Papermaking potential of hardwood pulps for decorative paper: a comparative study

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ABSTRACT: The papermaking potential of short-fibered pulps is evaluated with regard to the production of decorative paper for lamination. The approach follows two strategies, one based on pulp characterization under two extreme beating conditions and the other based on the evaluation of decorative papers produced in a pilot paper machine. The papers produced with eucalyptus fibers exhibited superior properties for this application as a result of better structural and strength properties. Among the eucalyptus pulps tested, the Iberian pulps appeared to be particularly well suited for this product, with a slight advantage for the Portuguese Eucalyptus globulus pulp.

Application: Portuguese eucalyptus pulp is a favorable and appropriate furnish to select for producing decorative paper for lamination.

In Portugal, most of the pulp produced is from *Eucalyptus globulus*. This pulp is commonly used for high-quality printing and writing papers, but it is also being used today for decorative papers for laminated products. This relatively new application for Portuguese pulp prompted this study. Our objective was to evaluate the suitability of different hardwood kraft market pulps as raw material for decorative papers.

DECORATIVE PAPERS

Decorative papers are used as components of decorative surfaces (laminates) on furniture, flooring, interior design, and facades. These highly complex specialty papers have become increasingly important. The demands on the functional properties can vary enormously, depending on the different areas of use and processing technologies involved, but decorative paper is always the starting material of the paper-based surfaces.

The paper can be pre-impregnated in the paper machine and subsequently printed and used as paper foil, or it can be printed first and impregnated afterwards [1]. In either case, the resin with which these papers are impregnated gives the laminate an extremely high resistance to scratches, impact, and heat [2, 3]. Here, we will limit our considerations to the print base papers.

Decorative paper consists of fibers that are low in lignin along with inorganic fillers (up to 40%). Such a high filler content, which does not contribute to the paper strength, requires a strong pulp. However, decorative papers also require good optical properties and good printability. Good printability requires a smooth surface and a certain degree of porosity to improve the absorption of inks and resins [1, 4]. In short, decorative paper should meet the following requirements:

- High opacity
- Optimum printability
- Quick resin absorption
- Sufficient wet strength
- Good runnability
- Color consistency
- Good surface smoothness
- Light and temperature fastness.

These properties are normally obtained by using short-fiber hardwood pulps reinforced with long-fiber kraft pulps (up to 20% for decorative paper and up to 40% for pre-impregnated paper). Inorganic pigments are used to improve paper brightness, opacity, and smoothness. The pigment most commonly used is titanium dioxide because of its high light-scattering coefficient.

EVALUATING THE PULP'S POTENTIAL

Measurements traditionally used to characterize pulps include drainage resistance and fiber length distribution. Handsheets created from the pulps are then tested for structural, strength, and optical properties. The results obtained are frequently presented as a function of beating time or drainage resistance and are compared at given levels of drainability.

This approach is not the most appropriate for testing the suitability of pulps for a specific application. However, the results can be handled in a nonconventional way, leading to an improved pulp characterization technique [5, 6]. Even if only conventional tests are applied, the pulp's papermaking potential can be evaluated by using pairs of properties. These pairs must involve relevant quality parameters for the paper grade under study. This method is particularly effective when the properties vary in opposite directions with beating.

If beating is performed at two different levels of specific edge load and if the energy input is varied at each load level, two sets of beating curves are derived. Provided the refining conditions used in practice are between the two levels tested, the area between the two curves, in terms of its position and size, gives a good indication of the papermaking potential of the pulp with respect to the properties of interest [5].

The strategy we adopted to evaluate the pulps is based on plots of two pairs of pulp properties relevant to decorative paper. The evaluation is also based on the comparison of properties measured on paper samples manufactured in a pilot paper machine.

EXPERIMENTAL

Six fully bleached, kraft, short-fibered market pulps were used in this study: four eucalyptus pulps, from Portugal, Spain, Brazil, and Chile, one birch pulp from Finland, and one Indonesian tropical mixed hardwood (TMHW). The pulps from Portugal, Spain, and Chile are based on *E. globulus*, whereas the pulp from Brazil is mainly *E. urograndis*. The samples were characterized with respect to certain physical and chemical parameters.

Eucalyptus	Fiber length,[a] mm	Fiber diameter (dry), mm	Flexibility index[b] (dry)	Fines (200 mm), % n/n	Coarseness, mg/100 m	Viscosity, mL/g	Pentosans, %
Portugal	760	15.6	55.8	13.3	8.4	1004	17.9
Spain	780	16.6	45.8	16.8	9.2	948	18.1
Brazil	683	15.2	44.7	15.8	7.9	887	15.7
Chile	693	16.3	57.5	14.9	8.4	841	17.5
Birch	857	19	58.5	16.6	11.5	655	22.1
TMHW[c]	927	20	51.9	47.2	12.8	563	9.8

[a]Length weighted. [b]Defined as the lumen diameter divided by the fiber diameter, multiplied by 100. [c]Tropical mixed hardwood.

I. Physical and chemical properties of pulps studied.

Fiber length, fines content, and coarseness were measured in a Kajaani FS 200 apparatus. Fiber cross dimensions were measured by optical microscopy. Pulp viscosity was determined according to ISO 5351-1, and pentosans were analyzed as specified by TAPPI T 223.

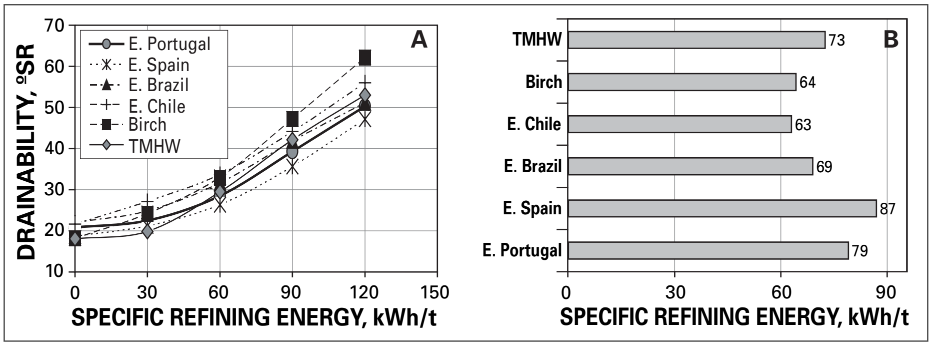
After disintegration (ISO 5263), pulp samples were refined in a conical pilot Escher Wyss refiner. Specific edge load theory (SEL) was used to define the refining intensity. The pulps were treated at two different and extreme values: 0.8 J/m and 3.0 J/m [7]. At each load level, the specific energy consumption was varied between 0 and 120 kW·h/ton. Samples of pulp slurry were collected for testing at 0, 30, 60, 90, and 120 kW·h/ton. The Schopper-Riegler method (ISO 5267-1) was used to quantify the degree of refining of the fiber suspensions.

We made conventional handsheets (ISO 5269-1) to evaluate their physical properties. Conditioned laboratory sheets (ISO 187) were tested for basis weight (ISO 5270), thickness (ISO 534), specific volume (ISO 534), air permeance (by the Gurley method, ISO 5636-5), tensile strength (ISO 1924-2), tearing strength (ISO 1974), and optical properties [8].

Decorative paper (100 g/m²) was produced from each pulp in a pilot machine (at 1 m/min), with the exception of the mixed hardwood. The furnish composition was as follows: short fiber (28.5% w/w), long fiber (5% w/w *P. radiata*, supplied by Arauco), titanium dioxide suspension at pH 9.4 (65% w/w), and wet-strength resin (1.5% w/w).

The short and long fibers were refined together in a conical pilot Escher Wyss refiner at a consistency of 4.5% and SEL of 1.2 J/m to 35 °SR. The final pH was adjusted to 6.0 with sulfuric acid, and the ash content was monitored during the paper production.

Basis weight, thickness, specific volume, air permeance by Gurley method,



1. (A) Drainability vs. specific refining energy at SEL = 0.8 J/m for different pulps. (B) Specific energy required to reach a freeness of 35°SR at SEL = 0.8 J/m.

dry breaking length in the machine direction (MD), and tear resistance in the cross-machine direction (CD) were determined in these samples. The test methods were the same as those used for the handsheets. Additionally, paper sheet porosity was measured by mercury porosimetry (in a Micromeritics Poresizer 9320), and resin absorption was evaluated as a percentage of weight increase.

RESULTS AND DISCUSSION

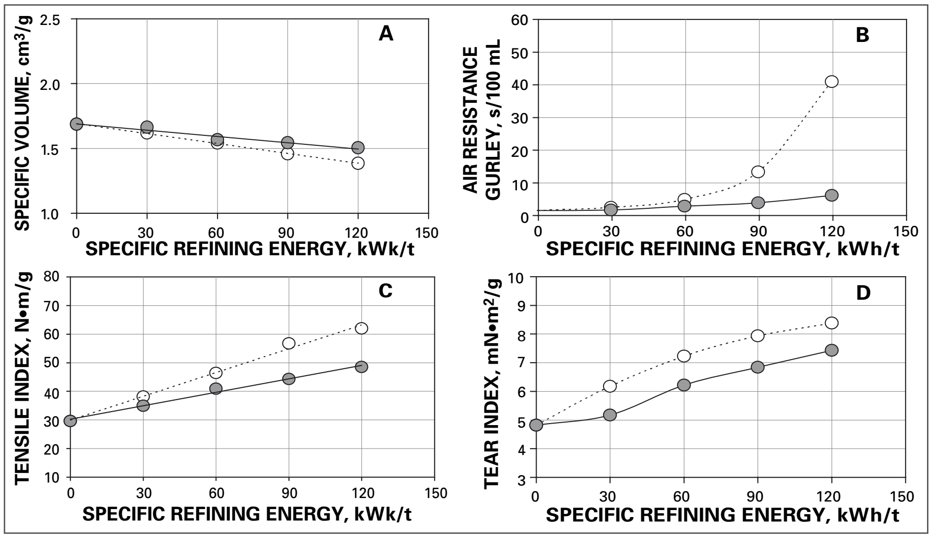
Table I presents some morphological and chemical parameters of the various pulps studied. As this table indicates, eucalyptus fibers are shorter and narrower than those of birch and tropical mixed hardwood. Eucalyptus fibers also exhibit lower coarseness. Among the eucalyptus pulps, the Iberian ones have the longest fibers. The highest content of fines was found for the tropical mixed hardwood pulp (about three times more fines).

As for the chemical characteristics, eucalyptus pulps present the highest values for viscosity, especially the Iberian pulps. The viscosity of the tropical mixed hardwood is probably underestimated since there was some evidence that not all the fibers were completely dissolved in the cupriethylene diamine solution. Birch had the highest pentosan content, and the mixed hardwood pulps had the lowest.

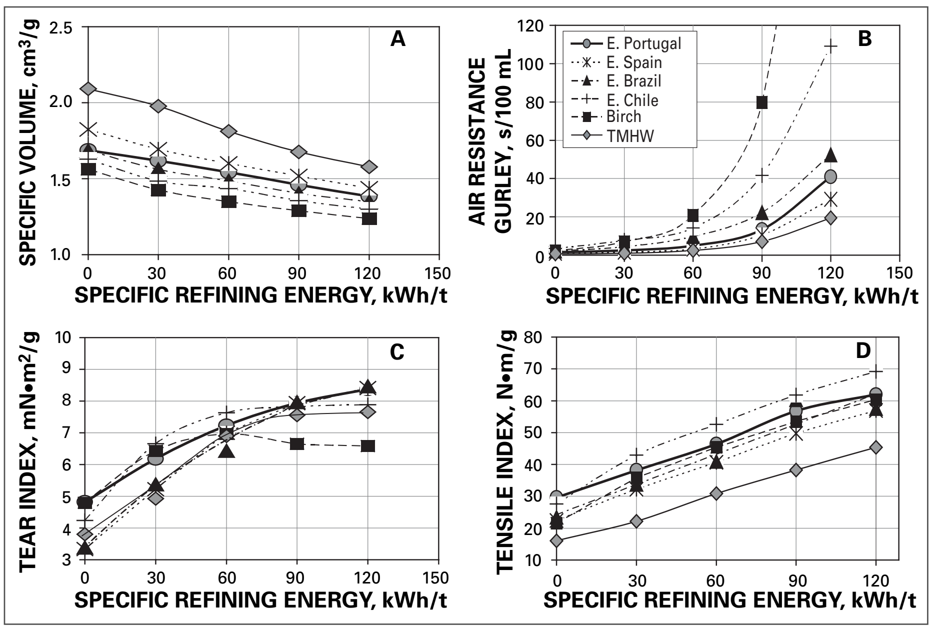
We first evaluated pulp quality in the traditional way, by plotting drainage resistance and physical properties of the pulp handsheets as a function of the specific beating energy consumption. In terms of data dispersion, the mean values of the coefficients of variance were as follows: 0.87% for drainability, 1.30% for specific volume, 6.73% for air resistance, 7.96% for tensile index, and 6.50% for tear index.

In **Fig. 1**, Graph A, pulp drainability is plotted against specific refining energy at the lowest SEL. Although all curves show an increase in freeness (°SR) with beating, their relative positions reveal that the effect that beating has on drainability is more marked for the birch, probably as a result of the high pentosans content of these fibers. Eucalyptus pulps exhibit approximately parallel behaviors. The curve of the tropical mixed hardwood pulp, despite the high content of fines of this pulp, is close to those of the eucalyptus. Identical tendencies were detected for the highest SEL (3.0 J/m), but the absolute values of freeness were lower, which is in agreement with the findings of other researchers [9, 10].

Graph B compares the specific energy required for each pulp to reach 35°SR, which is a normal value for the pilot paper machine. This figure indicates that Iberian pulps consume the most refining energy, whereas the pulp from Chile requires the least.



2. Papermaking properties vs. specific refining energy at different beating loads for Portuguese pulp. (Dashed curve, SEL = 0.8 J/m. Solid curve, SEL = 3.0 J/m.)



3. Papermaking properties vs. specific refining energy at SEL = 0.8 J/m for different pulps.

In light of the functional requirements for decorative paper, the structural and strength properties of the pulp are quite important for this paper grade. Although other properties have been tested [8], only the specific volume, air resistance, tensile index, and tear index will be considered here.

Figure 2 presents a plot of these properties for the Portuguese pulp at different energy levels for each specific edge load. The area between the curves represents the papermaking potential pertaining to these properties. As this figure shows, air resistance is most affected by changes in refining intensity (largest area between the curves), whereas specific volume is practically independent of the SEL value. Once again, the benefits of low specific edge load refining are evident for the short-fibered pulps studied.

Figure 3 illustrates the papermaking properties of the different pulps as a function of the energy input at the lowest refining intensity. Several differences can be noticed. With respect to the structural properties (Graphs A and B), eucalyptus pulps present curves that are in between those of birch and tropical mixed hardwood, with TMHW corresponding to the highest specific volumes and the lowest air resistances.

Concerning tearing strength, the curves for the eucalyptus pulps are ascendant, in general, as Graph C shows. The birch pulp achieves a maximum at about 60 kW·h/ton and decreases afterwards. The mixed hardwood pulp reaches a plateau at the highest energy inputs.

As for the tensile strength (Graph D), eucalyptus pulps generally exhibit the largest values. The pulp from Chile had the highest values, and the mixed hardwood pulp had the lowest values.

Although eucalyptus pulps require more beating energy to attain the same freeness, they produce handsheets that are bulkier and more permeable than those produced from birch. Eucalyptus pulps also develop better strength properties than birch pulps develop.

The higher density of the birch handsheets was expected, since birch fibers are more flexible (Table I) and conform more easily than the fibers of eucalyptus. This outcome is in keeping with the behavior observed for drainability (Fig. 1). However, contrary to the results of other research [9, 11], birch pulp did not show mechanical properties superior to those of eucalyptus pulps. Compared to the eucalyptus pulps, the mixed hardwood pulp exhibits inferior mechanical strength and higher structural properties, presumably as a result of the higher content of fines and fiber coarseness and lower hemicellulose content.

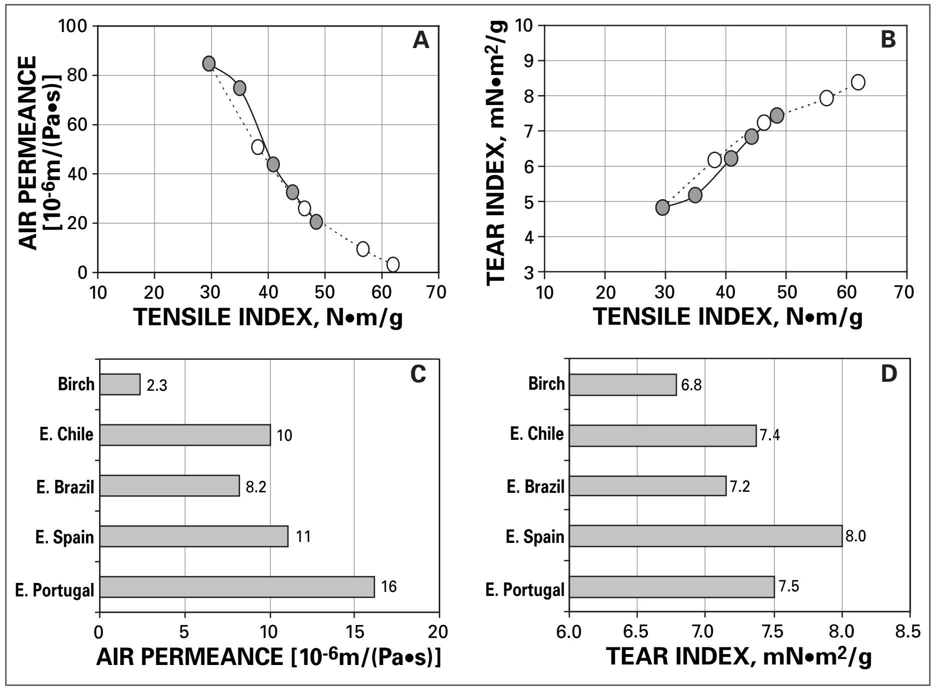
Papermaking potential of the pulps

As mentioned, we evaluated the pulps' potential for the production of decorative paper by performing conventional tests on pulp handsheets, based on properties relevant to the product. We also measured relevant properties on paper manufactured in a pilot paper machine.

The pairs of properties selected were (a) air permeance vs. tensile index and (b) tear index vs. tensile index. Tensile strength is the common property in both pairs since it closely reflects the increase in the bonding ability of the fibers with beating. Besides, it is not as sensitive to external factors as is the drainability, for instance [5].

Figure 4 presents the plots of these pairs of properties at different loads for the Portuguese pulp. As can be seen, the area between the curves is quite narrow in both cases. If refining were extended to larger energy values, such as 150 kW·h/ton, differences between the two curves would probably be more apparent.

The comparison is better illustrated in Graphs C and D of Fig. 4, where air permeance and tear index are compared at a given tensile index (50 N·m/g [12]). (The tropical mixed hardwood was not included in this comparison because this pulp did not reach the selected value of tensile index.) As these figures show, birch produced highly compact sheets that had strength properties inferior to those of eucalyptus. Among the eucalyptus pulps, Portuguese and Spanish pulps combine high air permeance with high strength, which are important quality requirements for the decorative paper. However, to achieve equal strength, the pulp from Chile requires the least refining energy, and the Spanish pulp requires the highest refining energy, which is in agreement with the pulp results of Fig. 1B.



4. (A) Air permeance (Gurley) vs. tensile index for the Portuguese pulp at different beating loads. (B) Tear index vs. tensile index at different beating loads for the Portuguese pulp. (Dashed curve, SEL = 0.8 J/m. Solid curve, SEL = 3.0 J/m.) (C) Air permeance for different pulps for a tensile index of 50 N•m/g at SEL = 0.8 J/m. (D) Tear index for different pulps for a tensile index of 50 Nm/g at SEL = 0.8 J/m.

Eucalyptus	Specific volume, cm^3/g	Air resist-ance, s	Breaking length, m	Tear index, nN·m^2/g	Resin absor-ption, %	Porosity, %
Portugal	1.23	10	4190	5.3	114	55.4
Spain	1.25	10	3619	3.3	116	56.1
Brazil	1.2	15	4531	4.7	110	54.7
Chile	1.16	21	4984	3.8	108	53.6
Birch	1.12	33	4052	5.5		53.3
Coeff. of var.	5.83	5.09	3.91	3.64	6.37	—

II. Properties of decorative papers produced in a pilot paper machine with different pulps, along with mean values for the coefficients of variation.

Decorative paper properties

The different pulps were used to produce decorative paper on a pilot paper machine, and the resulting papers were characterized in much the same way the corresponding pulp handsheets were characterized. Additionally, resin absorption and paper porosity tests were performed. These results are presented in **Table II**.

Although the papers made with fibers from Iberian eucalyptus possess higher bulk and air permeance, as a consequence of the higher porosity, South American pulps give rise to papers with better mechanical strengths. This outcome contradicts somewhat the conclusions withdrawn from the pulp tests (Figs. 4C and 4D). However, the results obtained for paper sheets cannot be directly compared to those of the pulp handsheets for two reasons. First, the paper sheets are fiber oriented. Second, the comparison of pulps was made at a given level of tensile strength.

In following the strategy of evaluating the pulp based on pairs of relevant properties, we decided to adopt a papermaking potential index, I_{ppt}. This index is defined as the dry breaking length divided by the air resistance (Gurley). This index combines strength and structural characteristics at the same degree of freeness (35°SR). The values of I_{ppt} were calculated from Table II: 419, 362, 302, and 237 for eucalyptus pulp from Portugal, Spain, Brazil, and Chile, respectively, and 123 for birch pulp. The coefficient of variation was 6.42%.

These results indicate that papers produced with pulps from Iberian eucalyptus exhibit high mechanical resistance and low air resistance. In other words, these pulps are the most appropriate for this paper grade. The Portuguese pulp showed a slight advantage.

CONCLUSIONS

To evaluate the potential of pulps for use in decorative paper, we tested the pulps after submitting them to different beating conditions. We also tested the decorative papers produced from the pulps in a pilot plant.

In the tests on the pulps, the eucalyptus pulps presented some similarities among themselves. However, eucalyptus pulp is different from birch pulp, which produces very dense sheets, and from tropical mixed hardwood pulp, which exhibits low strength. Nonetheless, eucalyptus pulps could be divided in two different groups: Iberian pulps, which present good structural properties, and South American pulps, which perform better in terms of mechanical strength.

As a comparison study performed at a given tensile index revealed, Iberian pulps require more beating energy but present the best combination of structural and mechanical properties.

The same conclusions were obtained from the results of the paper sheets produced in the pilot machine, confirming that the testing procedure was adequate to evaluate the papermaking potential of the pulps. **TJ**

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