OPTIMIZING EUCALYPTUS PULP REFINING

Manfredi, V. –Optimizing Eucalyptus Pulp Refining. *In:* International Papermaking & Environment Conference. Ed. Yang, S.; Ni, Y e Liu, Z. Tianjin University of Science and Technology, Tianjin – China: 12-14/05/2004 Book A: 41-50.

Vail Manfredi
Bahia Sul Celulose S.A.
Brazil
vail@bahiasul.com.br

ABSTRACT

This paper discusses the refining of bleached eucalyptus kraft pulp (BEKP).

Pilot plant tests were carried out in to optimize the refining process and to identify the effects of refining variables on final paper quality and process costs. The following parameters are discussed: pulp consistency, disk pattern design, refiner speed, energy input, refiner configuration (parallel or serial) and refining intensity.

The effects of refining on pulp fibers were evaluated against the pulp quality properties, such as physical strengths, bulk, opacity and porosity, as well as the interactions with papermaking process, such as paper machine runnability, paper breaks and refining control.

The results showed that process optimization, considering pulp quality and refining costs, were obtained when eucalyptus pulp is refined under the lowest intensity and the highest pulp consistency possible. Changes on the operational refining conditions will have the highest impact on total energy requirements (costs) without any significant effect on final paper properties.

It was also observed that classical ways to control the industrial operation, such as those based on drainage measurements, do not represent the best alternative to maximize the final paper properties neither the paper machine runability.

1. BACKGROUND

The use of wood as the raw material base for papermaking was one of the most important facts in the long history of paper industry. The eucalyptus kraft pulp began to appear on the world market in the mid-1960's, and since then, has been an important raw-material for a wide range of fine, specialty and tissue papers [1-2].

BEKP pulp is well known to combine important properties in a particularly favorable way. Eucalyptus pulp brings to paper excellent bulk associated with good strength and optical properties (opacity and light scattering coefficient) and also formation because its fibers are uniform, with low coarseness, stiff and uncollapsed, and are present in a larger number compared to other hardwood fibers [1-8].

As a general rule for all chemical pulps and for several paper grades, the fibers used directly from the bales do not provide the adequate sheet strength. They must be physically modified, and refining is the mechanical treatment to improve the fiber characteristics. Refining allows the papermakers to improve the final paper characteristics such the papermaking process itself.

During this treatment, pulp fibers are subjected to drastic mechanical actions. The fiber structure is modified, additional surfaces are created, and fiber's conformability is increased. Refining has a great influence on the fiber bonding, producing more flexible fibers, easier to bond, and leading to higher strength properties. In general, the refining process produces a number of modifications to the fiber morphology, such as fiber breakage or cutting, external fibrillation, secondary wall delamination [9-13].

Several other process factors, such as drying history, slushing regimes, stock concentration, pH, temperature, pulping and bleaching significantly influence the degree of modifications induced by mechanical refining, as well as inherent fiber characteristics including wood species, origin, age and chemical composition.

Refining requires large amount of energy and the structural modifications on fiber structure are not reversible. Due to this importance on the final results it has been intensively studied, and during the last decades, several refining models ("refining theories") have been presented. These models allowed a better understanding of the process itself, refining quantification, and comparison between different refiners. The "refining theories" have changed the process understanding from art to science.

In 1958 Wulsch and Flucher [14], confirmed the concepts presented by Smith [29] at the beginning of the century, and introduced refining intensity, expressed as the ratio between effective refining load and edge length per unit of time [17]. Brecht and Siewert [16], in 1966, extended the theory to define the term specific edge load (SEL). They demonstrated the dominating role played by bar edges in fiber treatment and also introduced specific energy as an important refining parameter. This was the origin of the "specific edge load theory" as it is known nowadays.

Being simple and very easy to be applied in daily mill activities it became the most accepted and used refining model around the world. The model assumes that the refining action occurs by fiber's deformation due to the impacts of edge bars on the pulp fibers in suspension. These impacts are related with the "total bar length by unit of time" (also named as "total cutting length") [13-28].

Number of impacts, refining intensity and specific refining power yield additional information to characterize refiner operation and to understand the relationship between the refining action and its results [13, 17-20, 30-31]. In this case, refining is described in terms of the probability of fibers being treated as a function of machine and process parameters.

Nowadays, the most common theoretical measures of refining are the "specific energy consumption" (expressed as kWh/t) and the "specific edge load" (expressed as

Ws/m), respectively, the amount and the severity (intensity) of refining.

The specific edge load determines the intensity and quality of refining. Reducing refining intensity (Ws/m) will improve fiber strength for all short fibers furnishes and for any type of refiner. It is reported that higher specific edge load values (higher "refining intensity") lead to "cutting" while lower values tend to fibrillate them. In addition, according to the model, at the same specific edge load and net refining energy, all refiners can be compared [11, 15, 18, 22, 23, 26-28, 32-46].

More recently, Steenberg [32] introduced the concept that fibers are not treated individually during refining, but they are present in the form of aggregates named "flocs". This concept has been recognized for several researchers [12, 15, 21, 24, 47-54]. Actually it is accepted that flocs are the individual bodies receiving the mechanical action (impacts) during the refining process.

2. EXPERIMENTAL

Refining curves were performed in a pilot plant equipped with a single disk refiner (12 inch diameter) with an automatic system to assure a positive pressure inside the refiner.

Refiner can be operated at different rotational speeds. Pulp flow through the refiner is controlled by a positive displacement pump, and can be changed to allow different level application of net energy. It is possible to run both single and multiple-passes under nominal consistencies varying from 2.0 up to 6.0%.

Pulp from commercial bales of bleached eucalyptus kraft pulp (BEKP) and single pass refining were used in this trial. Handsheet formation and tests were performed according to SCAN Standards.

3. RESULTS AND DISCUSSION

3.1. Refining Intensity

The imposition of cyclic strain on fibers is the common denominator of all types of refining [55, 56]. The magnitude of each cycle is characterized as various types of intensity parameters, and the total work done on fibers is usually represented as specific energy [56].

In this paper "refining intensity" is reported as the specific edge load (SEL), in Ws/m, while refining quantity, or "amount of refining", is expressed as the net refining energy, in kWh/t. In a very simple way, the mathematical equations used by the "specific edge load model", can be expressed as follows:

$$Bs = \frac{Pn}{Ls} \qquad We = \frac{Pn}{n}$$

where:

- Bs = Specific Edge Load, as Ws/m,
- Pn = Net Refining Power, as kW (Total minus No-Load Power),
- Ls = Disk "Cutting" Length, as m/s,
- We = Net Refining Energy, as kWh/t, and
- n = Refiner Production, expressed as t/h.

Figure 1 illustrates the effect of refining intensity on BEKP properties evolution. Refining intensities varying from 0.3 to 1.25 Ws/m were used. All other operational variables were kept fixed, such as consistency (4.5 %), refiner rotational speed (1185 rpm) and disk configuration (2.5 mm x 3.5 mm / 5º). Different net refining energies, in kWh/t, were obtained by the variation of the pulp flow through refiner.

Lower refining intensities, i.e. lower specific edge load values allowed faster pulp properties development, with better use of energy than the ones observed for higher intensities. In other words, and for the operational variables used in this trial, one will save energy when refining is performed at lower intensity.

These results were confirmed using a different set of operational variables, as illustrated by figure 2. In this case, refining intensity was changed from 0.5 to 1.5 Ws/m, operating at 4.5 % consistency and using disks of 3.0 x 3.0 / 5º at 1640 rpm.

The results showed that both pulp fiber collapsibility tendency (Apparent Density) and bonding ability (Tensile Index) are improved, at the same net refining energy consumption, when lower refining intensities were used. Nevertheless, the pulp property relationships (Figure 3) were not affected by refining intensity. Probably this occurs because these relationships are strongly related with intrinsic fiber characteristics.

At low intensity each impact on fiber is gentle. Savings on net refining energy and more uniform pulp quality can be observed. The overall results of low intensity refining are optimum strength and optical properties, higher refiner efficiency and lower specific refining energy consumption as frequently reported [11, 15, 22, 28, 32-40, 57-59].

From the results presented on figures 1 to 3, it is possible to conclude that eucalyptus pulp property relationships are not controlled by the *intensity* used in the refining process, i.e. the general paper quality is not affected by the refining intensity. Nevertheless, refining intensity has a strong influence on the total energy consumed by the process, being higher as refining intensity increases.

These results confirm that refining intensity (specific edge load) must be considered for all types of industrial refining optimization studies and industrial operations.

3.2. Consistency

Consistency has a strong influence in industrial refining operations because any variation of its value results in a variation of the refiner's throughput in tones/hour (production). In industrial operations refining consistency must be controlled in a small range [22, 36, 43, 45, 62].

In addition, the flow rate through a refiner is also an important variable because, together with stock consistency, affects the fiber mat thickness between rotor and stator when energy is applied. In general, higher amount of fibers on the bars and better stability of gap clearances, better fiber development and lower energy consumption [11, 34, 63-64].

For short fiber's pulp refining 4 to 6 % consistencies range is recommended. The use of the highest possible consistency is desirable, due to the improvement of vessel's rupture during refining avoiding vessel-picking problems in the paper [3, 46, 59-61].

Results on figure 4 show that the refining consistency has a significant effect on energy consumption during the industrial operation, specially when higher levels of net refining energy are used. When the same level of net refining energy is considered, being all other operational variables fixed, better results are obtained for higher consistency values. Lower net refining energy was required to reach the same pulp property value.

In addition, the total time that pulp stays inside the refiner is a significant factor in refining operation. Several studies had shown that residence time is important both for the quality of the pulp produced as well as for the refiners operation [20, 49, 54].

As the specific refining energy is measured as kWh/t, the increase on consistency means an increase on the retention time of the pulp flocs in the refiner, if the same refining operational variables are used. Increasing this retention time also increase the impact probability of the rotating disks on the fiber flocs going through the process, and that a higher number of impacts can hit each floc [30, 54].

As previously observed in the case of refining intensity (Figures 1 and 3), pulp property relationships were not affect by the pulp consistency at the refiner (Figure 5). Here again, the variation on pulp consistency will affect only refining energy's costs. Nevertheless, it is very important to avoid consistency variations because it will change the net refining energy, expressed in kWh/t, introducing variation in pulp properties due to differences on refining quantity that reduces refining uniformity.

3.3. Disk Configuration

Most of the research in refining had been concentrated on pulp consistency, disk design, knife-edge loads, rotor speed, automation, and development of new refiner designs that provide high compression and negligible shear. The number of impacts experienced on average by the fiber will be proportional to the total number of bar edges onto which it can staple.

The number and length of bars and the cutting angle of a refiner disk determine its ability to cut or to fibrillate fibers in an efficient manner. Low crossing angles promote cutting while high crossing angles promote fibrillation [22, 44, 63].

The refining disks used in this trial show a large variation on both bar and channel width. The general characteristics of theses disks are shown on table 1.

Figures 6 and 7 illustrate the effect of the disk configuration. If refining is performed at a constant refining intensity (Ws/m) there is no effect of disk configuration on the results. In this case all the refining curves were performed at 1185 rpm, 4.5 % consistency, and refining intensity of 0.5 Ws/m. This result was confirmed using other sets of operational variables (see table 1).

Therefore, our results showed that the disk configuration is not a relevant refining parameter for the pulp properties development when the refining is performed at constant "refining intensity". Nevertheless, the disk configuration is a critical parameter to control operational costs, specially those related with total refining energy consumption.

3.4. Rotational Speed

The rotational speed is the most important factor to control the frequency of impacts on pulp flocs suspension. Than, for constant refining intensity and consistency, higher number of impacts will be applied on pulp when higher rotational speeds are used.

Figures 8 and 9 illustrate the results obtained from refining curves combining refining intensities of 0.5 and 1.0 Ws/m and three refiner rotational speeds (890, 1185, and 1640 rpm).

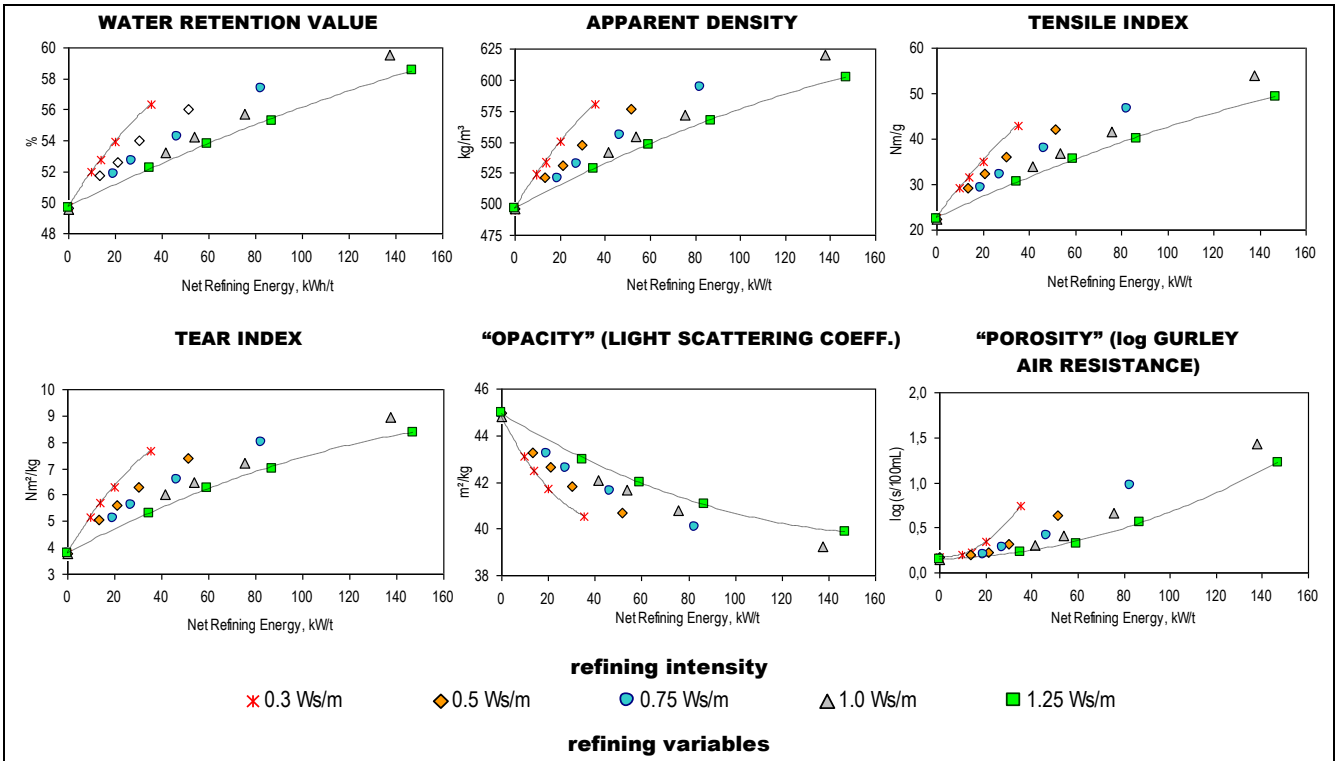
The results showed significant effect on pulp properties development only as function of the refining intensity (specific edge load) applied. No effect of disk rotational speed was detected during this trial. In addition, as from previous trials, no effect of rotational speed on pulp property relationships was observed.

Pulp properties development was not affected by disk rotational speed, but this speed causes a strong impact on the total energy requirement to reach the same pulp property value. Higher rotational speeds means higher no-load power in refining, contributing to increase the total power consumptions at the refiner, for the same net power (same net refining energy if the production rate is kept constant). This result agrees with previous information from literature [15, 59].

Using speed control in the refiner operators are able to control both the energy and the intensity and, as an additional advantage, the refiner can be operated at the slowest speed at which the pulp properties are acceptable, providing considerable energy savings [22, 34, 43-45, 63].

TABLE 1 – CHARACTERIZATION OF THE REFINING DISKS USED IN THE PILOT PLANT TRIAL

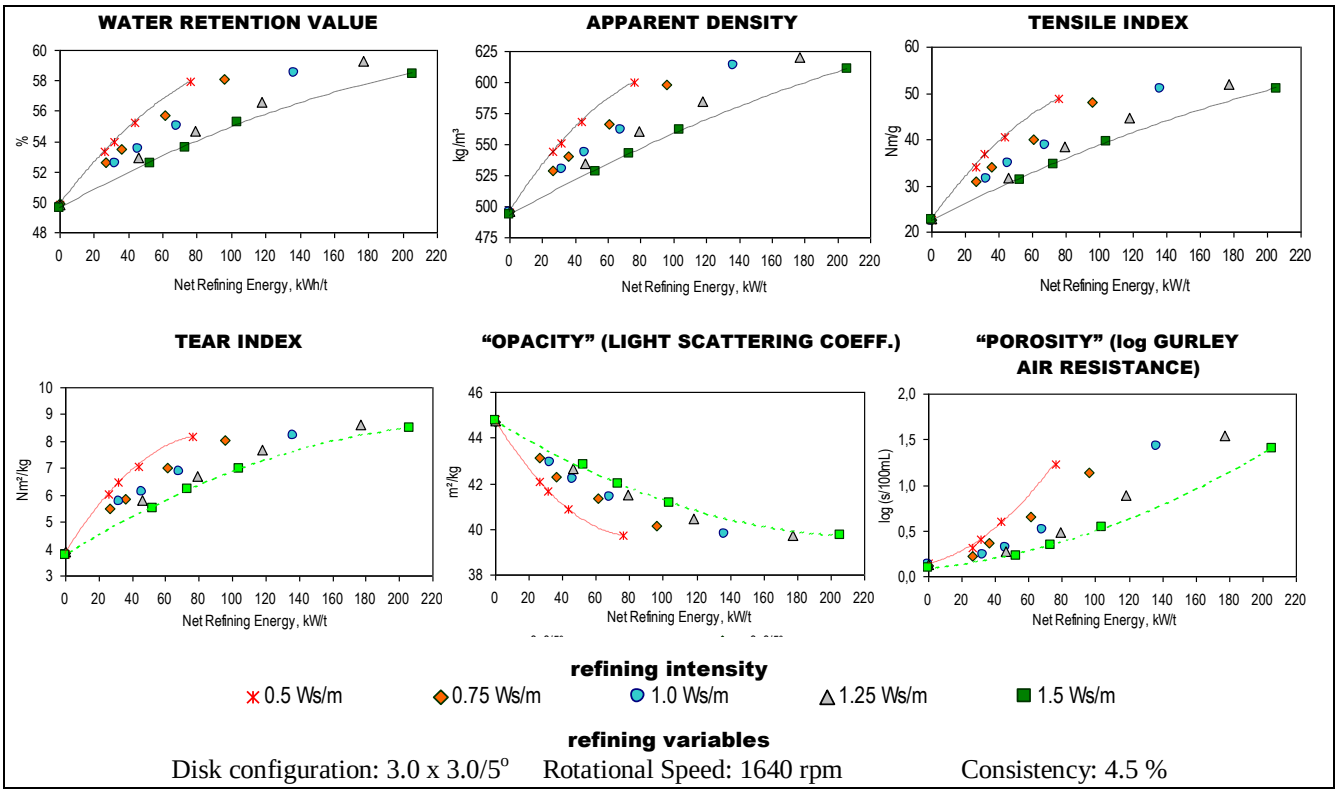
Design		Crossing Angle	"Cutting Length", cm/rev	Total "Cutting Length", km/s		
Bar	Channel			At 890 rpm	At 1185 rpm	At 1640 rpm
2	2.5	5	98147	14.56	19.38	26.83
3	2	5	86466	12.83	17.07	23.63
2.5	3.5	5	75629	11.22	14.94	20.67
2.5	3.0	5	74887	11.11	14.79	20.47
3	3	5	63028	9.35	12.45	17.23
3	3	10	61952	9.19	12.24	16.93
5	5	5	25988	3.85	5.13	7.10



refining variables

Disk configuration: 2.5x3.5/5° Rotational Speed: 1185 rpm Consistency: 4.5 %

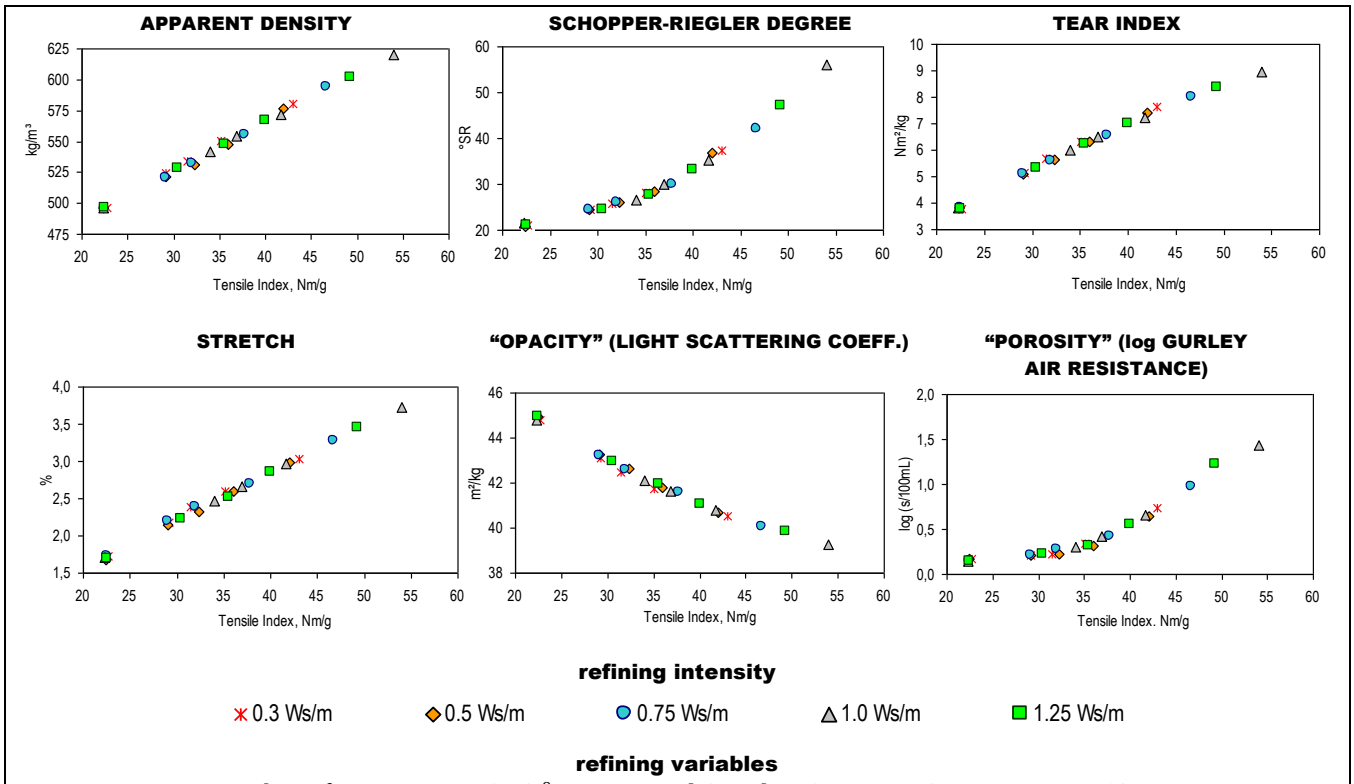
Figure 1 – Evolution of pulp properties during the refining. Effect of refining intensity.



refining variables

Disk configuration: 3.0 x 3.0/5° Rotational Speed: 1640 rpm Consistency: 4.5 %

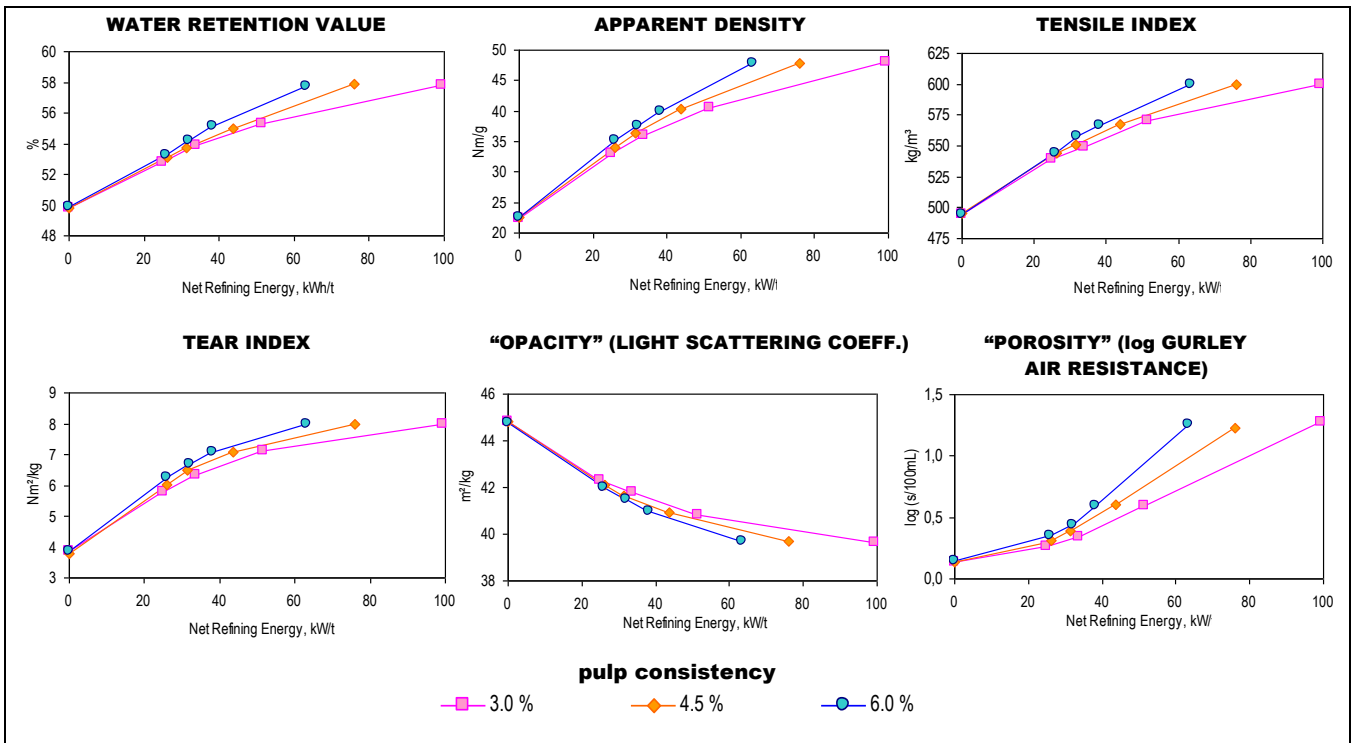
Figure 2 – Evolution of pulp properties during the refining. Effect of refining intensity.



refining variables

Disk configuration: 2.5x3.5/5° Rotational Speed: 1185 rpm Consistency: 4.5 %

Figure 3 – Pulp property relationships. Comparison at same Tensile Index for different refining intensities.



refining variables

Disk configuration: 3.0x3.0/5° Rotational Speed: 1640 rpm Intensity: 0.5 Ws/m

Figure 4 – Pulp properties development during refining. Effect of pulp consistency.

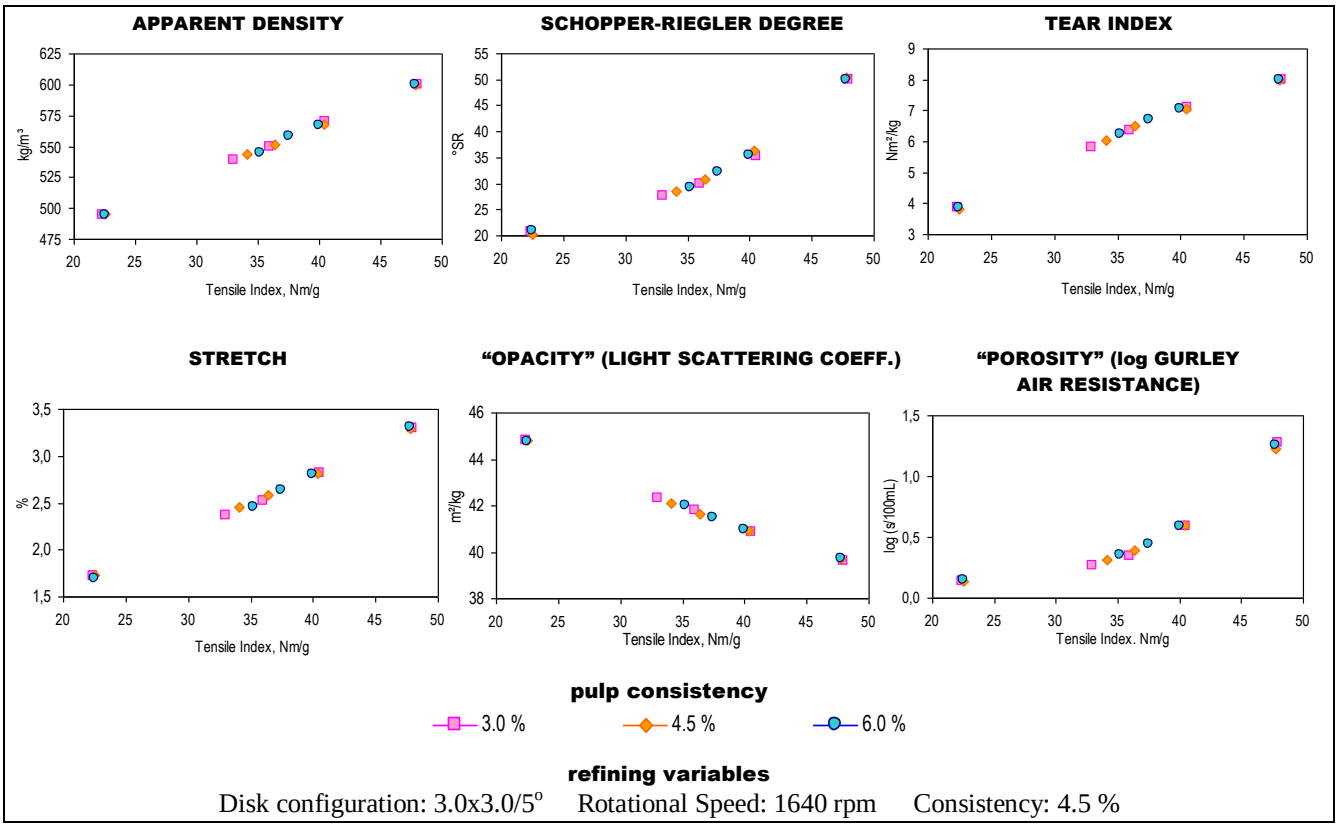


Figure 5 – Pulp property relationships. Comparison at same Tensile Index for different pulp consistencies.

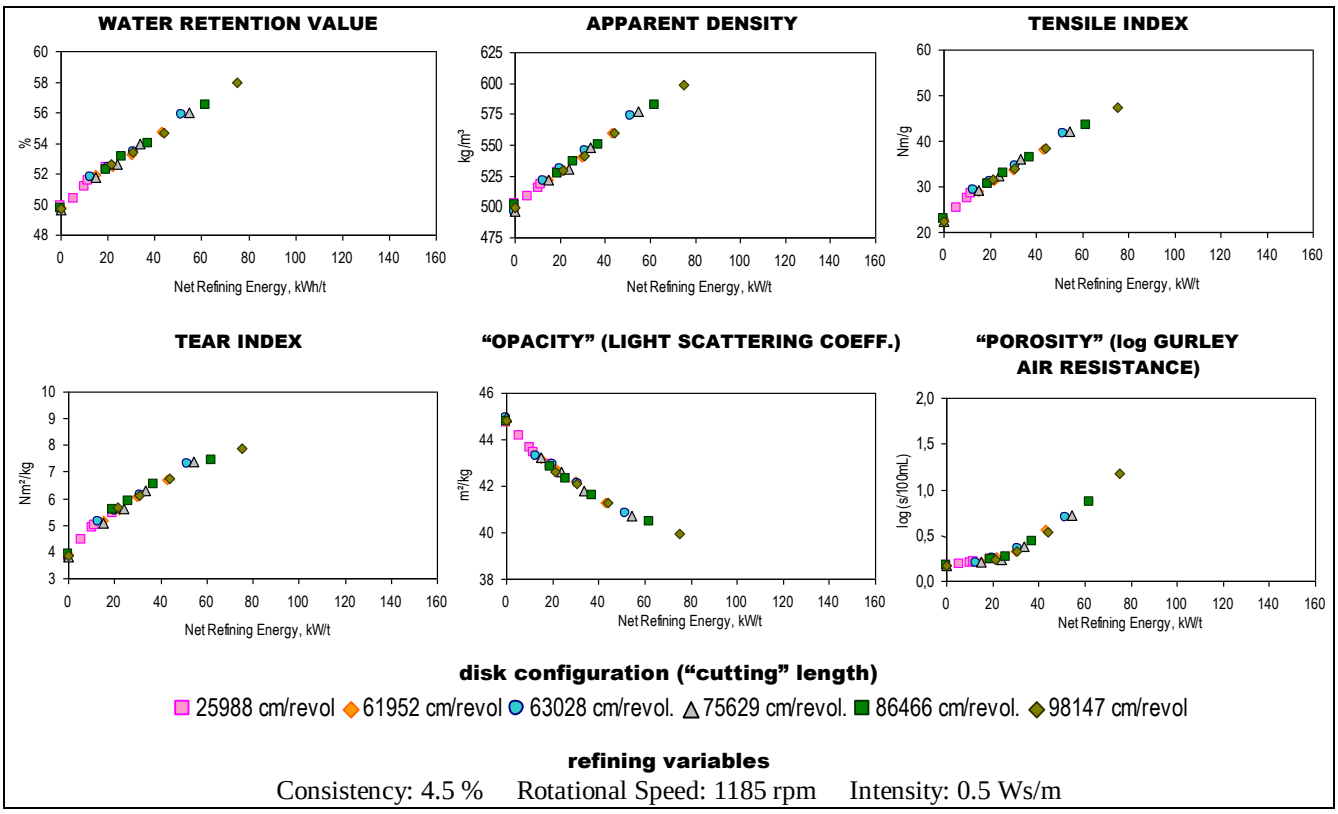


Figure 6 – Pulp properties development during refining. Effect of disk configuration.

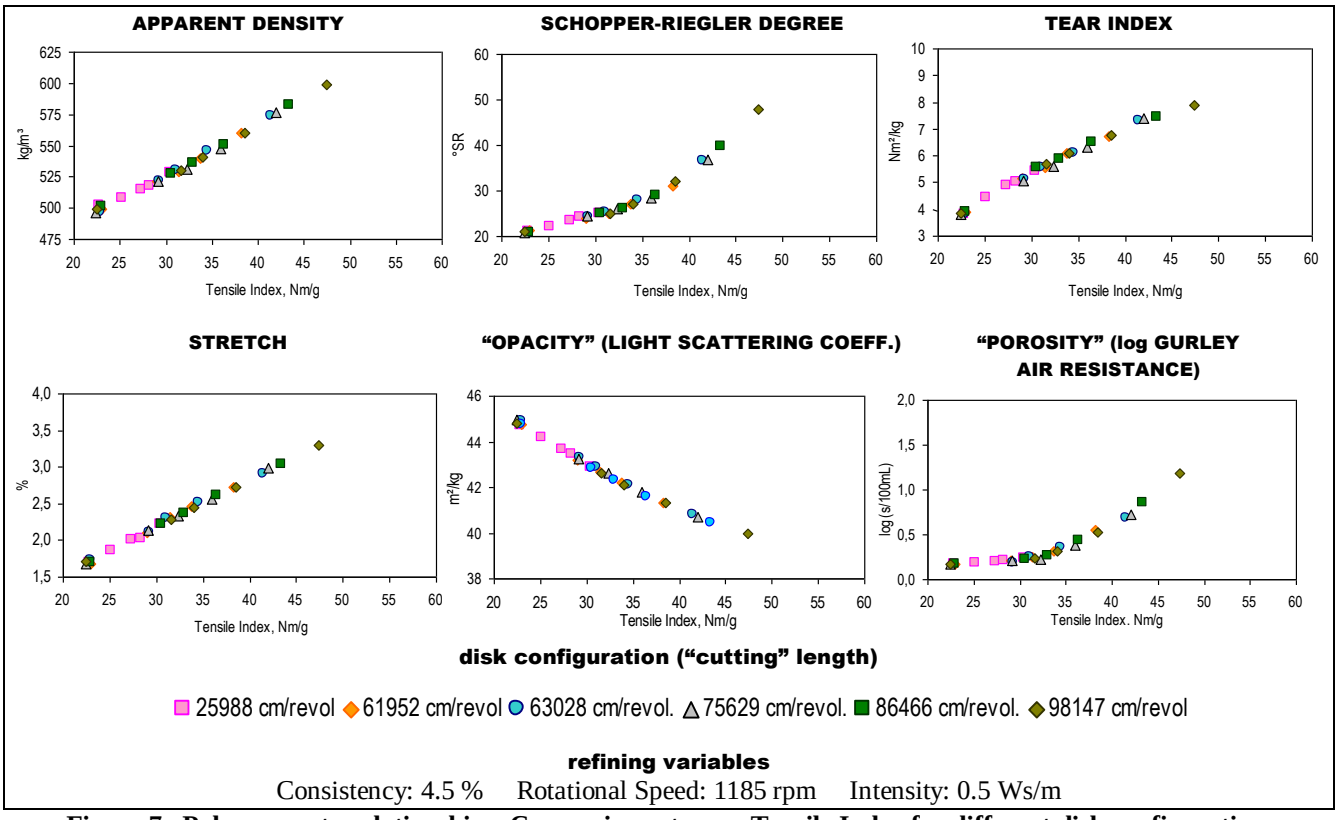


Figure 7– Pulp property relationships. Comparison at same Tensile Index for different disk configuration.

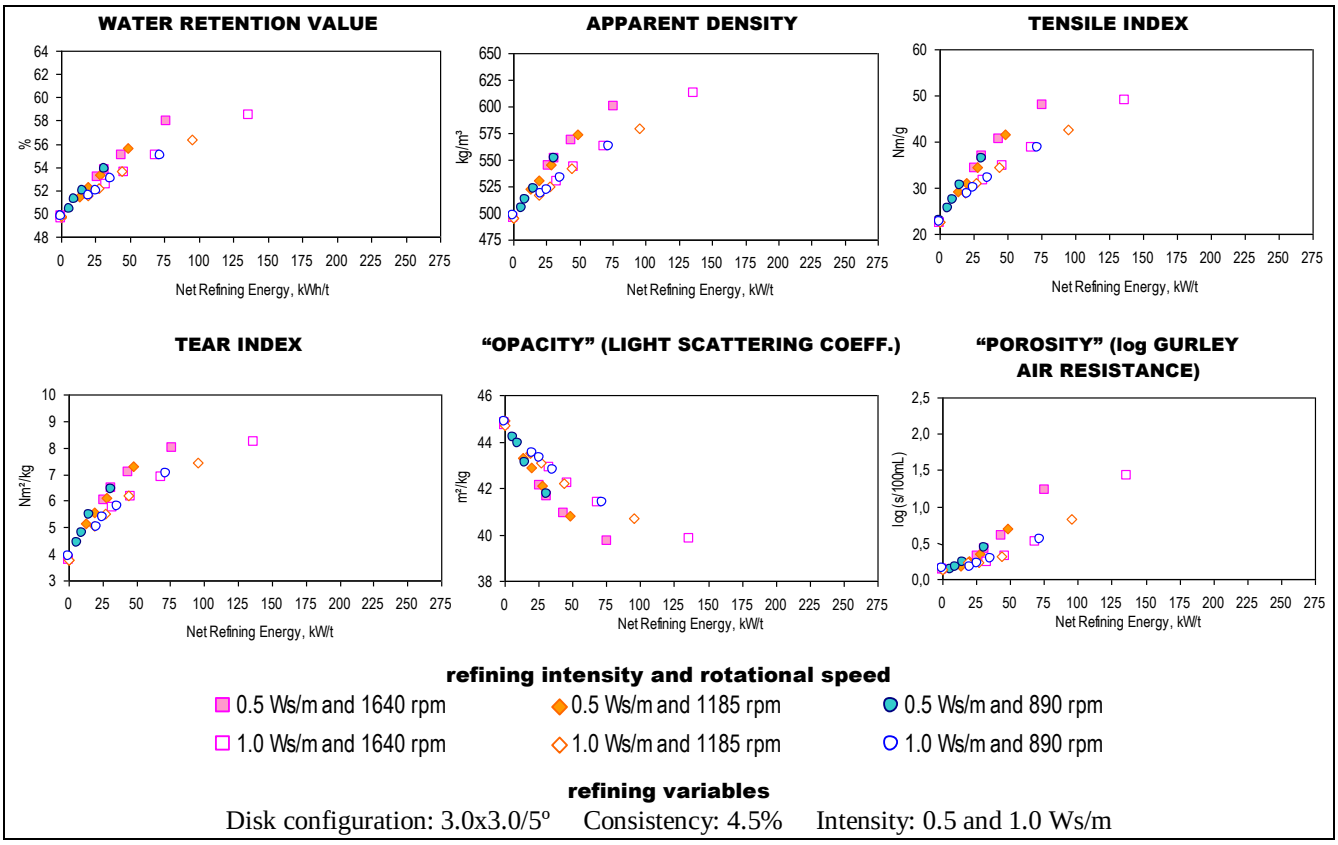


Figure 8 – Pulp properties development during refining as function of refining intensity and rotational speed.

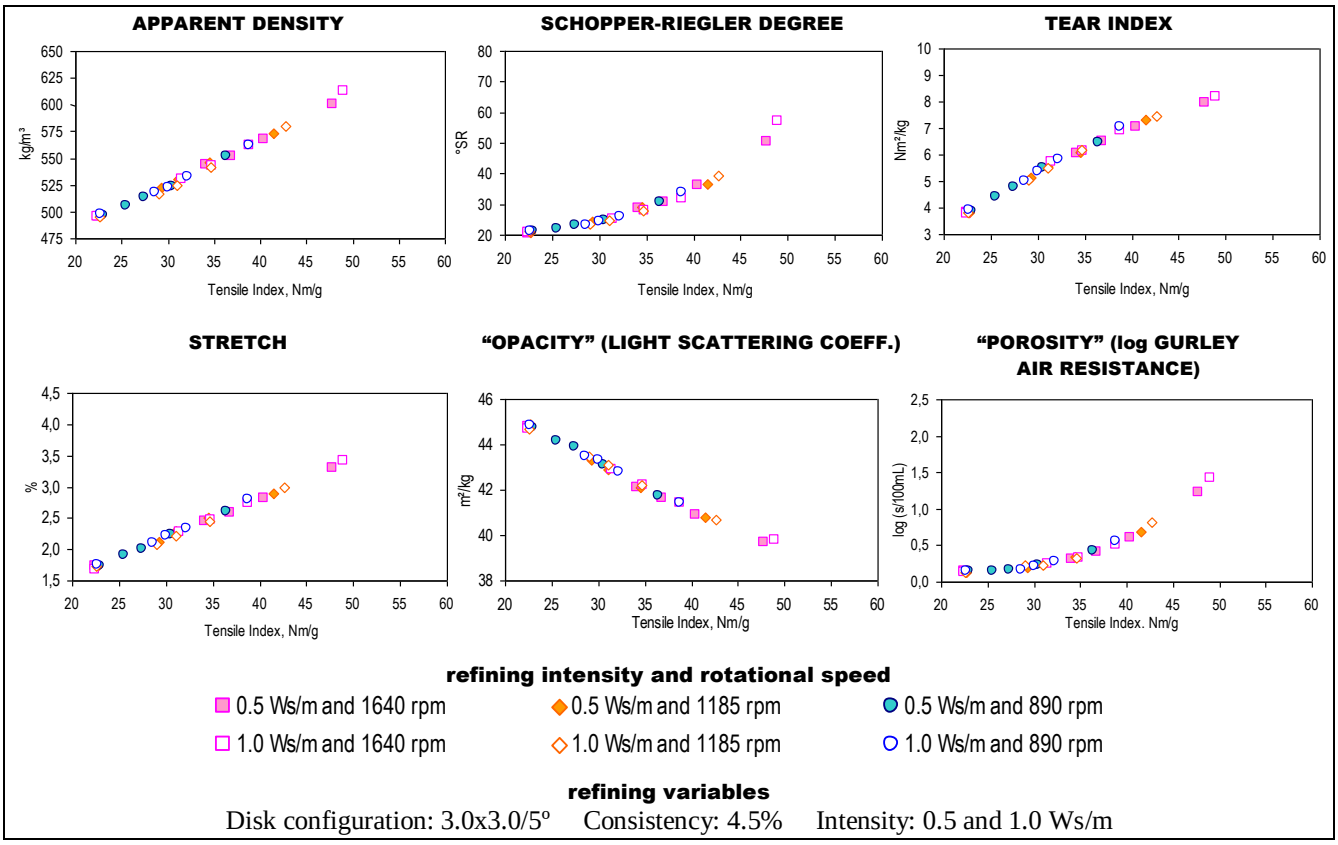


Figure 9 – Pulp property relationships. Comparison at same Tensile Index for different refining intensity and rotational speed.

CONCLUSIONS

Refining operation is the most critical parameter in assuring good results for both the development of paper characteristics and for paper machine runability and costs.

The results from pilot plant refining curves using the commercial BEKP showed that the best performance, in terms of energy consumption, is reached when the lowest refining intensity is used.

A significant effect of pulp consistency was also observed. Within the evaluated range (3.0 to 6.0 %), refining performed at higher pulp consistency showed lower refining energy requirement to reach the same pulp property values.

In cases where refining was performed under constant refining intensity (specific edge load), no effects from plate design (disk configuration) neither from disk rotational speed (refiner speed) were observed.

Pulp property relationships were not affected by the refining operational variables. This is an important result because it shows that papermakers can optimize refining process, energy consumption in special, without negative impacts on paper quality. Nevertheless, depending on the characteristics of the actual refining installation, some improvements should be necessary.

These results illustrate that eucalyptus kraft pulp must be refined under both the lowest refining intensity and the highest consistency as possible. Such operational conditions assure papermakers to get the best refining results.

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