 standard for domestic pellets requires ash content less than 0.7% for A1 class, less than 1.2% for A2 class and less than 2% for B class pellets, thus oak branches and twigs of all species do not meet the above standard requirements and they should not be used alone for pellet production.

Table 2. Hoximate analysis of logging residues									
Property	Thick branches			Thin branches			Turigo		
(%)	All*	Wood	Bark	All*	Wood	Bark	1 wigs		
Fir									
Ash	0.76	0.52	4.50	0.86	0.50	5.00	3.00		
	±0.01	±0.04	±0.07	±0.03	±0.02	± 0.06	±0.05		
VC	78.75 ^d	79.04 ^e	75.24 ^b	78.76 ^d	79.10 ^e	74.16 ^a	76.84 ^c		
vC	±0.205	± 0.482	±0.178	±0.220	±0.376	± 0.045	±0.050		
EC	20.49 ^b	20.44 ^b	20.26 ^b	20.38 ^b	20.40 ^b	20.84 ^b	20.16 ^a		
гC	±0.142	± 0.088	±0.294	±0.106	±0.446	±0.177	±0.170		
Pine									
Ash	0.79	0.38	2.68	1.16	0.42	3.06	2.27		
	±0.01	±0.03	±0.04	±0.04	±0.02	± 0.02	±0.06		
VC	77.42 ^c	81.24 ^e	73.23 ^b	77.92 ^d	80.17 ^e	72.80 ^a	76.79°		
vC	±0.332	±0.120	±0.455	±0.630	±0.105	±0.390	±0.191		
FC	21.79 ^d	18.38 ^a	24.09 ^e	20.92°	19.41 ^b	24.14 °	20.94 ^c		
FC	±0.280	±0.399	±0.275	±0.387	±0.236	±0.391	±0.211		
			0	ak					
Ash	2.53	1.20	6.96	3.81	1.33	8.01	4.14		
Asii	± 0.04	±0.03	± 0.06	±0.64	±0.42	±0.49	±0.69		
VC	79.96 ^d	80.32 ^d	75.72ª	78.84°	80.83 ^d	75.26 ^a	77.46 ^b		
٧C	±0.187	± 0.520	±0.177	± 0.386	±0.435	±0.859	±0.501		
FC	17.51 ^b	18.57 ^d	17.32 ^a	17.35 ^b	17.84 ^b	16.73 ^a	18.40 ^c		
ГC	±0.310	±0.433	±0.463	± 0.455	±0.196	±0.337	±0.503		
			Be	ech					
Ash	0.98	0.80	6.00	1.14	0.90	6.50	5.50		
Ash	±0.02	±0.02	± 0.08	±0.02	±0.04	± 0.70	±0.06		

Table 2. Proximate analysis of logging residues

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VC	80.73 ^c	79.51°	76.09 ^b	80.32 ^c	81.13 ^d	77.01 ^b	75.67 ^a
	±0.050	±0.190	±0.156	±0.390	±0.320	±0.230	±0.190
F C	18.29 ^b	19.69 ^d	17.91 ^a	18.63 ^e	18.02 ^b	16.49 ^a	18.83 ^c
	±0.263	±0.194	±0.155	± 0.407	±0.185	±0.113	±0.140

*All branches (wood and bark at average diameter from Table 1). In each column, figures followed by different letters (^S) indicate significant difference by the Duncan's multiple range test (P<0.05).



Figure 1. Ash content in the various types of logging residues

3.4 Volatile and Fixed Carbon content

Volatile content (VC) in fir ranged between 74.16% in the bark of thin branches and 79.10% in the wood of thin branches, in pine between 72.80% in the bark of thin branches and 81.24% in the wood of thick branches, in oak between 75.26% in the bark of thin branches and 80.83% in the wood of thin branches and in beech between 75.67% in twigs and 81.13% in the wood of thin branches. In all species, VC of wood was higher than in bark. Fixed carbon (FC) ranged in fir between 20.16% in twigs and 20.84% in the bark of thin branches, in pine between 18.38% in the wood of thick branches and 24.14% in the bark of thin branches, in oak between 16.73% in the bark of thin branches and 18.57% in the wood of thick branches and in beech between 16.49% in the bark of thin branches and 19.69% in the wood of thick branches. FC in all parts of pine was higher in bark than in wood while in oak and beech was higher in wood. In a study (Telmo, Lousada & Moreira 2010) of proximate analysis in 13 wood species, VC varied among the species between 74.7% and 87.1% and FC between 12.4% and 22.5%. In the same study VC and FC of oak wood was 81.70% and 18.00%, of pine 85.80% and 14.10% and of poplar 87.1% and 12.4%, respectively. Demirbas (1997) gives for beech wood 74.00% volatiles content and 24.6% fixed carbon content.

3.5 Ultimate analysis

Table 3 gives the carbon, hydrogen, oxygen and nitrogen content of the all branches and twigs, as well as the wood and bark of thick (d=>5cm) and thin (d=2 - 5cm) branches of fir, pine, oak and beech.

Table 5. Onimate analysis of logging residues									
Sample	Thick branches			Thin branches			Turias		
(%)	All*	wood	bark	All*	wood	bark	1 wigs		
Fir									
C	49.44 ^c	49.84 ^d	48.69 ^b	48.96 ^b	48.26 ^b	47.87 ^a	49.02 ^b		
C	±0.705	±1.397	± 0.428	±0.262	±0.266	±0.269	±0.160		

Table 3. Ultimate analysis of logging residues

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ц	6.45 ^b	6.62 ^b	6.14 ^a	6.44 ^b	6.45 ^b	6.39 ^b	6.58 ^b			
П	±0.146	±0.131	±0.030	±0.158	±0.135	±0.227	±0.036			
0	44.01	43.45	44.14	44.42	45.20	44.89	43.89			
N	0.10 ^a	0.09 ^a	0,91 ^e	0.18 ^b	0.09 ^a	0.85 ^d	0.51 ^c			
IN	±0.015	±0.005	±0.185	± 0.001	± 0.001	± 0.028	± 0.045			
Pine										
C	50.60 ^c	49.92 ^b	50.73°	49.92 ^b	49.02 ^a	49.75 ^b	50.00 ^b			
C	±0.325	±0.117	±0.340	± 0.272	±0.125	±0.310	± 0.480			
ττ	6.19 ^b	6.81 ^d	6.10 ^a	6.52 ^b	6.64 ^c	6.36 ^b	6.58°			
П	±0.075	±0.020	±0.045	± 0.144	±0.123	± 0.110	± 0.040			
0	43.08	43.20	42.68	43.36	44.21	43.48	42.66			
N	0.13 ^b	0.07ª	0.49 ^d	0.20°	0.13 ^b	0.41 ^d	0.76 ^e			
IN	±0.011	±0.005	±0.042	±0.020	±0.026	±0.020	±0.020			
	Oak									
C	46.23 ^b	46.92 ^b	45.12 ^a	46.90 ^b	46.50 ^b	45.22 ^a	47.61 ^c			
C	±0.519	±0.285	±0.254	±0.577	± 0.345	±0.143	±0.238			
ц	6.06 ^b	6.35°	6.33°	6.09 ^b	6.27°	5.78ª	6.22 ^b			
п	±0.102	±0.051	±0.051	±0.015	±0.090	±0.119	± 0.040			
0	47.42	46.52	48.33	46.70	47.01	48.59	45.00			
N	0.29 ^b	0.21ª	0.22ª	0.31 ^b	0.22ª	0.41°	1.17 ^d			
IN	±0.020	±0.010	±0.010	±0.040	±0.020	±0.010	± 0.060			
			Be	ech						
C	46.85 ^b	47.02 ^c	45.88 ^a	47.62 ^d	49.73 ^f	46.75 ^b	49.09 ^e			
C	±0.177	±0.794	± 0.551	±0.276	±0.211	± 0.529	±0.265			
ц	6.25 ^b	6.41 ^c	5.95 ^a	6.27 ^b	6.47°	5.97 ^a	6.68 ^d			
п	± 0.058	±0.015	±0.152	±0.148	±0.035	±0.079	±0.055			
0	46.65	46.40	47.59	45.85	43.64	46.89	42.66			
N	0.25 ^b	0.17 ^a	0.58 ^d	0.26 ^b	0.16 ^a	0.39 ^c	1.57 ^e			
IN	±0.010	±0.005	±0.061	±0.032	± 0.001	±0.017	±0.030			

*All branches (wood and bark at average diameter from Table 1). In each column, figures followed by different letters (S) indicate significant difference by Duncan's multiple range test (P<0.05).

Carbon content varied in fir between 47.87% in the bark of thin branches and 49.84% in the wood of thick branches, in pine between 49.02% in the wood of thin branches and 50.73% in the bark of thick branches, in oak between 45.12% in the bark of thick branches and 47.61% in twigs and in beech between 45.88% in the bark of thick branches and 49.73% in the wood of thin branches. In fir and pine thick branches had higher carbon content while in oak and beech carbon content was higher in thin than in thick branches. With the exception in pine, wood had higher carbon content than bark, in all species. Ragland, Aerts & Baker (1991) noticed that the carbon content of softwood species varies between 50 and 53%, and that of hardwood species between 47 and 50% mainly due to the varying lignin and extractives content. They also give 52.25% and 54.90% carbon content in oak and pine bark, respectively.

Hydrogen content varied in fir between 6.14% in the bark of thick branches and 6.62% in the wood of thick branches, in pine between 6.10% in the bark of thick branches and 6.81%, in the wood of thick branches, in oak between 5.78% in the bark of thin branches and 6.35% in the wood of thick branches and in beech between 5.95% in the bark of thick branches and 6.68% in twigs. With the exception of pine, there is no difference between thick and thin branches (wood and bark) in all species. Hydrogen content was in a descending order: pine>fir>beech>oak. Nurmi (1993) gives for trembling aspen > 5mm branch wood 46.84% carbon content and 5.96% hydrogen content while for the bark of the branch 48.05% carbon content and 5.77% hydrogen content. In the same study gives for scots pine branch wood 53.53% carbon content. Wilén, Moilanen & Kurkela (1996) gives for scots pine logging residues 51.30% carbon content and 6.10% hydrogen content.

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Oxygen content was determined by subtracting C, H, N and ash content from the whole mass (100%). In fir oxygen content varied from 43.45% in the wood of thick branches to 45.20% in the wood of thin branches, in pine from 42.66% in twigs to 44.21 % in the wood of thin branches, in oak from 45.00% in twigs to 48.59% in the bark of thin branches and in beech from 42.66% in twigs to 47.59% in the bark of thick branches. Oxygen content was in a descending order: oak>beech>fir>pine. Oxygen content was lower than carbon content in all fir and pine biomass components.

Nitrogen content in fir varied from 0.09% in the wood of thick and thin branches to 0.91% in the bark of thick branches, in pine from 0.07% in the wood of thick branches to 0.76% in twigs, in oak from 0.21 in the wood of thick branches to 1.17% in twigs and in beech from 0.16 in the wood of thin branches to 1.57% in twigs. In all cases, bark had 2-3 times higher nitrogen content than wood. It is worth mentioning in nitrogen content which is a determinant factor classification of biomass in qualities according to EN ISO 17225-2:2015 standard. According to Duncan's multiple range test it appears to be a grouping trend in softwood species (fir and pine) which have lower nitrogen content in thick than in thin branches and lower in wood than in bark. In hardwood (oak and beech) species there are no differences in thick and thin branches, while nitrogen content is higher in bark than in wood. With the exception of fir, nitrogen content was higher in twigs in all species. The above variation in nitrogen content for populous branch wood, branch bark and branch chip. Alakangas (2005) gives 0.30% nitrogen content for scots pine whole trees and 0.40% for pine logging residues. Oak and beech twigs have higher nitrogen content than the EN ISO 17225-2:2015 standard for domestic pellets and should not be used alone for energy uses, at least for pellet production.



Figure 2. Nitrogen content in the various types of logging residues

3.6 Heating value

Table 4 shows the heating value of the various branch components of fir, pine, oak and beech. The higher heating value (HHV) ranged in fir between 19.57 MJ/Kg in twigs and 20.80 MJ/Kg in the wood of thin branches, in pine between 20.75 MJ/Kg in the wood of thin branches and 21.00 MJ/Kg in the bark of thick branches, in oak between 18.72 MJ/Kg in the bark of thick branches to 19.52 MJ/kg in the wood of thin branches and in beech between 19.31 MJ/Kg in the bark of thin branches to 19.67 MJ/Kg in the wood of thick branches. With the exception of pine HHV was higher in wood than in bark in all species. According to Duncan's multiple range test, with the exception of pine, all species had higher heating value in thin than in thick branches and higher in wood than in bark. The above variation in HHV between the various types of residues is shown better in Figure 3.

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	6			U,					
Property	Thick branches			Thin branches			Turigo		
(MJ/kg)	All*	Wood	Bark	All*	Wood	Bark	Twigs		
Fir									
	20.57 ^d	20.61 ^d	20.48 ^b	20.79 ^e	20.80 ^e	20.32 ^b	19.57 ^a		
пп v	±0.04	±0.03	±0.01	±0.02	±0.02	±0.025	±0.015		
Pine									
HHV	20.95°	20.84 ^b	21.00 ^d	20.80 ^a	20.75 ^a	20.84 ^b	20.95°		
	±0.020	±0.015	±0.020	±0.045	±0.025	±0.025	±0.015		
Oak									
шиу	19.26°	19.15 ^b	18.72 ^a	19.31 ^e	19.52 ^f	19.13 ^b	19.30 ^c		
HHV	± 0.050	±0.110	± 0.090	± 0.060	± 0.085	± 0.090	±0.122		
Beech									
HHV	19.58 ^b	19.67°	19.41 ^a	19.63 ^b	19.70 ^c	19.31 ^a	19.42 ^a		
	±0.020	± 0.040	±0.020	±0.025	±0.015	±0.04	±0.02		

Table 4. Heating values (MJ/kg) of logging residues

*All branch (wood and bark at average diameter from Table 1), 2 HHV= higher heat value. In each column, figures followed by different letters (⁸) indicate significant difference by the Duncan's multiple range test (P<0.05).

On the average, heating value was in a descending order: pine>fir>beech>oak. Heating value was higher in softwood (fir and pine) than in hardwood (oak and beech). Philippou (1982) found in oak 19.65 MJ/kg and 18.79 MJ/kg, in poplar 19.78 MJ/kg and 19.62 MJ/kg and in pine 20.35 MJ/kg and 21.60 MJ/kg for stem wood and stem bark, respectively. Järvinen and Agar (2014) making pellets from pine and logging residues found that the average caloric content for the whole pine tree was 20.80 MJ/kg and for the residues 21.60 MJ/kg. Telmo, Lousada & Moreira (2010) found an average heating value (HHV) of pellets from beech wood 19.14 MJ/kg. Phyllis2- Database (ECN 2012) gives calorific value for beech bark 21.67 MJ/kg and an average calorific value of beech wood measured by 12 researchers 19.08 MJ/kg with a range between 16.48 – 20.51 MJ/kg. Shafizadeh, Chin & DeGroot (1977), Demirbas (1997) and Gillespie et al. (2013) found a correlation between carbon content and calorific value.



Figure 3. Higher heating value in the various types of logging residues

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4. Conclusions

This paper assessed the suitability of logging residues as an energy source. The properties of logging residues of fir, pine, oak and beech differ in some properties that are important for energy usages.

Bark percentage was higher in thin than in thick branches and varied between the species in a descending order: oak>fir>beech>pine.

Bark and ash content increased with decreasing diameter of branches. Ash content was higher in thin than in thick branches and it was higher in bark than in wood in all species.

Fixed carbon, carbon and hydrogen content differed between the various constituents of logging residues.

Nitrogen content of all branches varied from 0.10% in thick branches of fir to 0.31% in thin branches of oak. In overall nitrogen content was higher in oak and higher in thin branches in all species.

Relatively higher values of ash and nitrogen content found in the biomass of logging residues, are not as high as in the biomass of other lignocellulosic materials such as agricultural residues and annual plants which are being used for energy production.

Taking into consideration that the recovery of logging residues may be limited by other constrains such as maintaining long-term soil and site productivity, from the above results we could conclude that the branches of fir, pine and beech could be a proper material for energy usages while the branches of oak and the twigs of all species should be left to provide nitrogen and minerals to the forest soil. However, during their processing to energy, attention should be given to the proper servicing of the burners or gasifiers for avoiding accumulation or melting of the ashes.

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