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Full Length Research Paper

Use of banana tree residues as pulp for paper and combustible

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The aim of this work is to characterize banana tree residues and use it in pulping and combustion processes. The soda-anthraquinone pulping of the banana tree residues can be simulated by polynomial models, and then predict the pulp properties (yield, Kappa number, viscosity and brightness) as a function of operating variables (temperature 160 to 180°C, time 40 to 60 min and soda concentration 7.5 to 12.5%) with errors less than 20%. Operating under optimal conditions (160°C, 40 min and 7.5% soda), a pulp with 39.23% yield, 28.59 Kappa number, 48.25% brightness, 1149 ml/g viscosity, 48.0 Nm/g tensile index, 3.80 kN/g burst index and 4.83 mNm^2/g tear index was obtained. On the other hand, heating values (17751 kJ/kg), the flame temperature (1300 to 2400°C) and dew point temperature (48 to 54°C), of the different values of excess air used (10 to 50%) in combustion of the banana tree residues were determined and compared with other non-wood lignocellulosic materials. As a consequence, the price of energy obtained by combustion of these residues (3.38 10^{-6} €/kJ) was less than the price of coal (25.94 10^{-6} €/kJ) and much lower than those of fluid fossil fuels (>37.67 10^{-6} €/kJ).

Key words: Banana tree residues, pulp, paper, combustion.

INTRODUCTION

The banana tree residues from the felling operation consist of lignocellulosic material. The Spanish production of banana is around 387.000 tons/year. Considering that the "prune/fruit" relationship can be 0.8, the production of pruning can be more than 309.000 tons/ year (Rodríguez et al., 2010; Jiménez and Rodriguez, 2010).

Banana tree residues and crop residues in general, must be removed from the plantation for various reasons, such as pollution, pests, interference with soil cultivation, occupying large areas of soil cultivation, etc. (Rodríguez et al., 2010). In this removal, it is interesting to try to exploit the different fractions of waste, since in this way there may be benefits to reducing disposal costs.

The use of banana tree residues can be done in two general ways: by separating its components by fractionation, to be used separately or transformed without prior separation by physicochemical processes (combustion, pyrolysis, gasification and liquefaction) or biochemical processes (bioalcohol and biogas production) (Rodriguez et al., 2010; Jiménez and Rodriguez, 2010), or using them as reinforcements in cementitious matrix composites for affordable housing (Savastano et al., 2000; Arsene et al., 2007; Bilba et al., 2007).

In the process of separating its components, the most important use is to isolate the cellulose fibers for paper production. In this field, in recent years, it is a great concern for the integrated utilization of raw materials called biorefinery, consisting of the splitting of the various components of lignocellulosic materials and to use all of them in the production of paper using the traditional processes (such as Kraft) that use only a part of the cellulose. Thus, fractionation processes are investigated by heat treatments in a water medium (hydrothermal processes), which may lead to different products (food additives, drugs, sugar, ethanol, xylitol, furfural, etc.), and by pulping processes that do not use sulfur (such as soda pulping and the organosolv processes), which apart from obtaining pulp can separate lignin, which can be

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transformed into various chemicals (resins, polyurethanes, acrylates, epoxies, composites, etc.) (Caparrós et al., 2007; Dogaris et al., 2009; Alfaro et al., 2009; Quader and Lonnberg, 2005; Qiliang et al., 2008; Ziaie-Shirkolaee et al., 2008). This will improve performance and overall process economy.

Within classical pulping processes, the soda pulping is the most ancient and simplest, and is more suitable when using anthraquinone as a catalyst. The soda-anthraquinone pulping has been applied to various non-wood materials such as bagasse (Tapanes et al., 1985), empty fruit bunches (EFB) of oil-palm industry (Jiménez et al., 2009), tagasaste (Labidi et al., 2008), jute (Mahiuddin et al., 2005), sunflower stalks (López et al., 2005), wheat straw (Zhan et al., 2002), *Cynara cardunculus* (Abrantes et al., 2007), and various annual plants such as *Hibiscus cannabinus, Hibiscus sabdariffa, Sesbania aculeata, Crotalaria juncea, Tephrosia candida* and *Hesperaloe funifera* (Khan et al., 1996; Goswami and Saskia, 1998; Sánchez et al., 2010), etc., but no work on pulping of banana tree residues has been found in literature.

Despite the development of the internet and new information technologies, the consumption of cellulose pulp and paper has not suffered any decline in recent years, producing an increase of 10% in the last years of the last century, (Peters, 2003)

The use of lignocellulosics residual materials, such as, banana tree residues for the production of paper pulp is supported by the increasing consumption of this product, in effect, despite the development of the Internet and so-called new information technologies that is predicting a decline in consumption of paper, it rather grew by over 10% in the last 20 years of the last century (Peters, 2003), and 30% of paper consumed currently accounts for functions associated with the new trends information that non-existed ten years ago (http:/www.paperless.com). Moreover, while 90% of the raw materials for paper production are hardwood and softwood, in recent years the increase in the production of pulp from wood has been approximately 5%, compared to 10% or more of the non-wood pulp such as crop residues (FAO, 2007). In recent years, there has been a greater awareness in the use of alternative fibers material leading to a supply problem as well as high deforestation and replanting which can alter the ecological balance and climate change.

On the other hand, the virtually untapped potential of these biomass wastes as banana tree residues invites the development of processes which use them as energy sources. The energy potential of lignocellulosic materials can be exploited through the application of physico-chemical or biochemical processes, for the conversion of chemical energy into other simpler energies that are easier to learn (Rodriguez et al., 2010; Jiménez and Rodriguez, 2010). The easiest physicochemical process for the exploitation of lignocellulosic materials is combustion. The residual biomass of forests and agricultural waste (straw, stalks, stems, leaves, etc.) has been widely used as fuel for producing heat for heating or for producing steam or electricity in small industrial plants. These waste materials, at present, are still used as energy sources in combustion processes (Arvelakis and Kouki, 2002; Ozturk and Bascetinlik, 2006; Overend and Wright, 2008; Tock et al., 2010; Saidur et al., 2011; Li et al., 2012).

The aim of this study was to evaluate the optimal use of banana tree residues, by two ways: first by subjecting them to pulping process with soda-anthraquinone as pulping liquor, studying the influence of operating variables on the properties of the pulps and the corresponding paper sheets obtained from them; the second way is to use them as fuel, determining the heating values, flame temperature and dew point temperature of the combustion gases, comparing their values with those found for other lignocellulosic materials, coal and fossil fuels.

EXPERIMENTAL

Material

The banana tree residues were provided by the Agricultural Cooperative of Tenerife FAST, Spain. Banana tree (*Musa acuminate var. Dwarf Cavendish*) is a high herbaceous plant (2 to 16 m high), composed of long fibers strongly overlapping forming a pseudo-stem. Banana-trees produce generally large leaves (almost 2 m long and 30 to 60 cm wide) that were used in this work.

Analytical methods

Chemical analysis were carried out according to the following procedures: holocellulose (TAPPI T9m-54), lignin (TAPPI T13m-59), ethanol-benzene extractives (TAPPI T6m-59), ash (TAPPI T15m-58), volatile (UNE-32019); fixed carbon (difference between 100 and the sum of ashes plus volatiles). Elemental analysis was made using the Dumas method with a Eurovector “EA 3000” in the Spectroscopy Unit at the NIR/MIR Central Service for Research Support of the University of Córdoba.

Pulping and sheets making

Pulp was obtained by using a 15-L batch cylindrical reactor that was heated by means of electrical wires and was linked through a rotary axle (to ensure proper agitation) to a control unit including a motor actuating the reactor and the required instruments for measurement and control of pressure and temperature.

The banana tree residues were pulped in the reactor under certain conditions of soda concentration (7.5 to 12% w/w), anthraquinone concentration (1% w/w), temperature (160 to 180°C), time (40 to 60 min) and liquid/solid ratio (8:1 w/w). Next, the cooked material was fiberized in a wet desintegrator at 1200 rpm for 30 min and the screenings were separated by sieving through a screen of 1 mm mesh size.

Paper sheets were prepared on an ENJO-F-39.71 sheet machine according to the TAPPI 220 standard method.

Characterization of the pulp and paper sheets

The products (pulp and paper) obtained from the raw material were

Table 1. Elemental analysis and components analysis of banana tree residues.

Parameter (%)	Experimental*	Bilba et al. (2007)
Carbon	39.67	36.83
Hydrogen	5.65	5.19
Nitrogen	1.44	0.93
Sulfur	0.05	-
Cellulose	55.48	46.25
Lignin	22.25	15.07
Extractives	7.59	4.46
Ash	15.35	8.65
Volatile	70.14	-
Fixed carbon	14.51	-

*Percentage on weight. The values of the various experimental parameters are the average of three determinations, whose deviations with respect to the mean value are under of 5%.

characterized according to the following standard methods: yield (gravimetrically), viscosity (TAPPI T230-om-94), Kappa number (TAPPI T236cm-85), tensile index (TAPPI T494om-96), burst index (TAPPI T403om-97), tear index (TAPPI T414om-98) and brightness (TAPPI T525om-92).

Experimental design

To quantify the effects of variables a 2^n factorial design was used, consisting of a central experiment (in the centre of a cube) and several additional points (additional experiments lying at the cube vertices and side centers) (Montgomery, 1991).

Experimental data were fitted to the following second-order polynomial:

$$Y_e = a_0 + a_1 X_F + a_2 X_P + a_3 X_T + a_{12} X_F X_P + a_{13} X_F X_T + a_{23} X_P X_T + a_{11} X_F^2 + a_{22} X_P^2 + a_{33} X_T^2 \quad (1)$$

where Y_e denotes the response variables (viz; yield, Kappa number, brightness, viscosity, tensile index, burst index and tear index); X_T, X_t and X_S are the normalized values of the operational variables [temperature (T) time (t) and soda concentration (S) respectively); and a_0 to a_{33} are constants.

The values of the operational variables were normalized to values from -1 to +1 by using the following equation:

$$X_n = \frac{2(X-\bar{X})}{X_{max}-X_{min}} \quad (2)$$

where X_n is the normalized value of T, t and S; X is the actual experimental value of the variable concerned; X is the mean of X_{max} and X_{min}; and X_{max} and X_{min} are the maximum and minimum value, respectively, of such a variable.

Heating value

The gross calorific values (constant volume) were determined according to EN/TS 14918:2005 (E) Solid biofuels – method for the determination of the heating value, and UNE 164001 EX standards by using a Parr 6200 Isoperibol Calorimeter.

RESULTS AND DISCUSSION

Analysis of the banana tree residues

The results of the elemental analysis and the contents of cellulose, lignin, ethanol-benzene extractable, ash, volatile and fixed carbon for the raw material are presented in Table 1. Bilba et al. (2007) also analyze the banana tree residues (pseudo-stem core); the results are presented in Table 1. As it can be seen, there are many discrepancies, which may be due to several causes: (a) different variety of banana tree employed; (b) different fraction used (leaves, trunks or both mixture); (c) different methods of analysis used; (d) the presence of foreign materials such as sand, that can accompany the banana tree.

The carbon and hydrogen contents of banana tree residues (39.67 and 5.65%) were lower than those found in the literature for other agricultural residues (wheat straw -46.04 and 6.17%-, sunflower stalks -42.49 and 5.87%-, vine shoots -45.03 and 6.36%-, cotton stalks -46.16 and 6.08%, olive tree pruning -47.22 and 6.33%-). The nitrogen content was higher (1.44%) than those materials mentioned previously (0.50 to 1.26%). Finally, the sulfur content is low (0.05%), as for the materials considered (0.01% to 0.07%); it is important to note that this low sulfur content provide combustion gasses with a low SO_2 content, compared to gases from the combustion of fossil fuels (Jiménez et al., 1991).

The cellulose content of banana tree residues (55.48%) was lower than those of the materials previously considered (64.05, 61.22, 60.82, 63.01 and 60.6%, respectively for wheat straw, olive pruning, vine shoots, sunflower stalks and cotton plant stalks) but the lignin

Table 2. Values of operating variables used in the experimental design applied in the cooking of the banana tree residues with soda-anthraquinone and values of dependent variables.

Experiment	T (°C)	t (min)	S (%)*	YI (%)*	KN	BR (%)	VI (mg/L)	TE (Nm/g)	BI (kN/g)	TI (mNm^2/g)
1	170	50	10.0	26.5	69.2	45.8	600	9.0	0.64	1.60
2	180	60	12.5	14.7	23.9	47.6	400	3.0	0.34	1.12
3	160	60	12.5	20.4	44.3	46.8	480	6.0	0.43	1.76
4	180	60	7.5	20.3	40.5	47.1	469	3.0	0.43	1.77
5	160	60	7.5	27.5	69.9	44.1	613	10.0	0.56	1.99
6	180	40	12.5	22.6	46.7	46.2	487	6.0	0.35	1.21
7	160	40	12.5	30.0	76.6	44.1	815	17.0	1.14	2.84
8	180	40	7.5	29.0	74.5	45.1	613	15.0	0.96	2.26
9	160	40	7.5	38.2	92.2	43.3	1154	48.0	3.80	4.83
10	170	60	10.0	22.8	57.5	46.6	489	6.0	0.40	1.42
11	170	40	10.0	37.2	86.2	43.8	976	21.0	1.45	2.96
12	170	50	12.5	25.1	66.5	46.6	583	6.0	0.34	1.32
13	170	50	7.5	31.2	79.6	44.3	819	30.0	2.67	4.57
14	180	50	10.0	23.3	58.2	46.8	579	7.0	0.48	1.43
15	160	50	10.0	33.3	79.9	43.7	973	37.0	2.79	3.35

T, t and S, Temperature, time, and soda concentration, respectively; YI, yield; KN, Kappa number; BR, brightness; VI, viscosity; TE, tensile index; BI, burst index; TI, tear index. *percentage on weight. The values of the various experimental parameters are the average of three determinations, whose deviations with respect to the mean value are below 5%.

content was higher (22.25% vs. 14.46, 18.85, 21.62, 14.08 and 18.29% for wheat straw, olive pruning, vine shoots, sunflower stalks and cotton stalks, respectively). The extractives (7.59%) were low, compared to the materials considered (13.84 to 28.74%). The ashes (15.35%) were higher than those of the materials mentioned (3.72% for the vine shoots and 9.51% for sunflower stalks). Volatile substances (70.14%) were lower than those of the materials considered (74.63 to 88.25%), with the exception of the olive marc which is similar. Finally, the fixed carbon (14.51%) was lower than the materials considered (15.86 to 20.33%), but higher than the olive tree prunings (10.73%) (Jiménez and González, 1991).

Soda-anthraquinone pulping

Within classical pulping processes, the soda pulping is the most ancient and simplest, and is more suitable when using anthraquinone as a catalyst. The soda-anthraquinone pulping has been applied to various non-wood materials such as bagasse (Tapanes et al., 1985), EFB of oil-palm industry (Jiménez et al., 2009), tagasaste (Labidi et al., 2008), jute (Mahiuddin et al ., 2005), sunflower stalks (López et al., 2005), wheat straw (Zhan et al., 2002), *C. cardunculus* (Abrantes et al., 2007), and various annual plants such as *H. cannabinus, H. sabdariffa, S. aculeata, C. juncea* and *T. candida* (Khan et al., 1996; Goswami and Saskia, 1998), etc., but no work on pulping of banana tree residues has been found in the literature. Based on some of the works cited in the introduction, and after a few tentative experiments previous of the banana tree residues, the study of soda-anthraquinone pulping was carried out, and the obtained data presented are in Table 2. In all the-studies, we used a liquid/solid ratio of 8:1 and a concentration of 1% w/w anthraquinone. By fixing the experimental data into Equation 1, the following equations were obtained:

$YI = 26.81 – 3.95\ X_T – 3.34\ X_t – 5.13\ X_S$ ($R^2 = 0.89$; $F>19.47$; $p<0.0010$; $t>4.41$) (3)

$KN = 64.38 – 11.91\ X_T – 9.87\ X_t – 14.01\ X_S$ ($R^2 = 0.86$; $F>15.59$; $p<0.0023$; $t>3.95$) (4)

$BR = 45.46 + 1.08\ X_T + 0.74\ X_t + 0.97\ X_S$
($R^2 = 0.89$; $F>18.44$; $p<0.0013$; $t>4.29$) (5)

$VI = 670 – 149\ X_T – 90\ X_t - 159\ X_S + 81 X_T X_S$($R^2 = 0.86$; $F>5.36$; $p<0.0432$; $t>2.31$) (6)

Where YI is the yield, KN Kappa number, BR brightness and VI viscosity, X_T, X_t, X_S are normalized values of temperature, time and soda concentration, respectively and R^2, F, p and t are regression coefficient, Snedecor´s F, p-value (the probability of obtaining a test statistic by chance) and student t, respectively. The equations found for the tensile index, burst index and tear index are not adequately reproduced by the experimental results.

The values estimated using the previously enlisted equations reproduce the experimental results of the dependent variables with errors less than 14, 21, 2 and 19% respectively, for the yield, Kappa number, brightness and viscosity.

Table 3. Heating values of the banana tree residues experimentally determined by Equations 7 to 13, and the errors compared to recent experimental.

Experimental*	**17751**
Calculated equation 7	15853 (10.69%)
Calculated equation 8	17017 (4.14%)
Calculated equation 9	18015 (1.49%)
Calculated equation 10	20288 (14.29%)
Calculated equation 11	14774 (16.77%)
Calculated equation 12	14457 (18.56%)
Calculated equation 13	15708 (11.51%)

*The experimental value is the average of three determinations, whose values deviate less than 5 of the media.

The values of operating variables were determined by non-linear programming which provide optimal results (maximum or minimum) of the dependent variables for the range of values used in each variable. The yield and viscosity have maximum values (39.23 and 1149 ml/g, respectively) when operating at the minimum condition. In contrast, the Kappa number is low (28.59) and the brightness is maximum (48.25%) when the values of operating variables are high.

On the other hand, the influence that the temperature has on the tensile index, burst index and tear index can be observed (Table 2), by comparing the values of the experiments performed under identical conditions of time and soda concentration but at different temperatures, shows that these three dependent variables decrease with increasing temperature (compare data of tensile index, burst index and tear index from experiments 3 and 2; 5 and 4; 7 and 6; 9 and 8; 15 and 14; and 15 and 1). In Table 2, the experiments were compared at constant temperature and constant soda concentration at different times, and it was found that the values of stretch properties decrease with increasing time (compare data from experiments 6 and 2; 7 and 3; 8 and 4; 9 and 5; 11 and 10; and 11 and 1). Also, when we compared the experiments performed under constant conditions of temperature and time but with different soda concentration, it was found that the tensile, burst and tear index decreases with increasing soda concentration (the compared data from the experiments 4 and 2; 5 and 3; 8 and 6; 9 and 7; 13 and 12; and 13 and 1). Considering the foregoing, it follows that high values of the stretch properties require operation of the minimum values of operating variables. This is consistent with the values of the viscosity which also decreases with increasing values of operating variables.

From Equations 3 through 6, we may conclude that the operating variables that most influence the dependent variables were the soda concentration and temperature, and the least influenced is the pulping time.

Simulating the pulping process using Equations 3 to 6 we can propose several alternatives for the values of operating variables, so as to obtain pulps with features not far from their optimum values, while saving energy, reagents and capital investment for industrial facilities, operating with values of temperature, soda concentration and time processing less than the maximum considered, also achieving a better utilization of raw material than when operating under severe conditions. Thus, one possible compromise is good when operating with the low standardized values of the three operating variables (-1), since the viscosity, brightness and pulp yield variables decreased slightly or did not decrease at all, with respect to their maximum values. As such, it saves a lot of energy for heating the soda to the size required by the facility, which then result in less investment. Under the conditions specified are also achieved good values for the stretch properties of paper sheets, as shown in Table 2.

Energetic valuation

Heating values

Table 3 presents the experimental result of the heating values of banana tree residues. This value (17751 kJ/kg) is of the same magnitude or lower than those found in literature (Jiménez et al., 1991; Jiménez and González, 1991; Nieblas et al., 1990; Rey et al., 1993) for different lignocellulosic materials (wheat straw -18088 kJ/kg)-, sunflower stalks -16296 kJ/kg-, vine shoots -17941 kJ/kg-, cotton stalks -17857 kJ/kg-, olive tree prunings -18699 kJ/kg-, olive stones -19967 kJ/kg-, olive marc -21055 kJ/kg-, holm oak residues -20565 kJ/kg- and eucalyptus residues -20184 kJ/kg-). The lowest heating values of the banana tree residues, with respect to other mentioned lignocellulosic materials, were obtained due to their lower content of carbon, hydrogen, cellulose and extractives.

Empirical equations that predict the heating values (HV, kJ/kg) of lignocellulosic materials are found in literature (Jiménez et al., 1991; Jiménez and González, 1991):

$$HV = 393.81\ C + 230.22 \quad (7)$$

$$HV = 436.66\ C - 305.51 \quad (8)$$

$$HV = 173.89\ Ce + 266.29\ L + 321.87\ E \quad (9)$$

$$HV = 173.89\ Ce + 266.29\ (100-Ce') \quad (10)$$

$$HV = (1 - A/(Ce + L + E))\ (173.89\ Ce + 266.29\ L + 321.87\ E) \quad (11)$$

$$HV = 339.82\ T - 14308.93 \quad (12)$$

$$HV = 313.30\ T - 10814.08 \quad (13)$$

where C is the total carbon content (%), Ce, L, E and Z content of cellulose, lignin, extractives and ash (all in%),

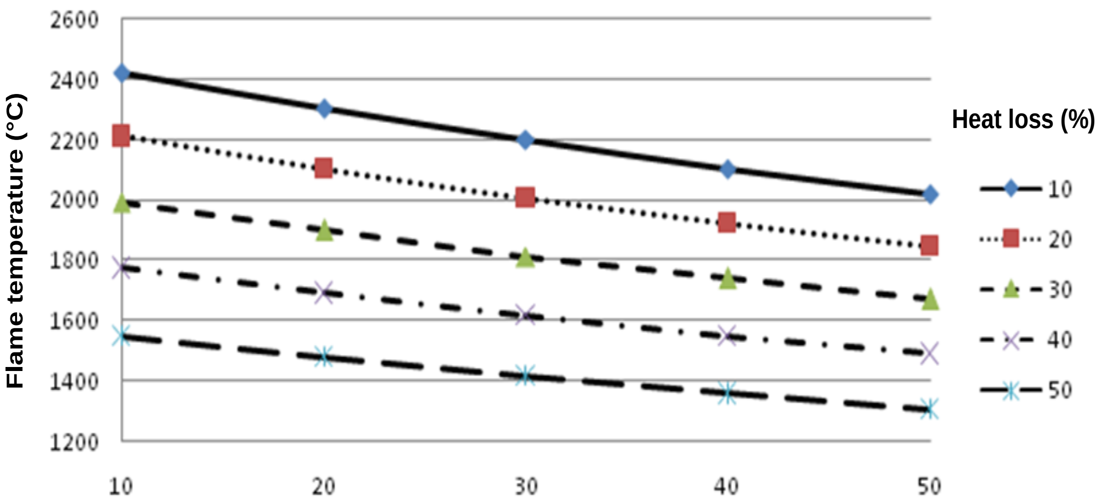

Figure 1. Variation of flame temperature for the banana tree versus excess air used in the combustion.

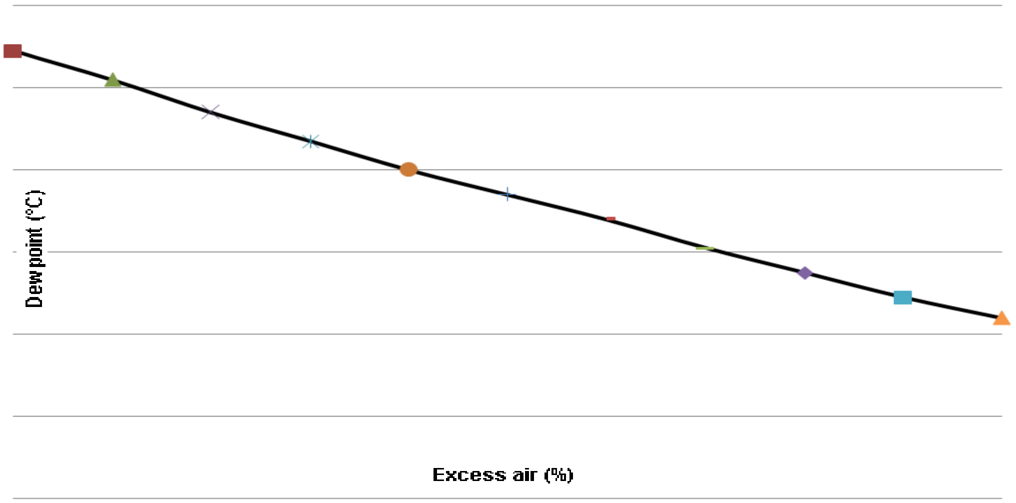

Figure 2. Variation of dew point temperature of combustion gasses as a function of excess air used in combustion.

Ce' the cellulose content on free base of extractives (%) and T the sum of the contents of volatile and fixed carbon.

The heating values presented in Table 3 were obtained by applying the experimental data (Table 1) in Equations 7 and 13 that shows the values of the errors in these estimates for the experimental values.

As noted, the Equations 8 and 9 were the ones that best reproduce the values of the heating values of the banana tree residues (with errors less than 4% in both cases).

Flame temperature and dew point temperature

Using the elemental analysis of the banana tree residues (Table 1) and following the estimation techniques described in the literature (Jiménez et al., 1991), the values of flame temperature and dew point temperature were determined, for the different values of excess air used in combustion (Figures 1 and 2). As can be seen from Figure 1, the flame temperature increases from about 1300 up to 2400°C when the heat losses and excess air were reduced (from 50 to 10% in both cases). Figure 2 shows that the dew point temperature decreases from 54 to 47°C, when excess air used in combustion increases (from 10 to 60%). The values of the flame temperature and dew point were of the same magnitude as those of other lignocellulosic materials (wheat straw, sunflower stalks, vine shoots, cotton stalks, olive wood and olive tree pruning) (Jiménez et al., 1991).

Table 4. Comparison of heating values and energy costs obtained by combustion of various fuel types.

Fuel	Heating values (MkJ/t)*	Cost of fuel (€/t)	Cost of the unit of heat (€/MkJ)
Banana tree residues	17.75	60	3.38
Orange tree	18.63	60	3.22
Orange tree pruning	16.87	60	3.56
Olive tree	19.11	60	3.14
Olive tree pruning	18.70	60	3.21
Hesperaloe funifera	17.76	60	3.38
Empty fruit bunches of oil-palm industry	19.05	60	3.15
Coal	25.94	100	3.86
Heating oil	37.67	800	21.24
Commercial propane	43.89	1650	37.59

*M = Million

The high values of flame temperature for all materials considered, demonstrate the possibility of using banana tree residues in the production of steam. The dew point is low for combustion, thus avoiding condensation in chimneys and flue pipes, preventing corrosion that could cause the condensation; anyway, in the event of such condensation, the phenomenon is not very serious considering the small sulfur content of the material. This is an additional advantage that makes these fuels clean.

Comparison of cost of the heat units obtained by combustion

Table 4 compares the heating values, unit cost of the fuel and cost of the heat units obtained by combustion of the different types of fuel (González et al., 2011).

As shown in Table 4, the prize of energy (MkJ) obtained by combustion of the lignocellulosic residues materials from agriculture and food industry is a little cheaper than that obtained from mineral coal and even much cheaper than the one obtained from fossil fuel fluids. Moreover, we should emphasize some of the advantages of the lignocellulosic residues studies: they are renewable and release very small amounts of sulfur dioxide in combustion gases and smaller amounts of ash than the solid fossil fuel, so, at worst, they are good competitors with fossil fuels.

Conclusions

The pulping of banana tree residue with soda-anthraquinone require a low cooking conditions (160°C, 40 min and 7.5% soda), providing a pulp with suitable properties (39.23% pulp yield, 28.59 Kappa number, 48.25% brightness, 1149 ml/g viscosity, 48.0 Nm/g tensile index, 3.80 kN/g burst index and 4.83 mNm^2/g tear index).

From an energetic study of the banana tree residue, it was deduced that banana tree residue have a heating values of 17751 kJ/kg, a flame temperature of 1300 to 2400°C and dew point temperature of 4 to 54°C, for different values of excess air (10 to 50%) used in combustion. These values are similar to other non-wood lignocellulosic materials. The price of the energy (kJ) obtained by combustion of these residues was less than coal and much lower than those of fluid fossil fuels.

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