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Design of an experimental procedure for energy evaluation from biomass

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Abstract

The rational and sustainable exploitation of nature resources is one of the priority objectives of our society. In this article a method is proposed to evaluate and exploit the energetic resources contained in different forest formations. This method is based on the use of a combustion bomb calorimeter to determine the calorific values of the different samples studied. These results were complemented with chemical analysis of the samples and with environmental and geomorphological studies of the zones were samples were taken. The results obtained during the last 3 years for the residual biomass originated from the forest formations existing in Galicia ensure the reliability and usefulness of the method that can be extended to any forest formation all over the world.

Keywords: Xyloenergy; Residual forest biomass; Rational and sustainable exploitation; Applied calorimetry

1. Introduction

The different energy and social crises experienced by the humankind, have encouraged the search for alternative energies. The increase in price of fossil fuels, and specially crude oil, is one of the main causes for the search of new alternative fuels satisfying the conditions of rationality and sustainability.

As a result of the studies developed by the Research Group TERmodinámica de BIoPROcesos y MATeriales (TERBIPROMAT), a method to evaluate the energy contained in residues forest biomass is proposed. This method ensures the rational and sustainable use of this energy [1–3].

The biomass was originated from the different silviculture tasks (reaforestation, wood exploitation, etc.) developed in Galician forests.

The results obtained up to date make us confident with the reliability of the method. Following the key directions, this method can be extended to every forest formation and country.

The calorimetric technique was static bomb calorimetry and the procedure previously described by Hubbard et al. [4]. The study was complemented by a complete elemental analysis of the biomass samples and the determination of moisture content, density, and ash percentage after combustion in the bomb.

The procedure consists of three main stages:

- Field work.
- Laboratory work.
- Analysis of results and elaboration of energy maps.

2. Experimental

The first, and very important, stage in this study begins with sampling, as the usefulness of the experimental measurements depends greatly on the samples being representative. The sampling was carried out according to a method carefully designed [1–3]. Samples were collected from a previously chosen 1 ha covered by homogeneous forest formations [5]. In this zone, all the significant physical environmental and geomorphological parameters such as topography and orography, slope, wind intensity, sun radiation, temperature, humidity, etc. were recorded by filling in a spe-

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cial technical form. All these parameters play an important role as they allow the construction of bioclimatic diagrams [6,7] very important to elaborate both an exploitation calendar and conclusions. The choice of an appropriate calendar is crucial to ensure a rational and sustainable exploitation.

Once the sampling zone was chosen and characterized, the average height of the trees was estimated by using a hypsometer, and then two of the trees were marked for analysis alter being cut down. Then, their branches were separated and joined to all the residues usually abandoned on the forest surface after forestry works. All these forest residues, without any economical value, were divided in three well-differentiated classes: leaves, branches having a diameters less than 3 cm, and branches with a diameter between 3 and 6 cm. All other kinds of residues originated from forestry task, such as bark and branches with diameter between 6 and 8 cm are usual collected either by forestry workers or by land owners.

After division of the three mentioned groups, each of them was weighed to determined their percentages of weight "in situ". The two kinds of branches were cut to small pieces and then each of the three groups were carefully mixed and reduced by a coning and quartering procedure to a representative bulk sample of 5–6 kg each.

After being collected the samples were stored in hermetically closed polyethylene bags to avoid loss of moisture, and sent to the laboratory in less than 12 h. It is very important to avoid the loss of moisture as it is a key parameter for the design of energy transformation plants.

Once in the laboratory, samples were weighed to 0.1 or 1.0 g using a double scaled Salter EP-22KA balance, and dried in a Selecta 200210 natural desiccating oven at 105 °C to constant weight [8] to determine moisture content as the weight loss. After the humidity was determined, the dry sample was ground using two different mills to homogenize the sample as much as possible. A part of the ground sample was then pressed to pellets to be burnt in the bomb calorimeter for calorific values determination.

Another part of the ground sample was used for determination of density and elemental composition (C, H, N, O and S) using a Carlo Erba analysis equipment.

Sample pellets of about 1 g [9] size were used for calorimetric experiments to determine calorific values, as the amount of energy released on burning by each unit of combustible mass. Two calorific values must be considered.

The higher heating value (HHV) is the amount of energy released on burning by complete combustion of a mass unit of sample, at constant volume in an oxygen atmosphere, assuming that the final products of combustion consist of O_2, CO_2, SO_2, and N_2 in the gas phase together with water, that contained in the sample and that generated from the combined hydrogen, in liquid form. This calorific value can be determined experimentally in the laboratory.

The lower heating value (LHV) can be calculated from the HHV assuming that the water in the products remains in the form of vapor. The knowledge of LHV is very helpful to evaluate forest resources from the energetic point of view.

The third stage of this study is the analysis of results, according to the criteria established beforehand and the construction of energy maps, thus making easier the understanding and the use of data.

In general, these criteria are based on:

- To quantify the surface (ha) of the forest formations available for exploitation. In this sense, it must be remembered that part of the covered surface should be preserved of exploitation because of its ecological importance.
- Quantification of the yearly forest residues generated.
- Quantification of the forest waste percentage that must be abandoned on the soil surface. According to our calculations, about 10% of the total amount.
- Mean calorific value over the year. This is a basic datum to take in account to evaluate the yield of the energy transformation plant. For the forest formations analyzed in this study, the mean calorific value was about 7400 $kJ\,kg^{-1}$.
- The yield of the energy transformation plant was assumed as 25%.
- Cuts timing for a rational and sustainable exploitation: shrub every 5 years, eucalyptus every 15 years, and pine every 20 years.

3. Results and discussion

From the analysis of the data shown in Table 1 [1–3], collected during the last 4 years, and corresponding to the three most important forest formations from the economical point of view existing in Galicia [5], it can be seen

- There is an exploitable forest surface of about 1,300,000 ha.

Table 1
Exploitation criteria and theoretical values of electricity production

Forest formations	Exploitation surface	Trees (ha^{-1})	Forest waste ($T\,ha^{-1}\,year^{-1}$) gross	Mean LHV ($kJ\,kg^{-1}$)	kWh generated over the year	Efficiency (%)	Economical incomes (€ $year^{-1}$)
Eucalyptus	240,000	2,500	270	7,200	3.3×10^{10}	25	7.3×10^{7}
Pine	500,000	2,200	360	7,600	2.6×10^{10}	25	2.8×10^{8}
Shrub	470,000	–	130	7,400	2.6×10^{5}	25	1.1×10^{7}

Table 2
LHV class

	LHV class		
	E. globules Labill	Pine sp.	Shrubs
November	4	5	3
January	4	5	5
March	4	4	5
May	5	4	3
July	5	4	4
August	3	4	5
September	4	4	5

LHV classes: class 1, LHV < 4500 kJ kg^{-1}; class 2, 4500 kJ kg^{-1} ≤ LHV ≤ 5500 kJ kg^{-1}; class 3, 5500 kJ kg^{-1} ≤ LHV ≤ 6500 kJ kg^{-1}; class 4, 6500 kJ kg^{-1} ≤ LHV ≤ 7500 kJ kg^{-1}; class 5, LHV ≥ 7500 kJ kg^{-1}.

- 6×10^{10} kW h can be recovered.
- Generation 3×10^{8}€.

Aside of the economical benefit it must be also considered the environmental benefit derived from a forest rearrangement.

- Minimization of the number of forest fires.
- To avoid phytoplagues that decrease the productive capacity of forest.
- Decrease of defertilizing processes.

Table 2 shows energetic data arranged following a table that modifies that proposed by Valette and Doat [10] and was elaborated taken into account the special characteristics of Galician biomass. Energy maps corresponding to all the forest zones and the four seasons of the year were constructed. These maps together with bioclimatic diagrams are very helpful to decide the most adequate moment of cuts and collection of residues.

4. Conclusions

The procedure here described ensures a rational and sustainable exploitation of the energy resources contained in the different forest formations existing in Galicia and it is very helpful to design energy transformation plants using as a fuel the biomass generated from forestry tasks. As main remarks:

- It ensures the availability of enough raw material and the obtention of economical benefit.
- The technology existing nowadays is good enough to be used.
- The type of the energy produced is high quality.

Energy maps help not only to elaborate energy exploitation campaigns but also to design prevention and forest fire fight methods.

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