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Forest waste as an alternative energy source

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Abstract

Flammability and calorific power changes during the year for forest waste from several species existing in Galicia (NW Spain) are studied. Measurements were made using a static bomb (calorific values) and an epiradiator (flammability). Simultaneously, thermochemical parameters, such as chemical composition, moisture content, density, and ash percentage, as well as bioclimatic indexes were determined.

The results so obtained, with calorific values exceeding 19 500 kJ kg^{-1} and average flammabilities of 2, make it advisable to use these materials as alternative fuels in different plants for electric power production. © 1999 Elsevier Science B.V. All rights reserved.

Keywords: Alternative energy; Xyloenergy; Forest waste; Calorific value; Flammability

1. Introduction

The current energy crisis makes modern society search for energy sources alternative to the almost exhausted fossil fuels. In this search, a good deal of new energy sources are found, among which solid urban waste and forest waste. These materials, heretofore considered as useless refuse, are beginning to be used as alternative fuels in wide social sectors all over the world.

In this paper, we are focusing on xyloenergy, i.e., the energy contained in forest biomass. In our case, most of this xyloenergy is contained in forest waste resulting of woodland cleaning, reafforestation, firebreak upkeep and other silviculture tasks.

In Galicia, most of the forest waste biomass is originated by very common scrub species which occupy about 15% of the region. These species are *Ulex europaeus* L., *Sarothamnus scoparius* (L.) Link, *Rubus fructicosus* L., *Pteridium aquilinum* L. and different species named generally as heath.

This residual biomass can be transformed into a fuel that can be used in special plants or in municipal solid waste (MSW) treatment plants as an alternative energy source. The energy obtained in these plants will later be transformed into electric power.

This thermochemical study of the residual forest biomass is based on the calculation of the calorific value through experiments carried out in a static bomb, following the procedure proposed by Hubbard et al. [1] and of flammability using procedure and tables set up by Valette [2].

Before commenting on the other thermochemical parameters used in this paper, we will define:

- The higher heating value (HHV) as the quantity of heat generated by complete combustion in a bomb

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calorimeter of a mass unit of sample in an oxygen atmosphere, assuming that both the water contained in the sample and that generated from the combined hydrogen remains in liquid form. If it is assumed that the water in the products remains in the form of vapour, the lower heating value (LHV) can be calculated. Its calculation will give us true information about the energy contained in the different materials.
- The flammability, as the easiness of a material to catch fire, both spontaneously or through exposition to certain ambiences.
- The rest of the thermochemical parameters studied were: the elementary chemical composition (C, H, O, N and S) as well as Cl and heavy metals (Cu, Cd, Mn, Pb and Zn), moisture content, density of the different forest species and ash percentage in the bomb at the end of the calorimetric experiment.

All these thermochemical parameters undergo the influence of the climatic conditions of the area. For this reason, the bioclimatic diagrams [3,4] of the different areas where the samples were collected must be taken into account. The bioclimatic diagrams, in which a lot of climatic features of the area studied are analysed (temperature, pluviosity, vegetative productivity, different bioclimatic indices, potential evaporation-transpiration, etc.), which have a decisive influence on all the above parameters and are key to an accurate interpretation of the results.

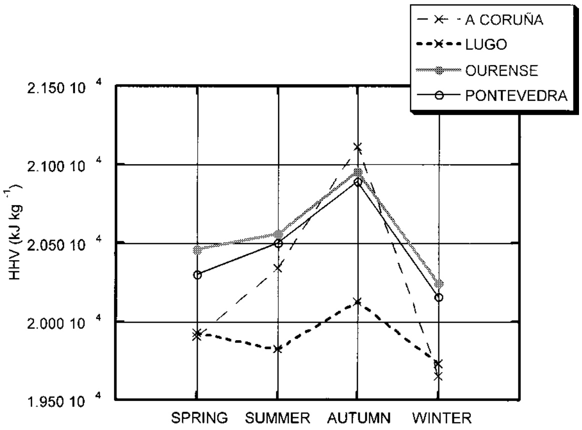

Fig. 1. Changes of HHV during the year of forest biomass in the four Galicia provinces.

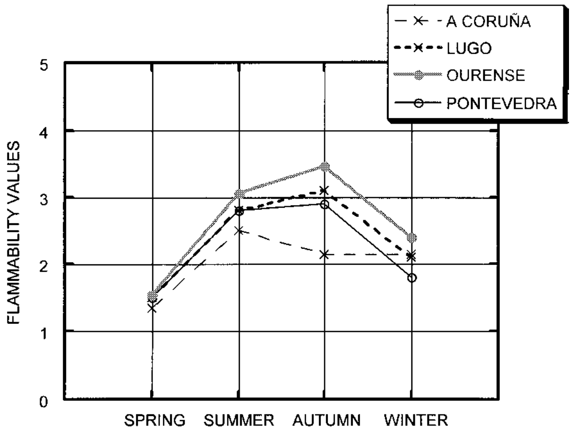

Fig. 3. Changes of flammability during the year in the four Galicia provinces.

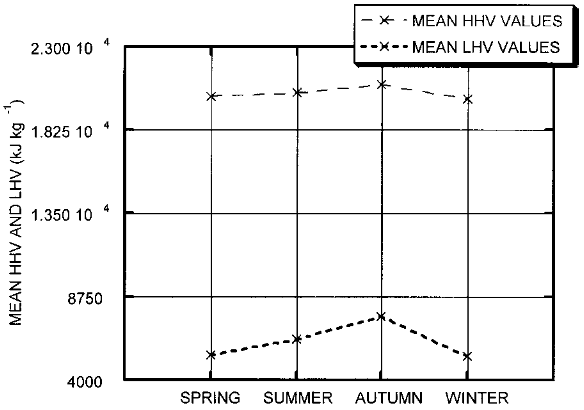

Fig. 2. Changes in mean HHV and LHV during the year.

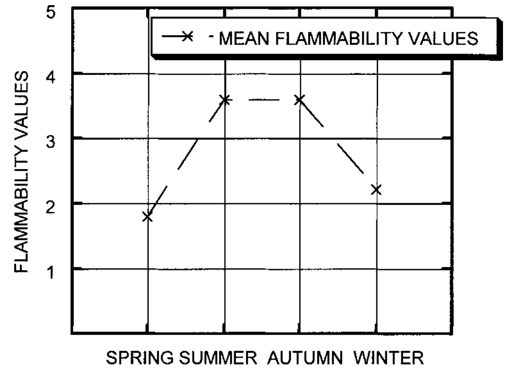

Fig. 4. Changes in mean flammability values during the year.

Table 1
HHV and LHV for forest waste and MSW wood

	HHV (kJ kg^{-1})	LHV (kJ kg^{-1})	Moisture (%)
Forest waste	20 300	6100	>40
MSW wood	17 800	14 600	12

Table 2
Flammability values according to the model proposed by Valette

	Spring	Summer	Autumn	Winter
S. scoparius (L.) *link*	1	1	2	2
U. europaeus L.	1	2	2	1
R. fructicosus L.	4	5	4	2
P. aquilinum L.	1	5	5	3
Heath	2	5	5	3

0: Very low flammability; 1: low flammability; 2: flammable; 3: moderately flammable; 4: very flammable; 5: extremely flammable.

The possibility of using forest waste as fuel, either directly or after a process to make them into pellets, that is a residual derived fuel (RDF), is currently being contemplated. The final decision depends on engineering and economic factors.

2. Experimental

The samples were collected from a previously chosen 1 ha of forest. The plots were divided into 1 m^2 size sites, five of which were randomly chosen. From every site, bulk samples consisting of bark, branches having a diameter not greater than 8 cm [5], from pruning of trees, fruits, leaves, and in general, all of the living parts of trees were collected. This bulk sample was reduced by a coning and quartering procedure to a representative sample of about 1 kg.

Table 3
Results of chemical analysis and concentrations of volatile metals, corresponding to the dry sample

	N (%)	C (%)	H (%)	O (%)	S (%)	Cl (%)	Cu (mg l^{-1})	Cd (mg l^{-1})	Zn (mg l^{-1})	Pb (mg l^{-1})	Mn (mg l^{-1})
P. aquilinum L.											
Spring	1.41	45.38	5.82	46.81	0.19	0.39	2.57	–	32.85	2.85	41.42
Summer	1.71	45.50	5.97	45.60	0.31	0.91	8.40	1.50	16.90	1.30	1963.10
Autumn	2.58	46.57	5.72	44.77	0.22	0.14	21.70	2.41	41.00	4.83	410.00
Winter	2.27	46.66	5.93	44.49	0.26	0.39	29.72	–	43.60	1.70	2140.00
S. scoparius (L.) *link*											
Spring	2.01	50.55	7.04	40.03	0.21	0.16	38.39	1.60	22.30	0.80	199.90
Summer	1.99	48.23	6.58	42.81	0.17	0.22	7.74	1.00	36.90	1.80	2756.70
Autumn	1.01	51.06	6.44	41.30	0.08	0.11	8.57	–	27.14	4.29	1600.00
Winter	4.84	46.20	11.53	37.34	0.09	0.11	4.30	–	44.00	1.43	3714.00
R. fructicosus L.											
Spring	1.73	47.22	6.13	44.58	0.16	0.18	16.71	1.67	16.71	0.80	10.00
Summer	1.71	45.64	6.05	46.23	0.14	0.23	44.30	1.00	26.30	1.10	1377.90
Autumn	2.97	46.21	5.98	44.53	0.13	0.18	18.00	–	24.00	54.00	1800.00
Winter	2.92	46.82	6.13	43.86	0.12	0.15	12.00	–	36.00	24.00	1840.00
U. europaeus L.											
Spring	1.00	49.70	6.88	42.07	0.23	0.12	15.00	3.33	89.28	1.80	60.00
Summer	2.67	48.70	6.71	41.49	0.07	0.36	19.24	1.60	25.60	4.81	1218.00
Autumn	3.06	47.03	6.41	43.35	0.08	0.08	8.08	–	36.40	12.10	1778.50
Winter	2.80	48.96	6.53	41.41	0.12	0.18	32.00	–	42.00	6.00	1920.00
Heath											
Spring	1.63	53.26	6.23	38.71	0.12	0.05	31.00	<1.00	42.00	6.00	130.00
Summer	1.41	53.23	6.52	38.74	0.07	0.03	23.00	<1.00	17.00	13.00	172.00
Autumn	1.00	53.74	6.38	38.75	0.10	0.03	51.00	<1.00	117.00	20.00	59.00
Winter	1.68	55.51	7.06	35.64	0.08	0.03	14.00	<1.00	28.00	4.00	138.00

Part of this sample was used in the flammability experiments [5] which were performed, following the standard UNE-23-721, using a standard epiradiator of 500 W constant nominal power. Flammability values were obtained according to the tables proposed by Valette [2].

The remaining sample was weighed to 0.1 or 1.0 g using a double scaled Salter EP-22KA balance and then left for 12 h in a Selecta 200210 natural desiccating stove. Humidity of the sample was determined as the weight loss of the sample after treatment in the stove.

Once the humidity was determined, the sample was ground using two mills of different power, a Retsch SM-1 blade mill and a Taunus MS-50 grinder, in order to homogenize the sample as much as possible, so making easier the preparation of the sample pellets to be used in the calorimetric experiments.

The final sample was divided into two parts. Part 1 was used in the analyses to determine humidity, density and average composition of each of the species being studied. The samples were analysed using a Carlo Erba analysis equipment for determination of elementary composition (C, H, O, N and S) and a Perkin-Elmer atomic absorption spectrophotometer to determine their C, H, O, N, S, Cu, Cd, Zn, Pb, Cl and Mn contents. The calorimetric experiments were performed using Part 2. Sample pellets of about 1 g size [6] were placed in a stainless steel crucible introduced into a Parr-1108 sealed static bomb calorimeter made of Carpenter-20-Cb-3 special stainless steel. The samples were ignited at (298.15 ± 0.01) K in oxygen at 3.04 MPa with 1 cm^3 of water added to the bomb. The electrical energy for ignition was determined from the change in potential across a 2900 μF capacitor when discharged from about 40 V through a platinum wire. The pellet was connected to the ignition system by means of a cotton thread fuse, empirical formula $\mathrm{CH_{1.686}O_{0.843}}$ [1] with $-\Delta_c U_o = 16\,250$ kJ kg^{-1} [1]. The samples, crucible, cotton thread and platinum wire were weighed using a Sartorius R 200 D balance (sensitivity±0.001 mg).

Water was added to the calorimeter from a weighed glass vessel and for each experiment a correction to the energy equivalent was made for the deviation of the mass of water added from 4631 g weighed to 0.1 g. Temperature of this water was measured to 10^{-4} K at intervals of 15 s by a stable and sensitive platinum thermometer (ASL S 391/100) and recorded by a resistance bridge (ASL F-26) connected to a computer (Amstrad PC-2086/30). The water in the jacket was circulated by stirring and its temperature was maintained at 298.15 K by a Tronac PTC-41 temperature controller with a precision of 0.003°C over a week, and including a probe, a heater, and a cooling coil. The energy equivalent of the calorimeter was determined from the combustion of benzoic acid (BCS CRN-ISOP standard reference sample) from the Bureau of Analysed Samples, having a certified specific energy of combustion under standard bomb conditions of 26 431.8 ± 3.7 J g^{-1}.

The energy equivalent of the calorimeter was determined from five calibration experiments *E*(calor)=

Table 4
Results of analysis of the total samples

	Density (kg m^3)	Moisture (%)	Bomb ashes (%)
S. scoparius (L.) *link*			
Spring	860	66.68	0.79
Summer	890	55.77	0.86
Autumn	740	47.55	0.16
Winter	800	59.00	0.32
U. europaeus L.			
Spring	830	61.32	0.71
Summer	840	59.49	0.73
Autumn	860	57.50	0.78
Winter	900	62.00	1.14
R. fructicosus L.			
Spring	910	57.97	1.89
Summer	850	65.66	0.84
Autumn	870	62.20	1.34
Winter	920	55.00	1.90
P. aquilinum L.			
Spring	520	68.53	2.25
Summer	580	71.48	2.86
Autumn	510	47.62	1.18
Winter	500	72.53	0.53
Heath			
Spring	1030	43.10	0.36
Summer	990	30.05	0.21
Autumn	990	40.25	0.79
Winter	990	37.30	0.49

Moisture (%)=100 (initial weight of collected sample−weight of sample after drying)/initial weight of collected sample.
Bomb ashes (%)=100 (weight of crucible and contents after combustion−weight of empty crucible)/weight of pellet.

22 402.5±1.9 J K^{-1} (0.0085%), where the uncertainty quoted is the standard deviation of the mean.

The temperature rise was corrected for stirring and exchange heating.

3. Results and discussion

Fig. 1 shows the changes during the year of HHV of forest waste. As can be seen these values are above 19 500 kJ kg^{-1} during the whole year.

Fig. 2 shows the great differences between HHV and LHV. These great differences are due to the high moisture content of the samples with mean values in the range from 37% (heath) to 60% (all the other species). These differences, however, were not observed in the biomass coming from MSW [7]. Table 1 shows a comparison between HHV and LHV for wood found in MSW and that in forest waste. Moisture content of biomass present in MSW is much lower than that of forest biomass. Calorific power of wood found in MSW is also lower than that of forest biomass. This is due to the fact that MSW wood originates from a more homogeneous source than that where forest biomass comes from. Moreover, MSW wood was processed and so part of its energy was lost.

Figs. 1 and 3 show that HHV changes and flammability changes during the year are very similar for the four provinces which compose Galicia. Changes in flammability during the year are shown in Figs. 3 and 4. As can be seen in Fig. 4, flammability mean value is very close to 2 according to Valette [2]. This value corresponds to the class flammable material. This point strengthens once more the use of residue biomass as an energy source, so preventing wildfires.

Table 5
Mean high heating values (HHVs) and mean low heating values (LHVs) of the different species along the seasons of the year

	HHV (kJ kg^{-1})	LHV (kJ kg^{-1})
S. scoparius (L.) *link*		
Spring	20 533.91±46.04 (0.22%)	3658.52±15.34 (0.42%)
Summer	19 019.07±93.92 (0.49%)	4118.10±35.07 (0.85%)
Autumn	20 520.97±51.89 (0.25%)	8180.37±27.21 (0.33%)
Winter	20 677.99±94.81 (0.46%)	4495.00±39.74 (0.88%)
U. europaeus L.		
Spring	20 182.38±64.15 (0.32%)	4789.63±24.81 (0.52%)
Summer	20 680.74±73.71 (0.36%)	5443.11±29.86 (0.55%)
Autumn	20 950.41±87.82 (0.42%)	6084.07±37.33 (0.61%)
Winter	20 472.57±81.33 (0.40%)	4829.08±30.93 (0.64%)
R. fructicosus L.		
Spring	17 777.51±11.11 (0.06%)	4702.22±4.67 (0.10%)
Summer	18 478.27±95.61 (0.52%)	3261.46±10.60 (0.33%)
Autumn	19 129.90±127.11 (0.66%)	4144.62±36.14 (0.87%)
Winter	19 451.13±57.71 (0.30%)	6062.74±25.99 (0.43%)
P. aquilinum L.		
Spring	17 613.89±50.45 (0.29%)	2586.99±18.90 (0.73%)
Summer	18 967.45±26.40 (0.14%)	6344.78±12.46 (0.20%)
Autumn	18 420.05±65.90 (0.36%)	7222.45±34.52 (0.48%)
Winter	18 624.83±56.50 (0.30%)	1156.84±15.53 (1.34%)
Heath		
Spring	22 728.69±200.97 (0.88%)	10 628.31±115.33 (1.09%)
Summer	21 653.13±129.04 (0.60%)	13 101.99±90.95 (0.69%)
Autumn	21 981.18±144.32 (0.66%)	10 803.87±86.59 (0.80%)
Winter	21 636.56±68.73 (0.32%)	11 280.60±43.62 (0.39%)

18 653.17±50.59 (0.27%) (mean heat value±standard deviation of the mean).

Table 2 shows flammability of the different forest species. Chemical elementary compositions, and volatile metals content are listed in Table 3.

Table 4 shows that mean ash content resulting from the bomb experiments is around 2%, much lower than that 25% corresponding to RDF [8]. This fact constitutes a clear advantage for thermal treatment of forest residues because in this process the rejected material would be minimised. Table 5 shows HHV and LHV during the year for all the forest species studied.

4. Conclusions

Bushes occupy around 15% of the forest surface of Galicia [9], approximately 450 000 ha. A rational planning would allow to obtain about 4×10^6 ton of forest residues every year. As the mean calorific value for these residues is about 20 000 kJ kg^{-1}, assuming a mean efficiency of 60% in the energy recovery plant, 940 kWh may be obtained per ton of biomass. In Spain, mean electricity consumption is 4123 kWh per year and person. That means that the use of forest biomass to obtain electric energy would suffice for 600 000 people electricity consumption which is around the total population of the two most important cities in Galicia (A Coruña and Vigo). Taking into account that conventional energy recovery plants use 16 000 kJ kg^{-1} fuels, it is easy to understand the benefit of using forest biomass as an alternative fuel for production of electric energy. This forest biomass could be used in different ways depending on economical criteria, but in any case the efficiency would be high. By using this biomass a two-fold objective would be achieved: first, the recovery and use of an energy wasted, and second, the prevention of starting and spreading forest wildfires [10–12].

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