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IMPACT OF THE RECYCLING PROCESS ON KRAFTLINER PAPER PROPERTIES – A COMPARATIVE STUDY BETWEEN EUCALYPTS AND PINE FIBERS

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ABSTRACT

In order to evaluate the recycling influence in the properties of papers composed of eucalyptus short fibers only, such as the Eukaliner®, compared to papers composed of 100% pine long fibers, a characterization of fiber was carried out and handsheets were formed in the laboratory for physical and mechanical resistance tests. The handsheets were submitted to the recycling process and each cycle was refining operation in Bauer refiner. Seven refining cycles were evaluated. The brown kraft pulps used in this essay were collected directly from the industrial process. Both the eucalyptus and pine fibers had reduction in the properties along the cycles, which is inherent to the recycling process. The refining partially recovered some physical-mechanical properties of the paper obtained and the consumption of energy for refining proved to be lower for the eucalyptus fiber.

The eucalyptus fiber had less impact in the length reduction and remained more preserved in relation to the pine fibers after consecutive recycling processes. The research showed that both the eucalyptus and pine fibers presented acceptable resistance along the seven recycling cycles assessed, overcoming the CCB$_{2022}$ (Cepi Container Board) document values for testliner papers. The relevance of this study is due to the increase in the offer of short fiber in the market, the higher sustainability and the lower cost in the eucalyptus production, the cellulose and paper obtained, besides granting higher printing quality and better performance in the conversion of those papers.

Key Words: *Cellulose, eucalyptus, Eukaliner®, recycling, testliner, quality*

INTRODUCTION

The impulse generated by the impending need to adjust to sustainable processes and products is the driving force in the search for constant innovation. In this sense, the industry is evaluating the characteristics of an innovative paper composed of eucalyptus short fibers only, its performance in the reverse logistics and in the recycling chain, as presented in Figure 1.

Figure 1. Paper recycling chain (source: Klabin internal communication)

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As established by Kreplin *et al.* (2019), kraftliner papers, NSSC fluting, corrugated cardboard, testliner 2 and testliner 3 can support at least 12 recycling cycles without any considerable decrease in fiber properties and resistance of the recycled paper. Even though it is possible to evaluate the behavior of fibers along the recycling cycles, in practice it is not possible to determine the number of cycles the fiber went through. According to Hunold *et al.* (1993), there are calculations for that determination, however, the several methods to obtain and prepare the material in study, as well as its origin, must be taken into consideration. The comparison of results with other studies already carried out is superficial, defective, as not always those methods are outlined. According to Kreplin *et al.* (2020), the recycling of corrugated cardboard, for up to 25 cycles was studied in laboratory and 16 cycles in a pilot project plant, with correction of the cellulose mass with chemical agents, maintaining appropriate characteristics.

Zhang *et al.* (2002), present that the chemical dosage, such as the application of superficial starch and dry resistance agents, increase recycled paper resistance, even positively influencing subsequent cycles. On the other hand, Park (2009), affirms that some resistance chemicals, loads and curable ink paints can migrate to the surface of the fiber, progressively damaging them and presenting loss for the recycling chain.

According to Hubbe (2010), the drying method directly impacts paper quality. More gentle drying better preserves the original characteristics of the fiber, when compared to more aggressive or excessive drying, which affects the hydration capacity of the fibers, making its interlacing more difficult. This phenomenon impacts on obtaining more fragile and brittle papers. The refining brings benefits in the sense of recovering the flexibility and fibrillation, reducing the damage caused by the repetitive drying processes.

However, according to Hubbe (2010), refining is another significant factor for maintaining the fiber interlacing property and proposes that refining prioritize external fibrillation, possibly maintaining its properties less altered than the fiber with higher internal fibrillation, supporting, therefore, a greater number or recycling cycles.

In this study, the characteristics of non-bleached brown fibers were evaluated with high Kappa number obtained through the kraft process, as well as the papers they formed in laboratorial scale aiming at comparing to the fiber and papers formed by pine pulp and high Kappa number and correlate with the characteristics of recycled papers formed by mixing short and long fibers, being the last ones present in greater scale, already available in industrial processes; and, then, evaluate the impact and feasibility of the introduction of the new product in the market.

METHODS

For this study, the samples were collected directly from the industrial process, after cooking, before refining in the pulp preparation and no chemicals were dosed to produce the handsheet in the laboratory.

Part of the handsheets was used for physical-mechanical resistance tests, whereas the other part entered in the laboratory recycling process, which included hydration, disaggregation, refining and, again, handsheets formation. Handsheets in all degrees of refining were mixed to enter the next recycling cycle. Fiber characterization analyses were also carried out. Figure 2 shows the simulated recycling process in laboratory.

Characterization of Samples

The eucalyptus pulp was collected at 42% dry content, Kappa number 101 mL $KMnO_4$/g and Schopper-Riegler (°*SR)* 16.

The pine cellulose pulp was collected at 4.9 dry content, Kappa number 68 mL $KMnO_4$/g and Schopper-Riegler (°*SR)* 13. Morphological analyses were carried out on Valmet's FS5 equipment and captured electronic scanning electronic microscopy images (SEM) of the virgin fiber samples without refining and in the seventh recycling cycle with degree Schopper-Riegler (°*SR)* 30 and 40.

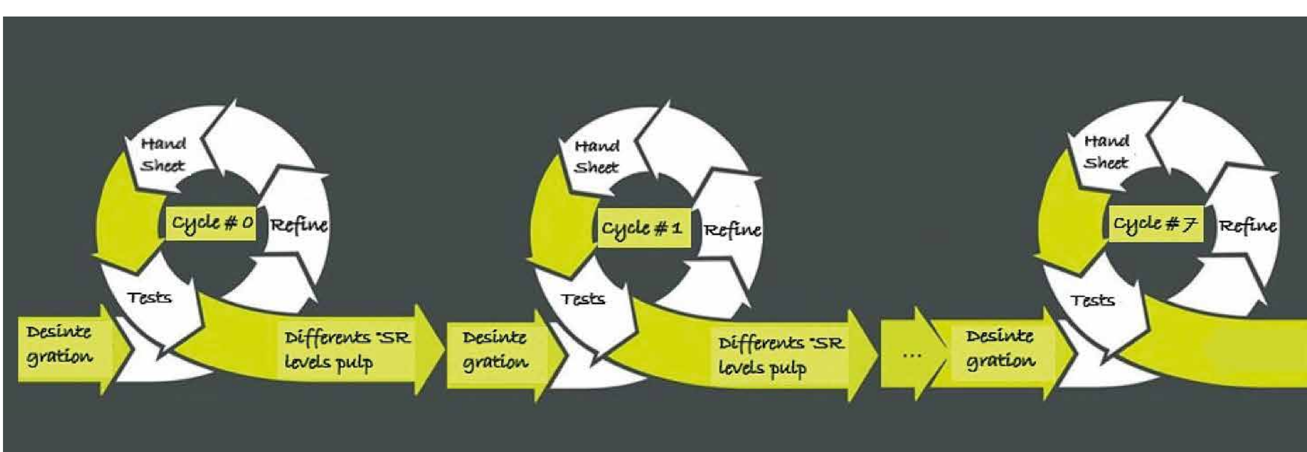

Figure 2. Steps of the laboratory recycling process

Test	Standard
Pulp suspension consistency	TAPPI T240 om-19
Drainage resistance	TAPPI T 221 cm-22
Kappa number	TAPPI T236 om-13
Fiber length of the pulp and paper	TAPPI T271 om-18
Scanning Electronic Microscopy (SEM)	Non standard
Laboratory beating of pulp (PFI Mill Method)	TAPPI T248 sp-15
Forming handsheets for pulp physical tests	TAPPI T402 sp- 98

Tests carried out on the pulp

All evaluations carried out on the pulp were done according to the table below:

Recycling process

Steps of the recycling process carried out in the laboratory are listed as follows:

- **Hydration**

Handsheets formed in the first recycling cycle were hydrated for about 4 hours using fresh water at room temperature. The process was repeated in all cycles.

- **Disaggregation**

After hydration, samples were disaggregated in Frank pulper pits– PTI supplier with dry content close to 1.5% in 10,000 revolutions for pine fiber and 5,000 revolutions for eucalyptus fiber, due to the ease of eucalyptus fiber disaggregation.

- **Refining**

Disaggregated fibers were refined in a Bauer refiner MD-3000 at 20, 25, 30 and 40°*SR*, with dry content close to 2.5%. In the initial recycling cycles the full capacity of the refiner, approximately, 50L and, as there were inherent losses to the process, the amount of refined pulp was reduced in each cycle.

As the handsheets with different degrees of refining were mixed before refining, the degree of refining of that mixture was returning close to the initial refining degree of the previous cycle, as the eucalyptus sample maintained the first refining point in 20°*SR* in the first and second cycle, 25°*SR* in the third and fourth cycle and 30°*SR* for cycles five, six and seven. For the pine samples the first refining point of 20°*SR* remained till the fourth cycle and 25°*SR* for cycles five, six and seven, as shown in Figure 3.

- **Handsheets Formation**

Handsheets in each degree of refining were formed and dried in each cycle using *Frank – PTI Rapid Köthen* automatic handsheets forming/dryer, with 100 g/m² basis weight for physical tests.

The recycling handsheets of paper were formed of approximately 250 g/m² using Techpap dynamic forming handsheets, without any defined fibers orientation. Extra handsheets were formed for recycling due to the high minimum volume of samples needed for the pulp recirculation in the Bauer refiner and, also, taking into consideration the process losses.

First pulp refining point used to make handsheets in each recycling cycle									
Fiber	°SR	0	1	2	3	4	5	6	7
Eucalyptus	16	X							
	20		X	X					
	25				X	X			
	30						X	X	X
	40								
Pine	13	X							
	20		X	X	X	X			
	25						X	X	X
	30								
	40								

Figure 3. Refining starting point of each type of fiber per recycling cycle

O PAPEL vol. 84, N.o 4, pp. 73 - 80 - APR 2023

Table 2. Analytical Procedures for analysis of paper

Test	Standard
Grammage of paper and paperboard	TAPPI T410 om-19
Thickness (caliper) of paper	TAPPI T411 sp-14
Bulk	TAPPI T500 cm-07
Short-span Compression Test *(SCT)*	TAPPI T826 om-13
Ring Crush Test (RCT)	TAPPI T 822 om-16
Corrugating Medium Test (CMT)	TAPPI T809 om-17
Concora Crush Test (CCT)	TAPPI T824 om- 14
Air resistance	TAPPI T460 om-16
Bursting resistance	TAPPI T807 om-15
Tear resistance	TAPPI T414 om-12
Tensile resistance, Elongation and TEA	TAPPI T494 om-13

- **Paper handsheets pressing and drying for recycling**

The testing handsheets were pressed at -0.8 *bar* and dried at 92 +- 1°C in the handsheets forming/dryer. Both the pressing and drying were kept for 15 minutes.

Paper sheets formed for recycling were pressed at 2.3 bar and dried in the drier at 100°C for 25 minutes in contact with the heated plate and tensioned through felt on the upper face.

Tests carried out on the handsheets

The formed handsheets were placed in an environment with a relative humidity of 50 ± 2% and a temperature of 23 ± 1°C (TAPPI 402 SP- 98).

Experimental tests were performed according to standard procedures and methodologies according to TAPPI, as shown in the table above.

RESULTS AND DISCUSSION

The shorter length characteristics of the fiber and the higher number of fibers per milligram of suspension provide a better connection among fibers and smoothness to the paper formed by eucalyptus fiber comparatively to the pine fiber. Figure 4 illustrates the morphological properties analyzed.

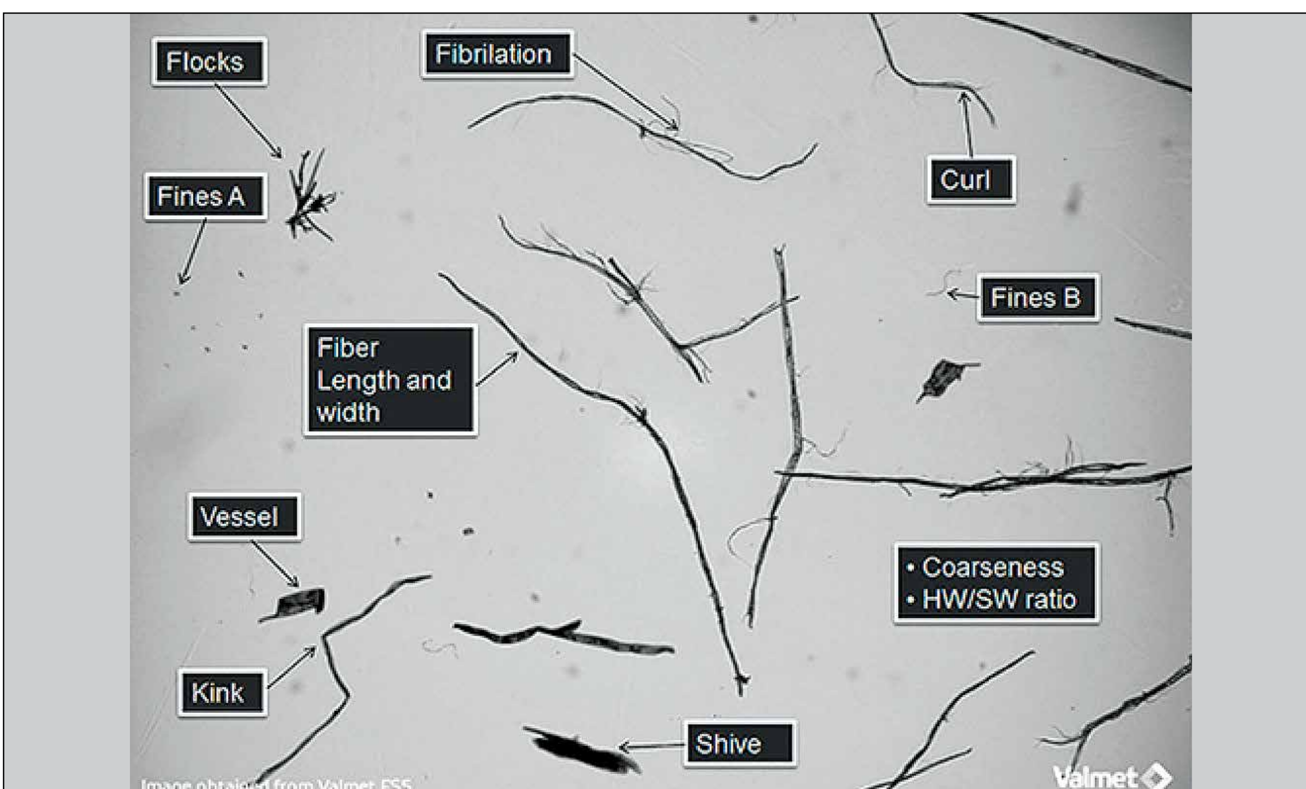

Figure 4. Fiber Morphological Properties (Source: Valmet - 2022)

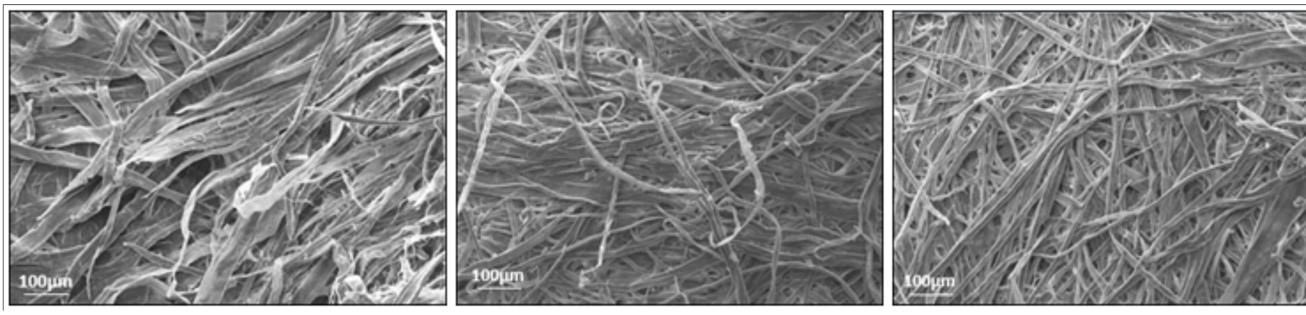

Figure 5. ESM of eucalyptus samples increased 300 X

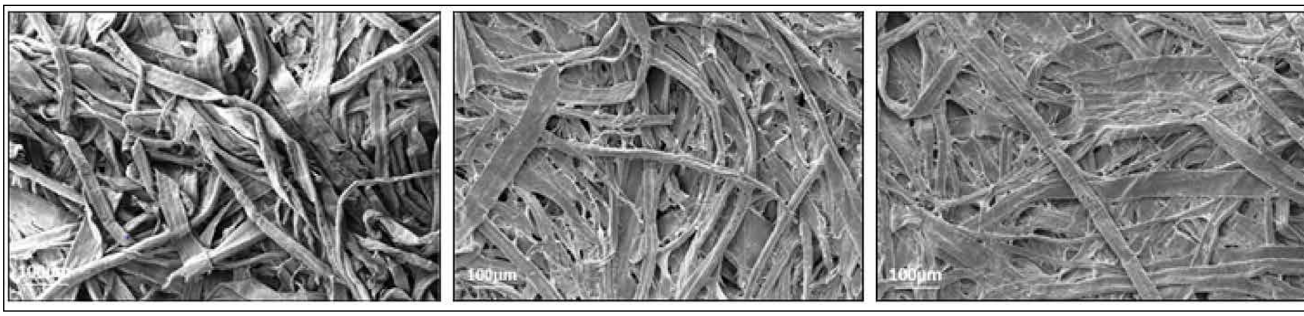

Figure 6. MEV of pine samples increased 300 X

Figures 5 and 6 show scanning electronic microscopy of the eucalyptus and pine virgin fibers in the initial refining degree and, also, the fibers of both samples in the seventh recycling cycle with 30°*SR* and 40°*SR*, respectively. The eucalyptus fibers showed to be more preserved, whereas the pine fibers were more collapsed. According to Foelkel (2007), this effect is mainly due to the wet pressing process of the paper sheet, giving better accommodation and connection among fibers during the paper sheet forming and, therefore, higher physical-mechanical resistance.

It is possible to observe in Figure 7 a decrease in fiber length and an increase in fines A for pine. The eucalyptus presented a loss in fiber length and a slight decrease in the proportion of fines A, which can be explained by the smaller size of the fiber, typical of eucalyptus. The increase in the proportion of fines is a question of the reduction in the size of the fibers, referring, specifically, to fines A, is a matter of the length of the fiber. The percentage of fines A positively influences paper smoothness, but a high increase may cause loss in resistance and negatively influence drainage in the paper machine. Fines A are flock shaped particles and smaller than 0.2 mm. Fines B are fibril-shaped particles with width smaller than 10 μm and length above 0.2mm. The sum of both types is the total fines. In this study, only fines A were measured.

According to D'Almeida (1998), the ship between width and thickness of the fiber wall indirectly shows the effect of fiber stiffening, which is more expressive when there is significant decrease in width and smaller decrease in thickness. What can be seen in Figure 8 is that the thickness in the fiber wall presented a proportional decrease, slightly, higher than the

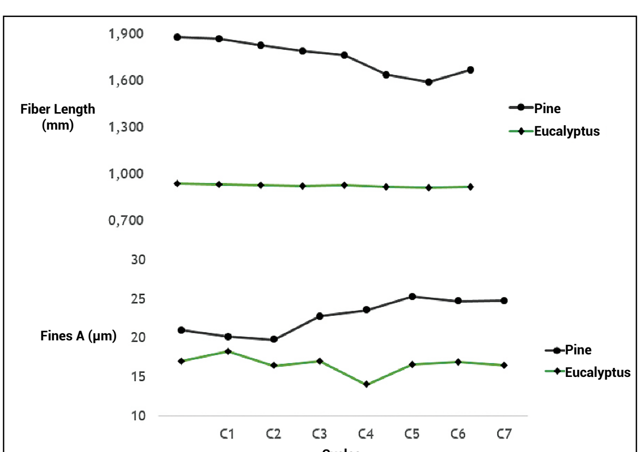

Figure 7. Length of the fiber and content of fines A

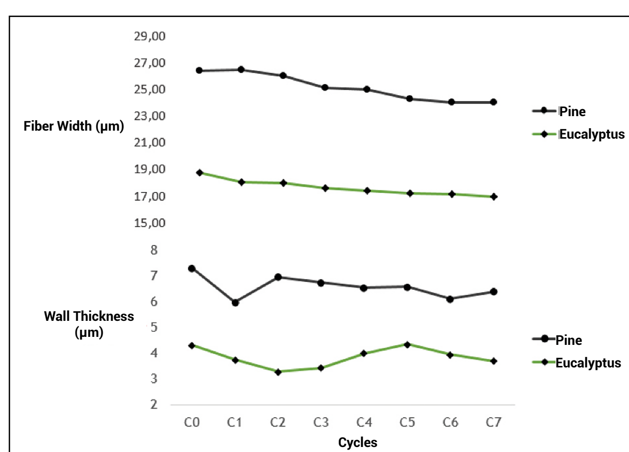

Figure 8. Fiber width and wall thickness

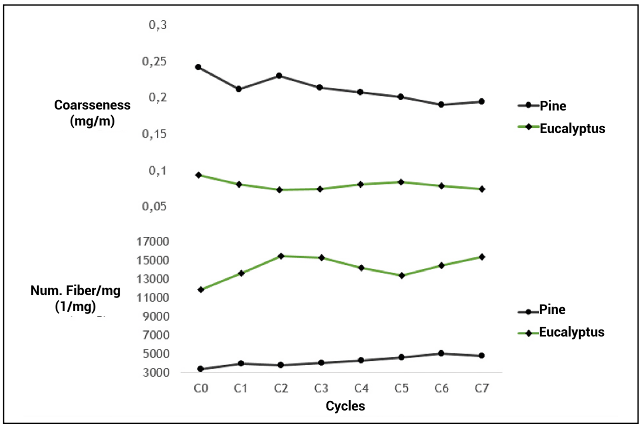

Figure 9. Coarseness and number of fibers per gram

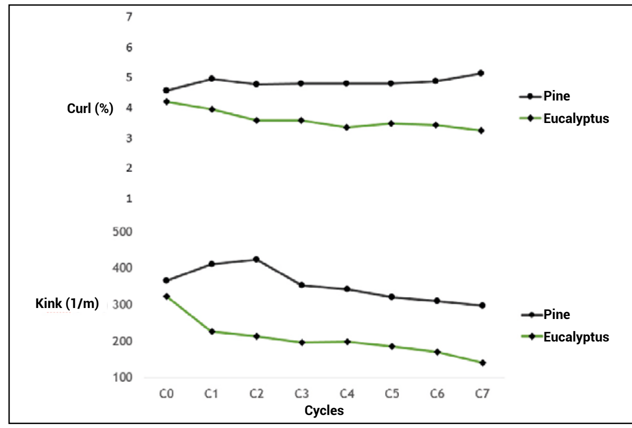

Figure 10. Curl and Kink

fiber width for both fibers, which tends to present that effect attenuated.

As presented in Figure 9, there was an increase in the number of fibers per mg due to the loss in fiber length, inherent to the process and there was also a reduction in coarseness, due to the loss in fiber width. These properties reveal the integrity or degradation of the fiber originated in the refining process, which can be more or less aggressive according to refining intensity. Although the loss of coarseness for the eucalyptus is proportionally higher than for the pine, in absolute numbers the eucalyptus fibers were more preserved.

In Figure 10, the percentage of curl presents a small increase for the proportion of curved fibers for pine and a decrease for eucalyptus, due to the longer length of the pine fibers. The increase in curl results in the fibers alignment in the moment of the paper formation. Kink reveals the number of damaged fibers, given that the decrease of that property more expressive for eucalyptus can be explained by the fact that those fibers were broken and not only folded.

The repetitive drying in the recycling process causes stiffening of the fibers, decreasing absorption capacity and water retention, leading to loss of flexibility and making the fiber to fiber connection difficult. It is possible to observe this effect in the following graphics, showing the tendency of obtaining a paper with less physical-mechanical properties. The drying methods, as well as the variation in temperature and retention time, directly influences hornification, which is irreversible, but can be attenuated by the refining operation.

This study assessed five degrees of refining and an option to present the results at 30°*SR* was made, because it represents the industrial reality in paper machines.

According to Figure 11, the paper formed by eucalyptus fibers presented higher thickness in relation to papers formed by pine fibers, which provides higher bulk, an important property for reducing the basis weight of paper sheet, with potential of using a less amount of fibers, thus being more sustainable and helping cut costs, besides conferring higher paper stiffness.

The results for the RCT index, according to Figure 12, shows a slight decrease for both fibers. The less resistance to air flow, according to Figure 12, demonstrated by the Gurley porosity, is due to the smaller interlacing of fibers resulting from the recycling process and higher bulk.

The results presented in Figure 13 for CMT 30 and CCT 30 show a decrease for the two types of fibers, even though, close for both. This phenomenon is due to the stiffness and loss of fiber-to-fiber connections inherent to the process. The eucalyptus fibers, as well as the pine fibers, presented satisfactory RCT, CMT30, SCT values and resistance to burst,

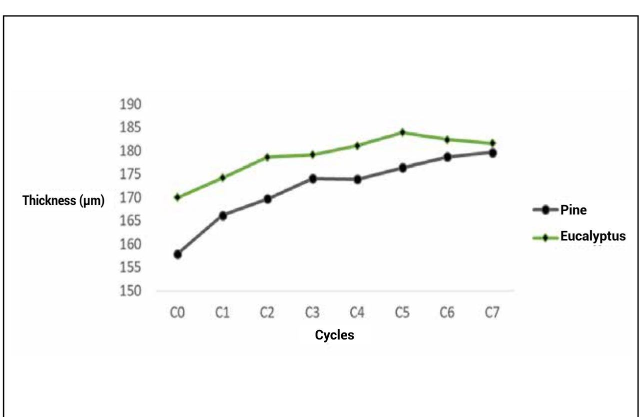

Figure 11. Pulp handsheet thickness

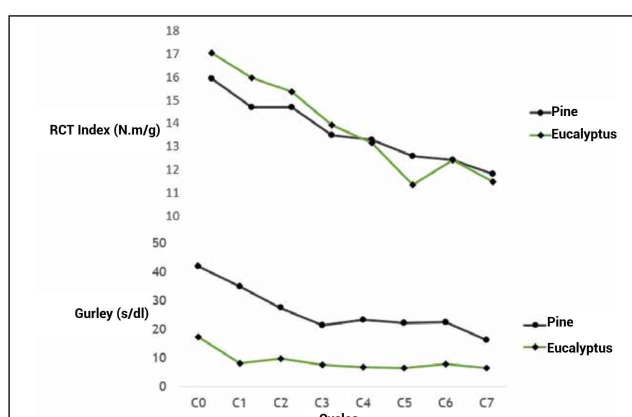

Figure 12. RCT index and Gurley Porosity

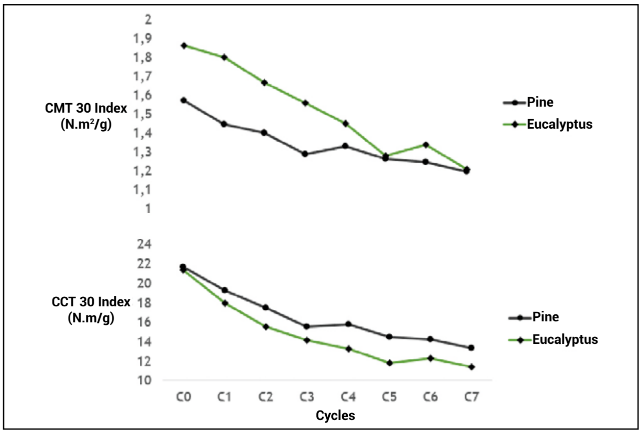

Figure 13. CMT 30 and CCT 30 indexes

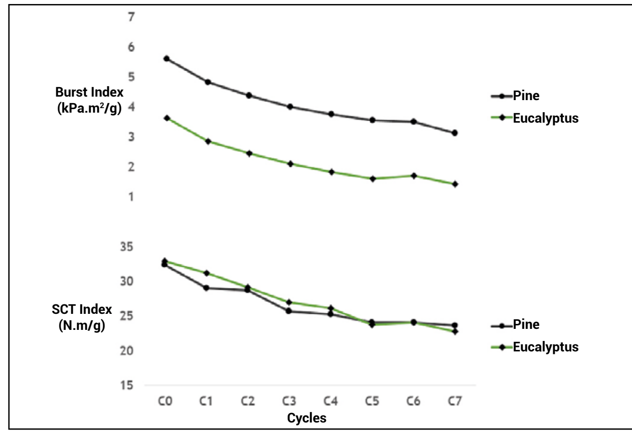

Figure 14. Burst index and SCT

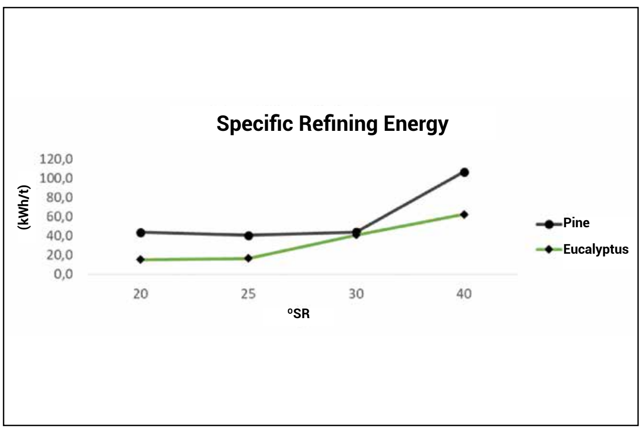

Figure 15. Refining Specific Energy Consumption

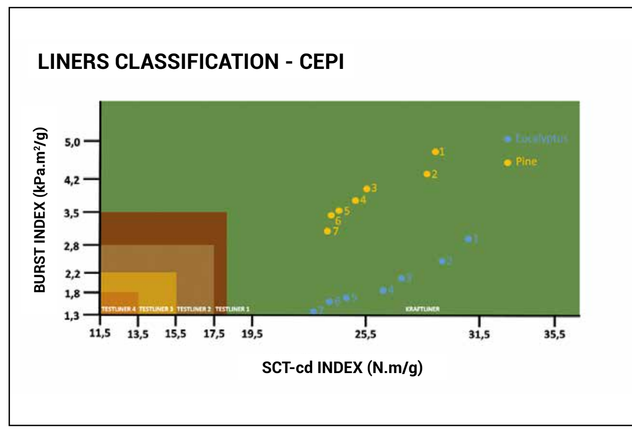

Figure 16. CEPI Classification for kraftliner papers (Source: CCB - adapted)

which are important properties for packaging papers, used as components for core and cover in corrugated sheets. These values can be seen in Figures 12, 13 and 14.

The curve, as shown in Figure 15, demonstrates a lower average consumption of refining energy for the eucalyptus in relation to the pine, considering that the cost of energy is very relevant in the paper production and recycling industry and this refining is important for the partial recovery of physical-mechanical properties.

Figure 16 illustrates the classification of testliner and kraftliner papers according to the CCB and shows that both the recycled papers made from eucalyptus fibers, as well as those made from pine fibers, presented superior properties to the testliner papers classified by the association (CCB).

CONCLUSIONS

It was observed in this study that the increase in the amount of eucalyptus fibers, that is now offered to the market for recycling, does not cause significant losses of properties that may compromise the quality of recycled papers produced from them. On the contrary, it presents production cost advantages, as eucalyptus is a cheaper raw material compared to pine, besides being more sustainable due to its faster growth and higher yield in pulping, consequently, less specific consumption of wood per ton of cellulose and higher production per day in the digester. It requires less consumption of energy for refining, as it is a key factor in relation to costs and essential for the recovery of physical-mechanical properties of papers.

On the other hand, recycled papers formed by eucalyptus fibers present higher smoothness, better printing quality, due to better index of formation, less consumption of energy in the conversion and better quality of boxes, making an expressive reduction in basis weight possible.

As a suggestion for future studies, properties like water retention properties of fibers and stiffness of papers can be evaluated to correlate with other properties.

New studies with the addition of chemicals to the recycled papers production process in lab, besides refining, are of major importance so that results assessed be closer to the plant environment.

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O PAPEL vol. 84, N.o 4, pp. 73 - 80 - APR 2023

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