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Spanish biofuels heating value estimation. Part II: Proximate analysis data

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HIGHLIGHTS

- Higher heating value is an important parameter to characterize biomass as a fuel.
- Data for 100 samples was experimentally determined.
- Equations to correlate ultimate and proximate analysis data and HHV were developed.
- Obtained experimental errors were under 5% in every case.

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ABSTRACT

Biomass is widely reported as a non-homogeneous fuel, with properties varying depending on its origin or the geographical region where it is obtained. Because of that, the development of predictive equations which are specific for the characteristics of certain regions' biomass is recommended. In this work, some correlations were obtained to relate the higher heating value (HHV) of a hundred Spanish-based biomass samples to their proximate analysis data. Some hybrid equations, using both proximate and ultimate analysis data are also proposed. Carbon, oxygen, ash and fixed carbon contents proved to be the most important values, while including moisture greatly improves them. As a result four equations were obtained with errors close to 5% for the tested samples, which representing a contribution to low cost routines to estimate and normalize the characterization of single or composed solid biofuels.

1. Introduction

In the current world energy scene, biomass presents some advantages, such as its neutrality concerning greenhouse emissions, its autonomy as a resource, avoiding dependence on foreign producers, its low NO_x and SO_2 emissions and its economic competitiveness with traditional fossil fuels [1,2]; that make it an attractive feedstock to effectively supply an important part of the huge energy demand.

Biomass sources may vary from sawdust to peach stone or maize grain originating in diverse kinds of industry, such as wood transformation, food conservation or crop wastes processing. Taking into account this heterogeneity, biomass characterization is needed to predict its behavior when used as a fuel.

Biomass properties can be classified into physical, chemical and thermal. While physical ones are to be studied by us in future works, chemical ones (such as ultimate and proximate analysis) are related in this work to a thermal one, that is higher heating value (HHV), probably the characteristic that better defines the suitability of solid biomass as a fuel.

In this way, **proximate analysis** refers to the moisture, ash, volatile matter and fixed carbon (or char) content, usually expressed in mass percentage, of the sample (see Fig. 1), while ultimate analysis measures the elemental composition of the sample in carbon, hydrogen, nitrogen, oxygen and sulphur (C, H, N, O and S) also in mass percentage.

As Fig. 2 shows, total moisture content (M) has two main contributions, one intrinsic and another extrinsic. Intrinsic or inherent moisture of a given substance is a thermodynamic property that depends on temperature and partial pressure of water in the environment. In complex materials such as the ones studied here, morphological and textural properties must be taken into account in order to interpret not only free and slight bounded moisture but slight variations in the shape of the equilibrium S-type curve. Water activity and thus, the temperature required for its removal depends on the water's degree of linking to the material: chemical bond, surface adsorption, or capillarity. Free moisture, or so called unbounded water under saturation conditions, can be physically removed by centrifugation, percolation or drainage, while linked moisture requires thermodiffusional procedures, such as transfer

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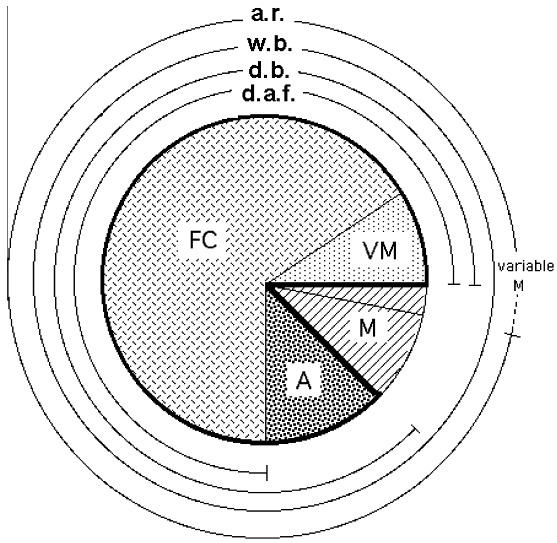

Fig. 1. Proximate fractions of biomass: (a.r) As received, (w.b.) wet base at laboratory contitions; (d.d.) dry base, (d.a.f.) dry ash free base; (FC) fixed carbon, (VM) volatile matter; (A), inerts as ash after incineration; (M) specified moisture content as a.r. or w.b.

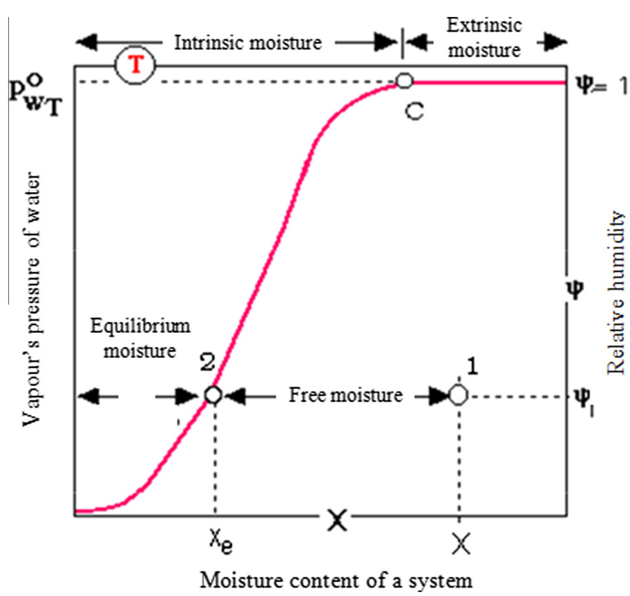

Fig. 2. Different kinds of moisture present in a sample.

to equilibrium at room temperature or above boiling temperature, that is in the range between 100 and 120 °C. Thus, sample moisture can be determined and expressed in three different conditions, as received (a.r.), that is with the moisture content at which the sample arrives to the laboratory, dry base (d.b.) after total moisture release and dry ash free (d.a.f.), or without moisture and ash [3]. The significant mass fractions (x) or mass relations (X) may be defined and calculated as habitually:

$$X = \frac{m_m}{m_d} = \frac{m_w - m_d}{m_d} \quad (1)$$

$$x_d = \frac{m_d}{m_w} = \frac{1}{1+X} \quad (2)$$

where; m_m, m_w and m_d are, respectively the weight of the sorbed water and the weights of sample at wet (w.b.) and dry base(d.b), as shown in Fig. 1.

The knowledge of biomass moisture is essential to determine the most adequate conversion technology for each case, i.e. thermal conversion processes require low moisture levels. In addition to this, moisture greatly affects fuel combustion behavior, plant management and design, since high moisture levels require a lot of energy for vaporization and they also produce high volumes of fumes due to inefficient combustion and supposed grinding problems for raw matter, which means higher energy consumption in pretreatment.

1.1. Moisture (M)

Moisture (M) adds non valuable weight to the fuel, so it decreases its effective bulk density, increasing transport costs and storing size. As evaporation is an endothermic process, moisture decreases fuel's useful energy content and combustion temperatures and, therefore, combustion's quality and efficiency.

High moisture content in fuels requires higher drying residence times, that implies larger chambers, affecting the entire design of the combustion system. Besides these facts, humidity increases the microbial respiration, decreasing fuels' physical quality, especially durability. In summary, it can be said that high moisture levels need larger equipment, creating more maintenance difficulties, decreasing combustion efficiency and increasing the process cost.

1.2. Volatile matter (VM)

Volatile matter (VM) can be considered as the fuel fraction (except moisture) released when it is heated at high temperature in the absence of air. It can come from the organic or inorganic yield of the biomass and is formed by a combustible part (gaseous C_xH_y, CO or H_2) and a non-combustible fraction (CO_2, SO_2, NO_x, H_2O and SO_3). Volatile matter influences the thermal decomposition and the plant design. High volatile contents make ignition easier at low temperatures, implying high reactivity and enriching the combustion process.

1.3. Fixed or non-combined carbon (FC)

Fixed or non-combined carbon (FC) is the fraction remaining after volatile matter is completely released, excluding ash and moisture, that burns forming char [4]. VM/FC ratio increases the degree of reactivity of the biomass. The higher this factor, the easier the ignition, and the lower the residence stage until combustion is completed.

1.4. Ash (A)

Ash (A) is the inorganic waste that remains after fixed carbon combustion. This parameter is influential in transport, handling and process costs. It affects the dust emissions, ash manipulation and combustion technology chosen, since it decreases HHV and combustion yield because of losses by poor combustion. High ash levels may generate slag deposits, creating higher thermal resistance to heat transfer and requiring more expensive equipment maintenance. In addition to this, depending on its composition, erosion may originate in chambers. Waste disposal and reuse may also be affected by composition, and in some cases these wastes can be used as fertilizers or in the concrete industry.

A first part of this work was focused on **ultimate analysis**. This consists in determining the carbon, hydrogen, nitrogen, oxygen and sulphur elementary composition of the studied samples, affecting higher heating value (HHV), gaseous emissions and ash composition of fuels. C, H and O are the most substantial components of biomass; high H/C ratio implies a high volatile content, while high O/C ratio implies a low volatile matter content [5], so C and H positively contribute to HHV, while O does so negatively.