SODA-ANTHRAQUINONE PULPING OF RESIDUES FROM OIL PALM INDUSTRY

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The main objective of the present work is to evaluate the suitability of soda-AQ process for pulping EFB (empty fruit bunches), viewed as an alternative raw material for pulp and paper production. To this end, a central composite design was used to study the influence of various operational variables – temperature (155-185 ºC), cooking time (30-90 min), soda concentration (10-20%), anthraquinone concentration (0-1%) and liquid/solid ratio (6:8) – during soda-anthraquinone cooking of EFB, on the pulp and paper sheet properties obtained.

The equations relating the dependent variables (pulp and paper sheet properties, yield, Kappa number, viscosity, beating degree, tensile index, stretch, burst index, tear index and brightness) to the independent ones (temperature, cooking time, soda concentration, anthraquinone concentration and liquid/solid ratio) were established, with errors below 15%, in all cases. The Kappa number range (10.8-74.3), viscosity (282-849 mL/g) and brightness (44.7-65.6%) of these cellulosic pulp materials are not appropriate for high-brightness printing papers. Instead, the physical properties (28.65 kN/g, 2.84%, 1.98 kPam^2/g, 0.54 mNm^2/g for tensile index, stretch, burst index and tear index, respectively) recommend the cellulosic pulp obtained from the soda-AQ process for strengthening the virgin fibre in recycled papers and also for developing certain types of packaging.

Keywords: non-wood, EFB, pulp, soda-anthraquinone, paper, experimental design

INTRODUCTION

In the beginning of the 1990s, it was thought that the development of new information technologies will decrease paper consumption. However, data of world paper and cardboard consumption do not support this statement, since the consumption increased[1] from 240 million tons/year in 1990 to 352 million tons/year in 2005, which means an increase of 47%.

Years ago, vegetable species like flax, cotton, white mulberry tree, bamboo and cereal straw were the main raw materials used for paper production. Wood species were not used until the middle of the 19th century, due to an increased paper demand, which was caused by printing press development. This fact challenged the search for different and cheaper raw materials. Nowadays, 90% of the cellulose fibres used to make paper come from wood species.[2] In the year 2000, the world pulp production from wood species was around 171.7 million tons while, in 2007, it exceeded 176.9 million tons, which means an increase of 3%. On the other hand, the world pulp production from non-wood species (straw, bagasse, esparto grass, flax, hemp, etc.) increased[3] from 15.5 million tons in 2000 to 18.4 million tons in 2007 (an increase of 18.7%).

In recent years, the environmental awareness of paper consumers has increased, and therefore not only an environmentally friendly production, but also the use of other raw materials are demanded. On the other hand, governmental organizations develop economic and human resources to research into the use of alternative raw materials.

Several authors[4-13] have studied the use of oil palm empty fruit bunches (EFB), rice straw, vine shoot, olive tree residues, sugar cane bagasse, etc., as alternative raw materials.

The use of such raw materials increases the added value of food and agriculture plantations by taking advantage of these residues (traditionally burnt) to obtain a high-demand product, and large paper variety, because of the different morphological characteristics of the fibres and of the chemical composition of these raw materials.

Of all alternative raw materials employed to produce pulp and paper, EFB has been chosen by many authors.[14-20]

The main EFB source is found in Malaysia, the greatest palm oil producer (51% of the worldwide production), which constitutes an important economic resource for this country. Cultures are also extending to countries of Western Africa (Nigeria, Guinea, Ghana, etc.), South America (Ecuador, Colombia, Honduras, etc.) and Asia (Thailand). The global production of oil palm has risen[3] from 22 million tons in 2000 to almost 39 million in 2007.

Palm plants start fruiting 4-5 years after planting; fruit production peaks at 20-30 years, after which it declines and the plants become unprofitable (especially because their fruits are too high to collect). Fruit bunches usually weigh 15-25 kg and contain 1000-4000 oval-shaped, 3-5 cm long fruits. Each hectare of oil palm produces an average of 10 t fruits per year, which give about 3000 kg of palm oil – as the main product[21] – and an important amount of EFB, which can be used for paper production.

In the present work, the soda-anthraquinone process was evaluated for pulp production from EFBs, an alternative raw material. First, oil palm EFBs were characterized by determining their contents of holocellulose, α-cellulose, lignin, 1% NaOH solubles, ethanol-benzene extractives and ash, and also their fibre length. Then, soda-anthraquinone pulping was assayed by an experimental factor design, to state the influence of operational variables during soda-anthraquinone pulping (*viz.* soda and anthraquinone concentrations, treatment temperature and time, and liquid/solid ratio) on the yield, viscosity, Kappa number and beating degree of the pulps, as well as on the tensile index, stretch, burst index, tear index and brightness of the paper sheets obtained.

EXPERIMENTAL

Raw material

EFBs have been obtained from African palm (*Elaeis guineensis*) provided by Straw Pulping Engineering S.L. of Zaragoza Company (Spain). Prior to chemical characterization and pulping, the raw material was washed, cleaned, sorted to remove foreign matters and air-dried, then stored to less than 50% relative humidity and aerated from time to time, to avoid rotting.

Raw material characterization

Following drying at ambient temperature, the raw material was cold-ground in a Retsch SM 2000 mill, to avoid altering of its composition. The ground product was sieved to select size fractions between 0.25 and 0.40 mm (No. 60 and 40 in the Tyler series). Particles larger than 0.40 mm are inefficiently attacked by the chemical reagents, whereas those below 0.25 mm can cause filtering problems.

The EFBs were characterized by analyzing their content of lignin, α-cellulose, hot water solubles, 1% NaOH solubles, ethanol-benzene extractives and ash, which were determined according to Tappi standards T-222, T-203 OS-61, T-207, T-212, T-204 and T-211, respectively. Also, their content of holocellulose, quantified by the method of Wise,[22] was determined. Fibre length was determined biometrically with a Visopan projection microscope, following cooking of the raw material in 10% soda, at 80 ºC for 1 h, and dyeing with 1% saffranin.

Experimental design

An experimental design involving several data points (tests) around a central composite point (control test) and some additional points (additional tests) was used to estimate the quadratic terms of a polynomial model. The design met the requirements that all parameters from the mathematical model should be estimated by a reasonable number of tests.[23]

The experimental design employed is defined by three parameters: number of variables, k; constant p, which takes value 0 for $k < 5$, and 1 for $k \geq 5$; number of central points, n_c. These parameters originate three sets of points:

- 2^{k-p} points, constituting a factorial design
- $2*k$ axial points
- n_c central points

The total number of points (experiments) shall be given by the following expression:

$$n = 2^{k-p} + 2*k + n_c$$

When parameter p is 1, a considerable reduction in the number of points of the factorial design may be observed, without affecting the determination of the first- and second-order parameters, according to the relationship:

$x_k = \Gamma_{j=1,k-1}\, x_i$

showing that the normalized values of variable k-th coincide with the product of the normalized values of variables k-1, for the points of the experimental design.[24]

The total number of tests needed for the five independent variables studied [*viz.* soda concentration (S), anthraquinone concentration (A), temperature (T), time (t) and liquid/solid ratio (R)] was 27.

The values of the independent variables were normalized to levels from -1 to +1 by using Eq. (1), facilitating a direct comparison of the coefficients and the assessment of individual effects that the independent variables may have on each dependent variable:

$$X_n = 2\frac{X - \bar{X}}{X_{\max} - X_{\min}} \qquad \text{(Eq.1)}$$

where X_n is the normalized value of S, A, T, t or R, X is the experimental value, $\bar{X}$ – the average value of maximum values ($X_{\max}$) and minimum values ($X_{\min}$).

The experimental data were fitted to the following second-order polynomial:

$$Y = a_0 + \sum_{i=1}^{n} b_i X_{ni} + \sum_{i=1}^{n} c_i X_{ni}^2 + \sum_{i=1,j=1}^{n} d_{ij} X_{ni} X_{nj} \qquad i<j$$

where Y denotes a characteristic or property of the pulp (yield, Kappa number, viscosity or beating degree) or paper sheets (tensile index, stretch, burst index, tear index or brightness), coefficients a_0, b_i, c_i and d_{ij} standing for the unknown characteristic constants estimated from the experimental results.

Pulping

The raw material was cooked in a 15 L batch reactor, where it was stirred by rotating the vessel *via* a motor connected through a rotary axle to a control unit, including measurement and control instruments of pressure and temperature. The vessel was furnished with an outer electrical heating jacket, to facilitate attainment of the working temperature (5 ºC/min).

Soda-anthraquinone pulping was selected due to its environmental and economic advantages (such as no unpleasant smell generation – since no sulphur compounds are used, a an increase in the pulp production – as lower cooking time values are needed to obtain the same pulp quality and high yield values), to make the implementation of this process possible in factories situated in the vicinity of agricultural areas, since it may be adapted for low productions and may be applied to any raw – wood or non-wood – material.

Also, the addition of small amounts of anthraquinone presents some advantages:[25,26] it increases delignification rate, stabilizes carbohydrates and ensures good chemical and physical characteristics in pulps and paper sheets. Anthraquinone acts as a redox catalyst of the reactions in which it is involved.[27,28] The electrons from the aldehyde groups of carbohydrates present in its fibres are transferred to the anthraquinone molecule, so that the aldehyde groups become carboxyl groups. This transformation makes the carbohydrates stable, increases the yield and avoids peeling. Due to the electron transfer, the anthraquinone passes into its reduced form, anthrahydroanthraquinone. The acceleration mechanism of delignification with anthraquinone involves the attack of the anthrahydroanthraquinone transitional and reactive structures of lignin.[29]

According to previous tests and to the suggestions of other authors,[7,14] the operation intervals of the five operational variables used during soda-anthraquinone cooking of EFB were selected, as follows: temperature (155, 170 and 185 ºC), time (30, 60 and 90 min), soda concentration (10, 15 and 20% o.d.), anthraquinone concentration (0, 0.5 and 1% o.d.) and liquid/solid ratio (4, 6 and 8).

After pulping, the cooked material was washed with water at room temperature to remove the residual cooking liquor and was fiberized in a disintegrator at 1200 rpm for 30 min, at room temperature and 10% consistency. The pulp was then beaten in a Sprout-Bauer refiner and the fiberized material was passed through a Sommerville screen model K134 to remove the uncooked particles.

Also, Kraft pulping was assayed using wood species (*Eucalyptus globulus* and *Pinus pinaster*), to compare the pulp and paper characteristics obtained from EFBs and wood species, in the most frequently industrially applied process – Kraft. The pulping conditions applied for *Eucalyptus globulus* were the following: 16% active alkali, 25% sulphidity, 170 ºC, 40 min, liquid/solid ratio: 4; and for *Pinus pinaster*: 20% active alkali, 30% sulphidity, 170 ºC, 40 min and liquid/solid ratio: 4.

Using EFBs as a raw material, a factor design has been assayed, to establish how many experiments are required to study the influence of the operational variation, during soda-anthraquinone cooking, on the pulp and paper properties.

Pulp and paper sheet characterization

The yield, Kappa number, viscosity and beating degree (in a Shopper-Riegler apparatus) of the pulps were calculated in accordance with UNE standards (*viz.* 57-034, 57-039 and 57-025, respectively).

The tensile index, stretch, burst index, tear index and brightness of the paper sheets obtained on an Enjo-F39.71 sheet former were calculated according to the UNE 57-054, 57-028, 57-058, 57-033 and 57-062 standards.

RESULTS AND DISCUSSION

EFB characteristics

Oil palm empty fruit bunches contain 4% hot water solubles, 40.2% soda solubles (1%), 1.8% alcohol-benzene extractable material and 3.2% ash.

Figure 1 plots the results of chemical analysis of EFBs as well as of some food and agricultural residues: rice straw, olive prunings, vine shoots, cotton stalks and sugarcane bagasse. Data on the holocellulose, α-cellulose and lignin values of the other raw materials were taken from literature.[30-33] Figure 1 shows that all raw materials showed a similar lignin content (around 20%). On the other hand, more variations were observed in the holocellulose and α-cellulose contents; also, cotton stalks showed the highest percentage of α-cellulose with respect to total holocellulose, followed by EFB. The hemicellulose/α-cellulose ratio is suitable for the production of cellulose pulp and paper, to promote swelling of the fibre and to increase its plasticity, flexibility and link ability, thus improving density and sheet properties.[2,34] Based on these results, it seems appropriate to use EFB as a cellulose source.

Comparing data from Table 1 on holocellulose, α-cellulose and lignin of EFB, *Pinus pinaster* (softwood) and *Eucalyptus globulus* (hardwood), it could be observed that EFB has slightly lower α-cellulose and lignin contents than *P. pinaster*, but very similar holocellulose contents. On the other hand, EFBs evidence slightly lower holocellulose and α-cellulose contents, but very similar lignin contents, as compared to *E. globulus.*[19,35-37]

Figure 2 illustrates the results of some characteristics of the EFB fibres; thus, Figure 2a shows an image of EFB fibres, obtained on a Visopan projection microscope, which permits observations on such fibres and on some typical vessels of this raw material. The vessels are elongated and narrow, typical of graminaceae, such as bagasse, bamboo, etc., raw materials used for producing cellulosic pulps. On the other hand, Figure 2b shows the distribution of EFB fibre length – one may notice that the most abundant EFBs are around 0.50-0.70 mm long.

The width of the EFB fibres was also measured, an average value of 14 μm being recorded (26 and 8 μm were the maximum and minimum values found). Considering these results[38] and knowing that hardwood has a length of around 1 mm and a width of around 17, it can be concluded that EFB fibre length and width are, respectively, around 40% and 18% lower (depending on the species) than hardwood. On the other hand, softwood fibre[39] is abound 3-5 mm long and abound 40 mm wide, meaning that EFB length and width are 75 and 65% lower, respectively, than those of softwood.

Table 1
Chemical analysis of EFBs, softwood and hardwood

Analysis	Non-wood	Softwood	Hardwood
(%)	EFB	*Pinus pinaster*	*Eucalyptus globulus*
Holocellulose	67.0	69.6	80.5
α-cellulose	24.5	26.2	20.0
Lignin	47.9	55.9	52.8

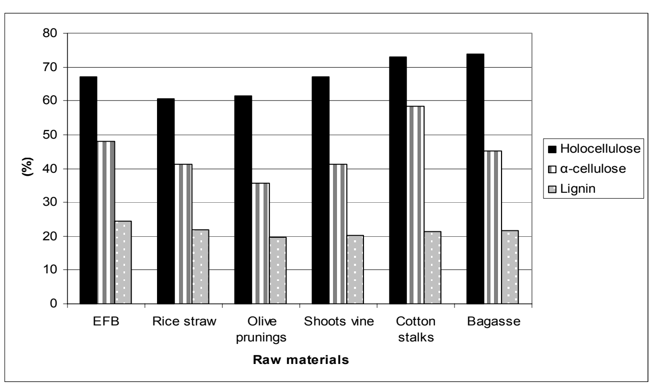
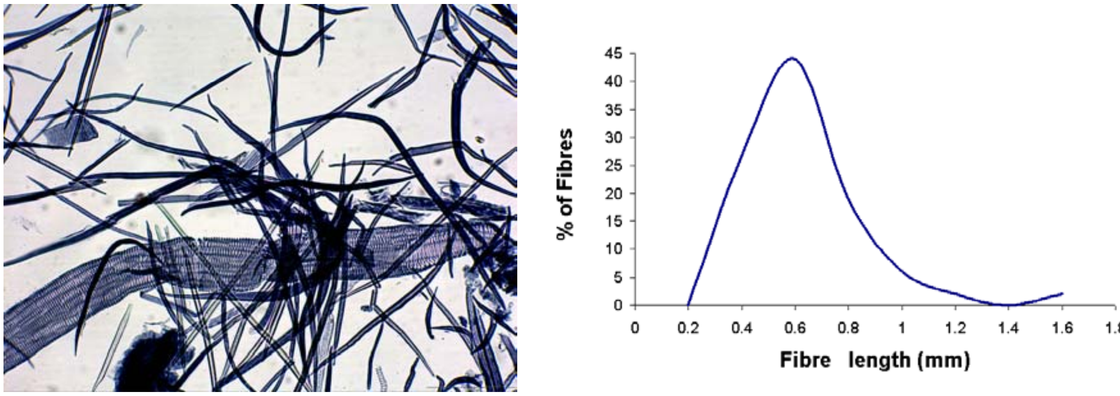


Figure 1: Chemical composition of different raw materials



a) b)

Figure 2: Empty fruit bunch fibres (10X)

Based on our results, as well as on literature data,[19,40] it can be concluded that EFBs may be used as a raw material for pulp and paper industry, since their biometric analysis results and composition are similar to those of wood species.

Pulp and paper sheet production

Tables 2 and 3 show the values of the operational variables used in the 27 tests required by the factor design, as well as the average result for each dependent variable of the pulp properties and for paper sheet properties, respectively.

Multiple regression analysis[41] of the experimental results with the BMDP© software, using all the terms of Eq. (2) – except those with Snedecor's *F* values and Student's *t* values less than 4 and 2, respectively – in conjunction with the stepwise[42] method, allowed the following equations, relating each dependent variable to the independent variables with a 95% confidence (the statistics for each equation are shown in brackets):

$$YI = 38.7 + 1.7X_A X_R - 2.5X_t - 3.0X_S - 3.7X_T \quad \text{(Eq. 3)}$$

(multiple-R = 0.98; R^2 = 0.96; fitted-R^2 = 0.95; p < 0.000; t > 6.56)

$$KN = 42.4 + 0.6X_T X_A - 0.8X_R - 1.9X_A - 7.8X_t - 9.4X_S - 12.2X_T \quad \text{(Eq. 4)}$$

(multiple-R = 0.99; R^2 = 0.99; fitted-R^2 = 0.99; p < 0.061; t > 1.99)

$$VI = 738 - 59X_t - 62X^2{}_R - 30X_S + 34X_R - 37X_t X_A - 40X_t - 40X_T - 44X_t X_S + 43X_A - 62X_T X_S - 69X_T X_t \quad \text{(Eq. 5)}$$

(multiple-R = 0.97; R^2 = 0.94; fitted-R^2 = 0.89; p < 0.021; t > 2.58)

$$SR = 14.8 + 0.9X^2{}_R + 0.5X_S X_A + 0.6X_A X_R - 0.6X_S X_R + 0.7X_t X_A - 0.7X_t X_R - 1.6X^2{}_A \quad \text{(Eq. 6)}$$

(multiple-R = 0.91; R^2 = 0.83; fitted-R^2 = 0.76; p < 0.018; t > 2.60)

$$TI = 24.63 - 0.91X_T X_S - 1.02X_t X_S - 1.07X_T X_t - 1.21X_R - 2.88X^2{}_T - 2.98X^2{}_S + 1.47X_R + 1.65X_A X_R + 1.94X_t \quad \text{(Eq. 7)}$$

(multiple-R = 0.96; R^2 = 0.93; fitted-R^2 = 0.89; p < 0.016; t > 2.67)

$$ST = 2.27 - 0.11X_A - 0.12X_T X_t - 0.46X^2{}_S + 0.34X_t \quad \text{(Eq. 8)}$$

(multiple-R = 0.94; R^2 = 0.89; fitted-R^2 = 0.87; p < 0.004; t > 3.19)

$$BI = 1.72 + 0.04X_S X_R - 0.05X_T X_A - 0.15X^2{}_t - 0.15X^2{}_T + 0.06X_A + 0.07X_S - 0.07X_T X_S + 0.08X_R - 0.08X_t X_R - 0.09X_T X_t + 0.10X_A X_R - 0.26X^2{}_S + 0.13X_t - 0.17X_t X_S \quad \text{(Eq. 9)}$$

(multiple-R = 0.99; R^2 = 0.97; fitted-R^2 = 0.94; p < 0.062; t > 2.06)

$$Ti = 0.47 + 0.02X_A X_R - 0.03X_t X_S - 0.03X_T X_S + 0.04X_t - 0.07X^2{}_S \quad \text{(Eq. 10)}$$

(multiple-R = 0.90; R^2 = 0.82; fitted-R^2 = 0.78; $p < 0.053$; $t > 2.05$)

$$BR = 59.7 - 0.6X_T X_t + 0.6X_t X_A + 0.6X_t X_R - 0.6X_S X_R - 1.4X^2{}_t - 1.7X^2{}_T - 0.8X_S X_A - 0.9X_T X_S - 2.4X_A X_R + 3.4X_t + 3.9X_S + 4.9X_T \quad \text{(Eq. 11)}$$

(multiple-R = 0.99; R^2 = 0.99; fitted-R^2 = 0.98; $p < 0.036$; $t > 2.32$)

where YI denotes pulp yield, KN – Kappa number, VI – viscosity, SR – beating degree, TI – tensile index, ST – stretch, BI – burst index, Ti – tear index, BR – brightness, and X_S, X_A, X_T, X_t and X_R – the normalized values of S (soda concentration), A (anthraquinone concentration), T (temperature), t (time) and R (liquid/solid ratio), respectively.

The linear programming implemented by More and Toraldo[43] allowed us to identify the normalized values of the independent variables providing the optimum values of the dependent variables for the pulp and paper sheets (Table 3). Consequently, the optimum results found within the interval assayed were 49.6%, 10.7, 882 mL/g, 17.1 ºSR, 28.65 Nm/g, 2.84%, 1.98 kPam^2/g, 0.54 mNm^2/g and 69.9% in screened yield, Kappa number, viscosity, beating degree, tensile index, stretch, burst index, tear index and brightness, respectively. The operational conditions corresponding to these optimum values are shown in Tables 2 and 3; as a function of the final use of the product, one or another set of conditions will be applied.

The yields obtained, sometimes with low values, are in line with the high value of soda (1%) extractives obtained in the chemical characterization of the EFB, which assumes a lower yield after cooking, because of the elimination of these compounds.

The high values of Kappa number, as well as the low degree of brightness, can be explained by the fact that lignin is harder to remove in its more condensed form, there remaining residual lignin of deep colour, or by the high content of hemicelluloses (Fig. 1) that can translate into a high xilan content,[44] possibly leading to hexenuronic acids, which might affect the determination of Kappa number.

Due to the viscosity, Kappa number and brightness values obtained, these pulps do not appear as suitable for the production of writing or press paper.

The slenderness ratio can justify the good physical properties found in paper sheets, although the most fibres have low length (0.50-0.70 mm). Some strength properties, such as tensile strength, bursting strength and folding endurance will not be greatly different, and no significant difference will occur between long and short fibres. Longer fibres also tend to produce more open sheets, due to their higher bulk and air permeability, as compared to shorter fibres.[45]

Finally, the *Eucalyptus globulus* and *Pinus pinaster* wood species were employed in Kraft pulping, to compare the pulp and paper characteristics obtained for EFBs and wood species. Table 5 shows a comparison between the optimum results found for soda-anthraquinone EFB pulps (Table 4) and the experimental values obtained for *Eucalyptus globulus* and *Pinus pinaster* Kraft pulps. Table 5 also evidences that soda-anthraquinone EFB pulps showed acceptable yield and viscosity values (similar to those obtained for *Eucalyptus globulus* pulp), which recommends them for the production of pulp and paper of suitable quality. It was also observed that soda-anthraquinone EFB pulp recorded slightly lower values of paper sheet properties than those obtained for *Pinus pinaster* Kraft pulp, yet higher than those obtained for *Eucalyptus globulus* Kraft pulp. On the other hand, soda-anthraquinone EFB pulp showed the highest brightness. Consequently, the optimum brightness reached by EFB soda-anthraquinone pulping was higher than that obtained by standard *Eucalyptus globulus* and *Pinus pinaster* Kraft pulping, without affecting the other pulp characteristics.

Table 2
Values of cooking variables and dependent variables for pulp properties

Experiment	T, ºC	T, min	Soda, % (d.w.)	Anthraquinone, % (o.d.)	Liquid/ solid ratio	Screened yield, %	Kappa number	Viscosity, mL/g	Beating degree, ºSR
1	170	60	15	0.5	6	39.2	41.1	765	15.0
2	155	30	10	1	4	45.5	70.2	599	10.0
3	155	30	10	0	8	46.3	74.3	507	17.0
4	155	30	20	1	8	44.3	49.1	817	15.0
5	185	60	15	0.5	6	37.0	29.7	681	15.0
6	170	60	15	1	6	37.8	42.1	728	14.0
7	170	30	15	0.5	6	40.1	52.7	701	15.0
8	170	60	10	0.5	6	41.3	51.9	849	14.5
9	185	30	10	1	8	42.4	44.8	823	14.0
10	185	30	20	1	4	32.1	28.6	728	13.0
11	170	60	20	0.5	6	37.6	33.9	643	15.0
12	170	90	15	0.5	6	37.6	34.0	667	15.0
13	185	30	20	0	8	32.5	28.6	593	14.0
14	170	60	15	0.5	8	38.8	42.6	757	16.0
15	155	60	15	0.5	6	42.3	53.8	793	14.0
16	185	90	10	0	8	33.6	32.4	645	14.0
17	170	60	15	0	6	39.6	45.1	693	13.0
18	155	90	20	0	8	36.3	38.7	689	12.0
19	185	90	20	0	4	31.4	15.8	282	15.5
20	155	90	20	1	4	34.5	36.8	688	15.0
21	185	90	20	1	8	29.0	10.8	376	15.0
22	155	90	10	1	8	43.9	51.2	706	15.0
23	185	90	10	1	4	33.0	31.0	561	14.0
24	155	30	20	0	4	42.5	54.8	588	15.0
25	155	90	10	0	4	44.7	60.6	640	14.5
26	170	60	15	0.5	4	39.3	40.1	605	16.0
27	185	30	10	0	4	43.0	49.1	615	14.0

Table 3
Dependent variables for paper sheet properties

Experiment	Tensile index, Nm/g	Stretch, %	Burst index, $kPam^2/g$	Tear index, mNm^2/g	Brightness, % ISO
1	21.6	2.00	1.61	0.42	60.6
2	8.7	1.24	0.49	0.26	45.8
3	14.9	1.46	0.51	0.31	44.7
4	22.5	1.24	1.65	0.46	46.9
5	20.8	2.12	1.51	0.45	62.5
6	24.1	2.11	1.85	0.48	60.9
7	22.8	1.86	1.44	0.38	55.8
8	21.6	1.99	1.47	0.44	55.5
9	21.9	1.66	1.18	0.39	53.8
10	14.0	1.38	1.01	0.29	64.0
11	23.1	1.88	1.47	0.41	61.9
12	27.5	2.97	1.72	0.55	61.3
13	19.5	1.73	1.40	0.36	64.0
14	25.6	2.46	1.90	0.48	60.7
15	24.0	2.27	1.64	0.49	54.0
16	19.2	2.20	1.27	0.43	63.4
17	23.9	2.28	1.50	0.47	58.0
18	20.7	2.14	1.15	0.43	63.0
19	18.4	2.14	1.09	0.36	65.1
20	19.5	2.08	1.32	0.40	63.3
21	20.8	1.73	1.20	0.38	65.6
22	23.5	2.22	1.48	0.47	50.7
23	20.0	1.92	1.30	0.51	63.9
24	16.6	1.48	1.02	0.42	52.7
25	22.6	2.46	1.48	0.44	45.9
26	25.8	2.35	1.69	0.50	60.0
27	16.5	1.69	0.93	0.35	52.5

Table 4
Values of operational conditions used in soda-anthraquinone EFB pulping
to obtain optimum values of dependent variables related to pulps and paper sheets

Dependent variable	Optimum value of dependent variable (maximum or minimum*)	Normalized values of independent variables for obtaining optimum values for dependent variables				
		X_T	X_t	X_S	X_A	X_R
Yield, %	49.6	-1	-1	-1	±1	±1
Kappa number	10.7*	1	1	1	1	1
Viscosity, mL/g	882	1	-0.86	-1	1	0.27
Beating degree, ºSR	17.1	-	1 -1	1 -1	0.19 -0.19	-1 1
Tensile index, Nm/g	28.65	-0.16	1	-0.15	1	1
Stretch, %	2.84	-1	1	0	-1	-
Burst index, $kPam^2/g$	1.98	-0.25	0.13	0.2	1	1
Tear index, mNm^2/g	0.54	1	1	-0.43	-1	-1
Brightness, % ISO	69.9	1	1	1	-1	1

Table 5
Comparison between experimental values obtained for eucalyptus and pine Kraft pulps and optimum values obtained for soda-anthraquinone EFB pulps

	Yield, %	Kappa number	Viscosity, mL/g	Beating degree, ºSR	Tensile index, Nm/g	Stretch index, %	Burst index, kN/g	Tear index, mNm^2/g	Brightness, % ISO
Eucalyptus globulus Kraft*	51.5	15.5	832	12.3	23.53	0.70	0.22	0.24	59.4
Pinus pinaster Kraft**	40.9	28	575	12.8	38.03	2.87	3.23	1.32	54.9
EFB Soda-Aq***	49.6	10.7	882	17.1	28.65	2.84	1.98	0.54	69.9

* 16% active alkali, 25% sulphidity, 170 ºC, 40 min and 4 liquid/solid ratio
** 20% active alkali, 30% sulphidity, 170 ºC, 40 min and 4 liquid/solid ratio
*** Optimum conditions in different processes

CONCLUSIONS

The chemical composition of empty fruit bunches (EFBs) allows their use as raw materials to produce cellulosic pulps.

In the ranges of the operational variables considered (155-185 ºC, 30-90 min, 10-20% soda, 0-1% anthraquinone and 6-8 liquid/solid ratio), the optimum values obtained for EFB pulp and paper properties, by soda-anthraquinone pulping, were as follows: 49.6%, 10.7, 882 mL/g, 17.1 ºSR, 28.65 kN/g, 2.84%, 1.98 $kPam^2/g$, 0.54 mNm^2/g and 69.9% for yield, Kappa number, viscosity, beating degree, tensile index, stretch, burst index, tear index and brightness, respectively.

The ranges of Kappa number (10.8-74.3), viscosity (282-849 mL/g) and brightness (44.7-65.6%) of these cellulosic pulp materials are not appropriate for the manufacture of high-brightness printing papers, while their physical properties (28.65 kN/g, 2.84%, 1.98 $kPam^2/g$, 0.54 mNm^2/g for tensile index, stretch, burst index and tear index, respectively), permit the conclusion that the cellulosic pulp obtained from soda-AQ processes can be used to strengthen the virgin fibre in recycled papers and to develop certain types of packaging.

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