Papermaking

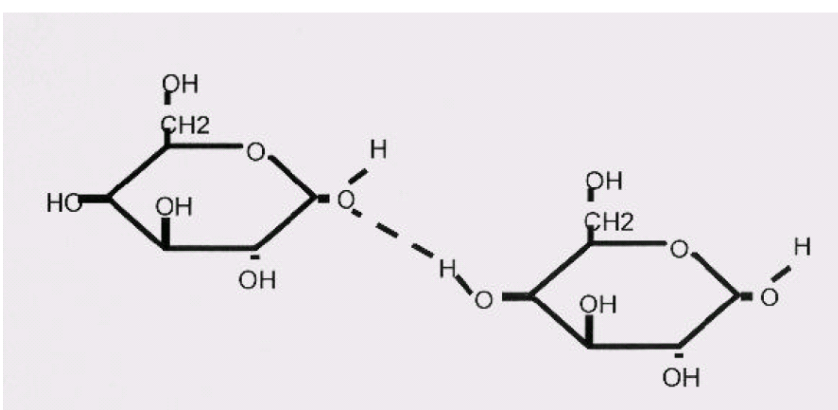
STOCK PREPARATION – LC REFINING

A special thanks to FineBar™ for the excerpted notes from their
Introduction to Stock Prep Refining Manual available at:
www.finebar.com

1. Structure of Paper & The Role of Refining

Paper is a tangled web of fibers. The fibers are more or less lying in a flat plane, and they are attached to one another at the many points of contact that occur wherever one fiber lies across another fiber. The strength of paper is largely determined by the strength of the attachments at these fiber crossing points. While it is true that strength of the individual fibers can also be a factor in determining the strength of the resulting paper, it is often the case that paper fails when the fiber-fiber bonds fail.

The linkage that occurs at the fiber crossing points of paper is made up of hydrogen bonds which are formed between corresponding points on two cellulose or hemicellulose molecules when an interconnecting water molecule is removed by drying. A representation of this type of bond in cellulose is shown below.

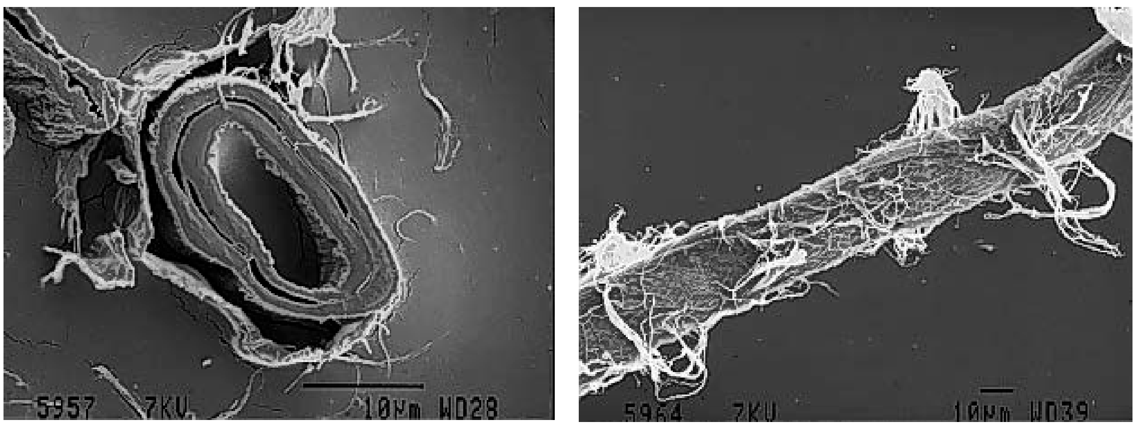


Anything that can increase the number of hydrogen bonds engaged at a crossing point will increase the strength of the linkage and, thus, the strength of the paper.

For simplicity, consider just two fibers and a single crossing of one over the other. If the cell wall of these fibers is very rigid, as with a glass tube for example, the area of contact at the crossing point will be small. On the other hand, if the fiber walls are very flexible, as with a bicycle inner tube, the contact area at the crossing point will be much larger. It is important to recognize that as fibers become mo re flexible and collapse to ribbon-like structures, the contact area increases dramatically – as does the potential number of hydrogen bonds that can be formed. The thickness of the cell wall has a dominant influence on the "collapsibility" of the fiber. For this reason, the type of wood used largely determines the potential for achieving critical paper properties. However, for any given fiber source and pulping process, it is the process of refining which essentially determines the extent to which the fibers collapse.

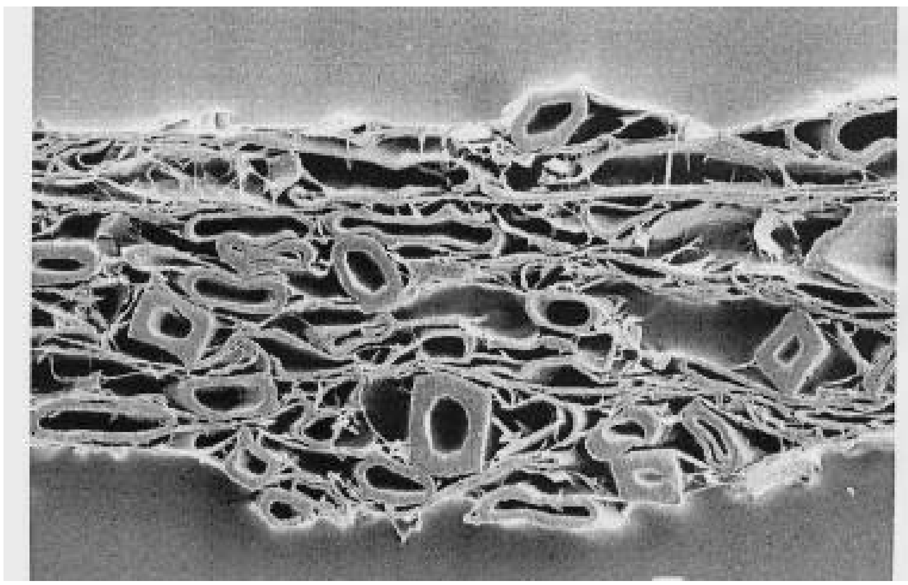
The degree of fiber collapse and the resulting increase in contact area are important in determining how many bonds can potentially be formed. It is also necessary that the surfaces in contact have a relatively large number of exposed bonding sites. This can be accomplished by ensuring that all the surface lignin has been removed together with the primary cell wall, and that many of the fibrils near the exterior of the S2 layer are "teased" out so as to create the effect of a frayed rope. The removal of lignin and primary wall material is largely accomplished in the pulping process. The "teasing out" of fibrils, referred to as fibrillation, is accomplished in refining.

The principal objectives of stock preparation refining are thus: 1) to increase the flexibility of the cell wall to promote increased contact area, and 2) to fibrillate the external surface of the fiber to further promote the formation of hydrogen bonds and increase the total surface area available for bonding. From the figure below, we see that the cell wall is weakened through delamination of the cell wall and the outer wall of the fibre is fibrillated.



Now that we have examined what happens at a single fiber crossing point, we can consider what the aggregate effects are on the structure of the paper sheet.

The function of the paper machine is to convert a suspension of fiber and water into a relatively moisture-free web with specific characteristics. If you visualize a layered structure of fibers piled one on top of the other, the thickness of the resulting paper may be equivalent to anywhere from five individual fiber thicknesses up to several tens of fiber thicknesses. If the fibers act like rigid cylinders, the paper sheet will be very thick and full of void spaces (i.e. it will be bulky); whereas if all the fibers collapse to ribbons, the sheet will be much thinner and denser. Indeed, the most evident result of refining is an increase in the density of the paper that is formed. Along with this increase in density comes a reduction in air permeability (or porosity), an increase in tensile strength, and often a reduction in tear strength. Whether or not a reduction in tear strength occurs, refining almost always increases the fracture toughness of the sheet. It is easy to imagine that surface smoothness will be better when ribbons are used in place of rigid cylinders, so long as the ribbons lie flat in the plane of the sheet. Figure below shows a typical cross section of paper, illustrating quite clearly how fiber collapse might affect several paper properties.



Another effect of increasing bonding and paper density is to make the resultant sheet less opaque (i.e. more transparent). For printing papers, this is an undesirable side effect because sheet opacity is important in preventing the printing on one side of the paper from showing through on the other side.

It is important to remember that there are other steps in the forming process that substantially affect paper properties. After the sheet is formed on the machine, water is removed in the press section where the nature and extent of press loading can have considerable effects on paper properties. Pressing increases the density of the wet mat and of the finished paper as well. In the drying section of the machine, conditions will again affect final sheet properties. Hydrogen bonds form when intervening water is removed, after which a significant amount of shrinkage takes place both in the individual fibers and in the paper sheet. Fibers shrink mostly in the cross-wise direction rather than along their length. However, the cross-wise shrinking of one fiber can cause a length-wise compression of a fiber that is bonded to it in a perpendicular orientation. The resulting internal stresses can dramatically affect paper properties (e.g. dimensional stability, curl). The extent to which the sheet is restrained during drying can play a large role in determining paper performance.

Clearly, while refining is a very important step in engineering the structure of paper, is only one of several critical process steps. It is impossible to optimize any one of the critical steps without due consideration of the others.

So far, we have discussed the refining process and how it affects paper structure in a mostly qualitative way. In later sections, we will try to quantify the process and learn how to use refiners and refiner fillings to assist the paper maker in achieving economic and product quality benefits.

2. Refining Equipment

Laboratory refiners

PFI Mill

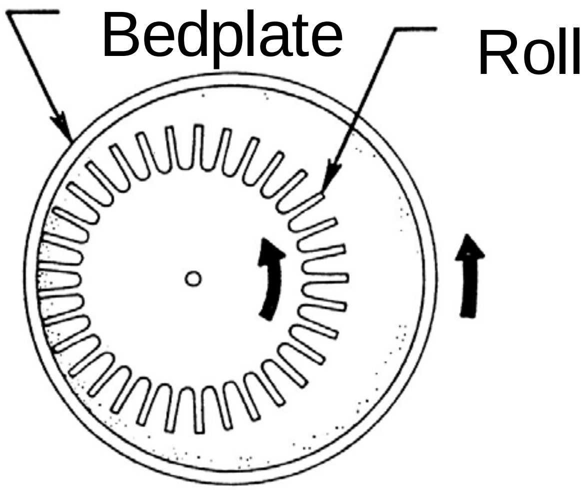
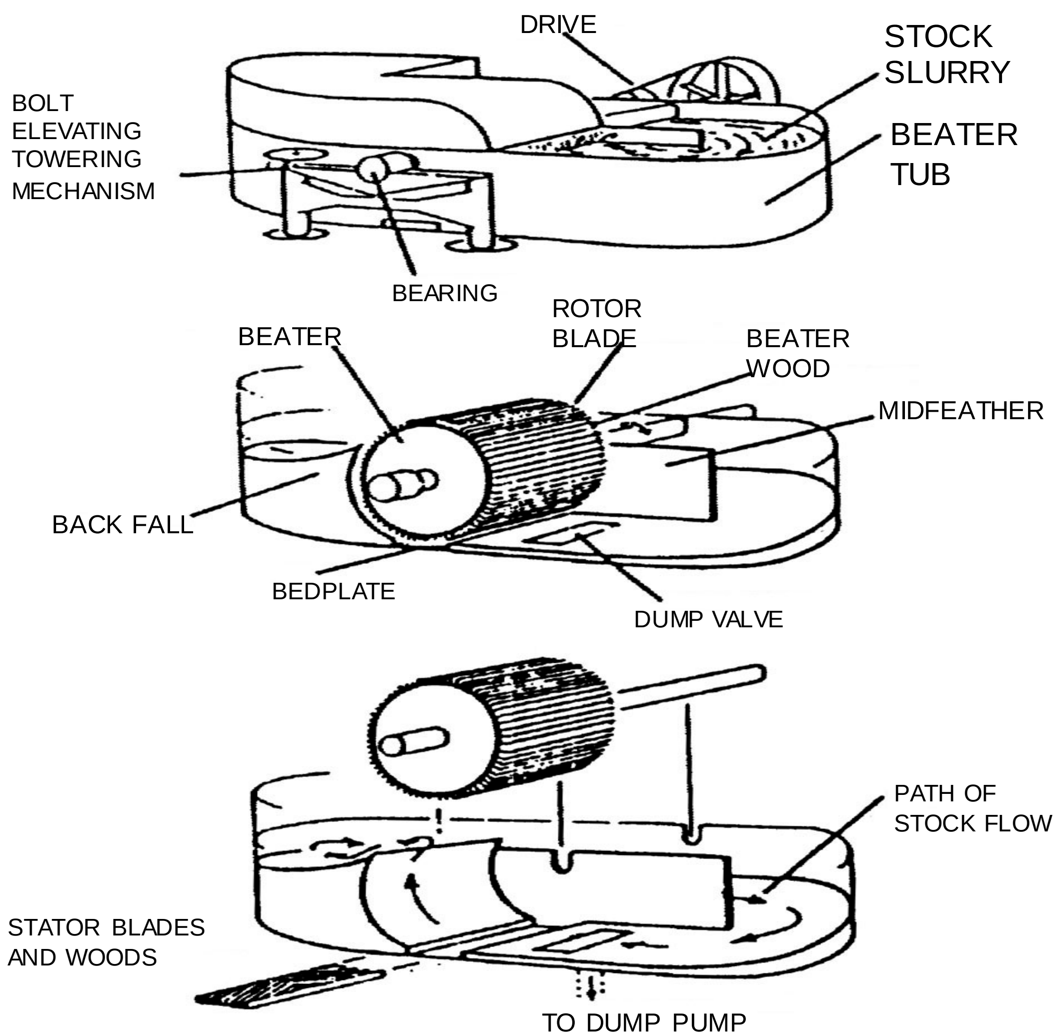


Figure: PFI laboratory refiner

To evaluate pulp in the laboratory, it must be first beaten or refined, as is the case in industrial papermaking. Several types of laboratory refiners exist for this purpose. The most common is the PFI mill. The PFI mill, shown schematically, is by far the most common laboratory refiner in use today. However, its action differs substantially from industrial refiners. It operates at 10% consistency as opposed to the normal 3-4% in industrial refiners. It is in essence a very high energy, very low intensity refiner. It gives strength increases often well beyond those obtained in mill refiners



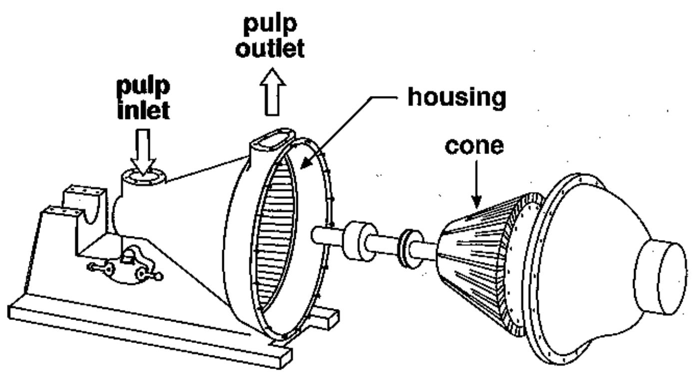
Hollander Beater

The **Hollander Beater** was invented in Holland in the late 17th century.

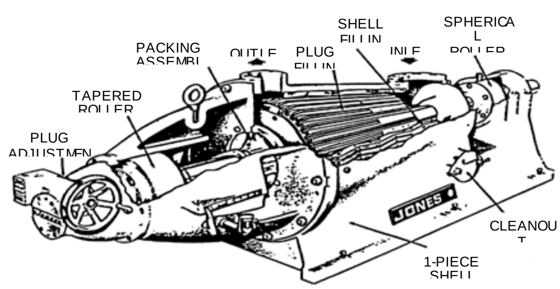
This is one of the first refiners used. It uses a bar and groove rotor to impose cyclic compression into the fibres as they flow through an open trough. These are not used commercially but are used in some laboratories and used in making 'hand-made' papers.

Modern refining equipment

Refiners can be either disc refiners or conical refiners. Conical refiners are shown in the following figures. The pulp enters through a feed port, travels between a conical rotor and stator and then leaves through the discharge port. The rotor and stator will have a bar and groove pattern. Only one of the elements will rotate (the rotor). The gap between the refiners can be controlled by pushing the rotor and stator together.

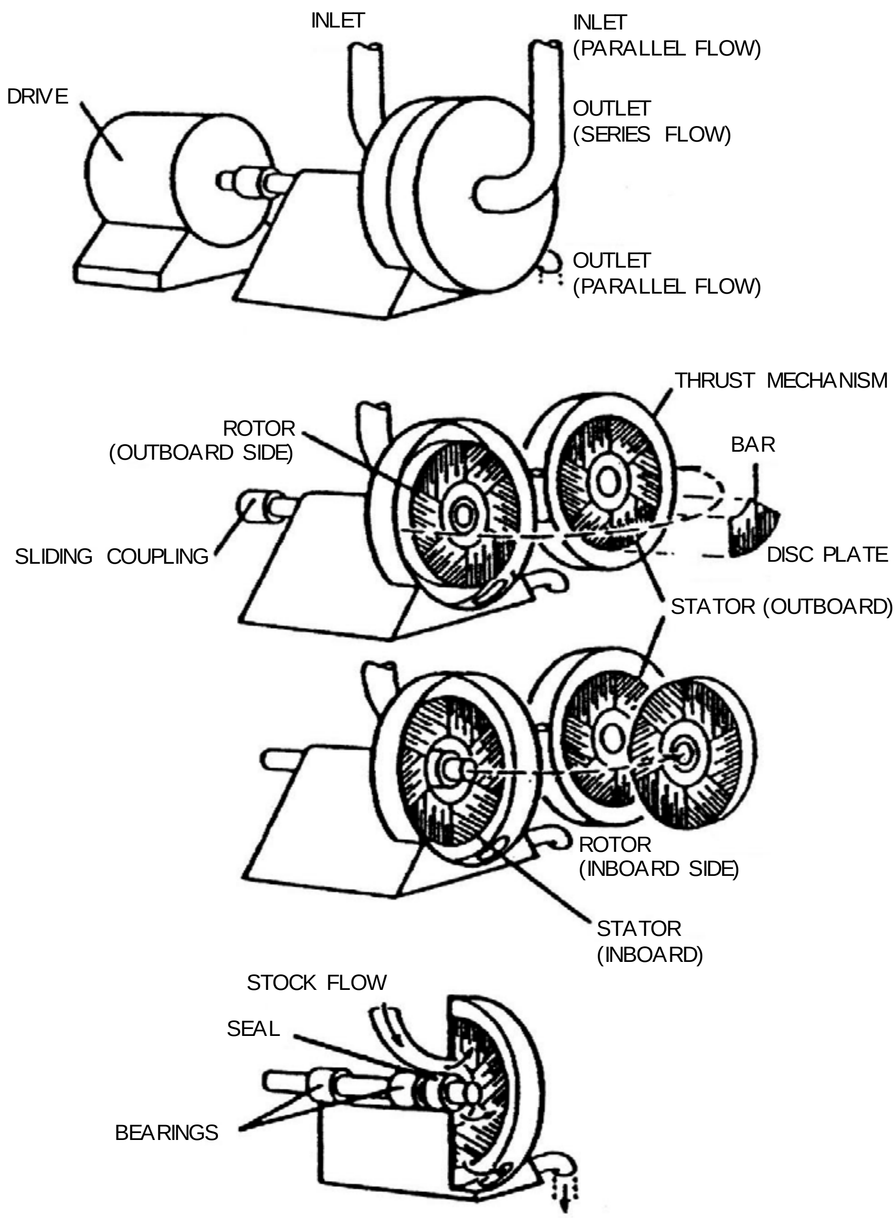


Conical Refiners

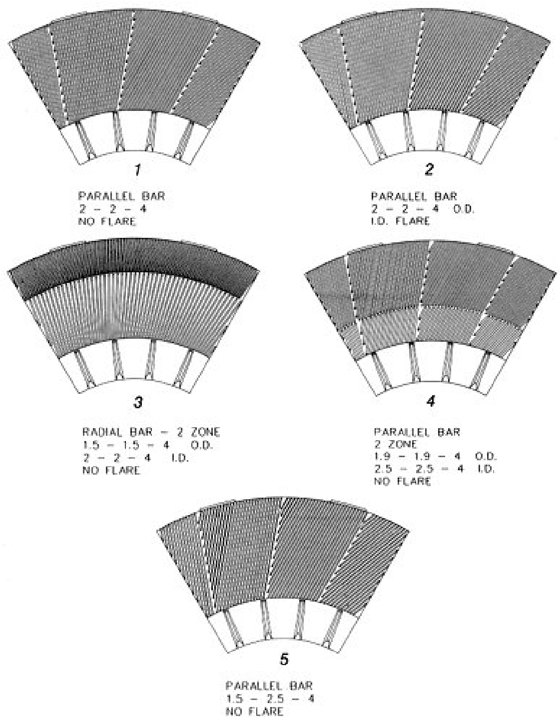


A disc refiner is very similar to the conical refiner. The pulp travels between two discs with bars and grooves. There are essentially three categories of disc refiner:

1. Single disc refiners, where the pulp goes between a rotating rotor and a stationary stator.
2. Twin refiner where the rotor and stator both rotate.
3. Double disc refiner where the pulp moves between a rotating rotor that has bars and grooves on both sides and it moves against two stationary stators.



The refiner plates come in a large number of patterns to control the intensity of treatment and capacity, although, these are often competing. Refiners can have a ‘fine’ bar pattern that gives high intensity but lower throughput or can have a coarse bar pattern that gives a high intensity treatment (even cut the fibres) and a larger flow rate through the refiner. The sampling of the different types of patterns can be seen below.



4. Theory of Refining

i) Qualitative Analysis

In this section, the details of stock preparation refining process will be examined more closely. It will be shown that fiber and pulp properties can be manipulated by altering the refiner plate configuration and the operating conditions of a refiner in order to achieve an optimal combination of paper properties.

Pulp refining is a process in which fiber flocs collect on refiner bar edges and are subsequently deformed by compressive and shear forces such that the cell wall of at least some of the fibers is permanently modified.

The nature of the cell wall modification is dependent on the magnitude of the compressive stresses (or strains) that occur during the deformation of the fiber flocs. The extent of the cell wall modification depends on how frequently fiber flocs are collected and subsequently deformed for a given mass of fiber. In pulp refining, we are interested in both the magnitude and the frequency of these deformations.

Within each fiber floc, the average cell wall deformation of individual fibers is directly related to the deformation of the floc itself: e.g. if the floc is only slightly deformed, then the average fiber cell wall deformation will also be slight. On the other hand, if the floc is greatly deformed, then the stresses and subsequent deformation of individual cell walls will be much greater. If the deformation of the fiber floc is so extreme as to cut it into two, a portion of the fibers within the floc are also likely to be cut.

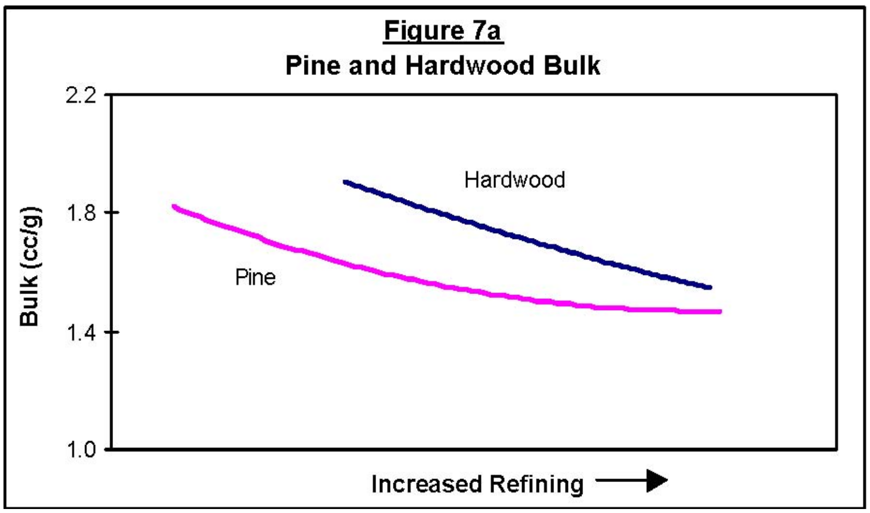
Recognizing that the deformation of the cell wall of an individual fiber during refining can only be accomplished by deforming the fiber floc in which it lies is a very important concept. First, it makes it quite obvious that the nature of deformations is highly varied. Even if it were possible to precisely control the degree of deformation of the floc, the randomly distributed fibers within the floc would be subjected to a wide range of deformations. Therefore, it is only possible to speak of average degrees of deformation and average subsequent effects on fibers. Second, it underscores the importance fiber flocs. How many and how large are the flocs that support the refining load at any instant? What effect does a change in the refiner filling design have on the size and number of fiber flocs?

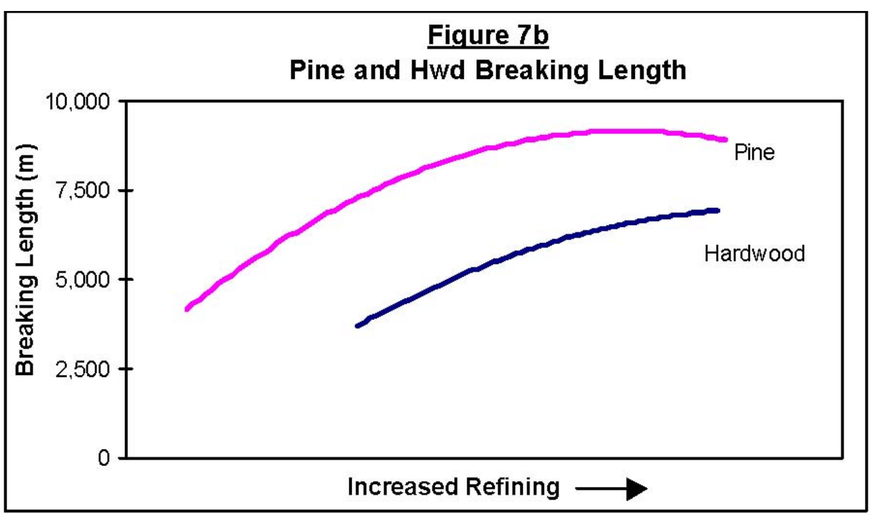
In the earlier section on paper structure, the two-fold objective of stock preparation refining was described as follows:

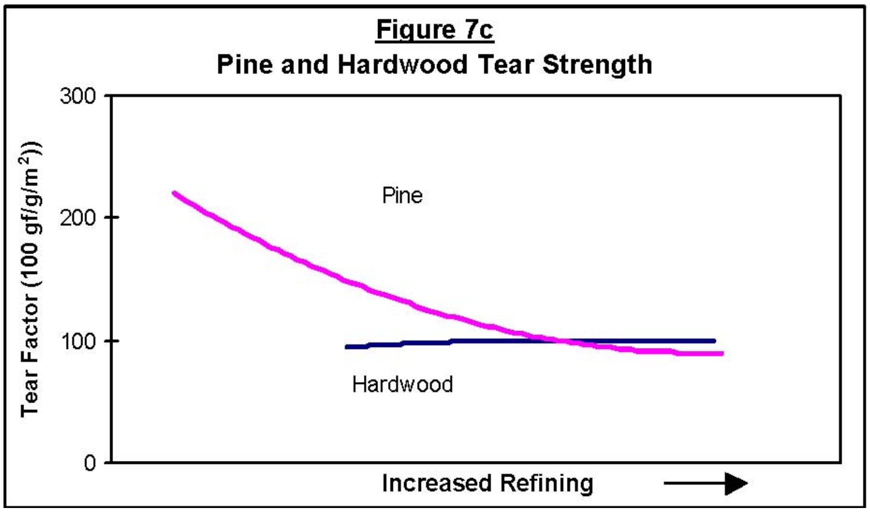
1. Increase the flexibility of the cell wall in order to promote increased contact area, and
2. Fibrillate the external surface to further promote the formation of hydrogen bonds as well as increase the total surface area of fiber available for bonding.

The more refining that is done, the greater the increase in both fiber flexibility and surface fibrillation. Yet for a given amount of refining, there is no direct evidence linking the nature of the cell wall deformation with the resulting fiber characteristics. This would require a mechanism for precisely deforming a large number of individual fibers and then applying some sort of quantitative inspection criteria on those fibers after deformation. Nonetheless, there is some indirect evidence from measured pulp and paper properties which suggests that high magnitudes of cell wall deformation tend to cause surface fibrillation and internal swelling and, in the extreme, fiber cutting. Lower magnitudes of cell wall deformation tend to promote surface fibrillation without much cell wall swelling, along with a greatly reduced likelihood of fiber cutting. Recognizing the probabilistic nature of the refining process, it is quite certain that all of these effects take place to some degree under any given refining condition. However, it is possible to control the emphasis of one effect relative to the others by controlling the intensity of refining.

In the following section, the idea of refining intensity and its relationship to cell wall deformation will be discussed. Quantitative methods for calculating intensity will be described, and the practical application of these analytical methods to papermaking problems will be reviewed. Before discussing the effects of refining intensity, it is worthwhile looking at the general behavior of paper properties as the amount of refining is increased. Figures below illustrate typical refining trends for mill refined softwood and hardwood kraft pulps.







ii) Quantitative Analysis

Specific Energy

The main parameter to characterize the refining effect is the amount of energy that is delivered to the pulp. This is called the Specific Energy, *E*, and it is calculated as,

$$E = \frac{P - P_{No-Load}}{QC}$$

Where Q is the volumetric flow rate through the refiner and C is the consistency. It is usually given in kW hr/tonne. The table below gives the typical specific energy input for the major grades (ref: FineBar)

Table: Specific Energy input for the major pulp grades (ref: FineBar)

Grade	Pulp	hpd/t	kWh/t
Fine Papers	Hardwood	1.5-6.0	30-120
	Softwood	2.0-6.0	40-120
News	SW Kraft	1.0-3.0	20-60
	Groundwood	1.0-3.0	20-60
Linerboard	OCC	1.5-3.0	30-60

Table: Typical Freeness drop for a given Specific Energy (ref: FineBar)

Furnish	CSF Drop per 20 kWh/t
Bleached SWD Kraft	20-40 ml
Bleached HWD Kraft	60-100 ml
GWD / TMP	3-7 ml
OCC	40-70 ml
Mixed Office Waste	50-70 ml
News	10-25 ml

<u>Specific Edge Load Theory</u> At the microscopic level of fibers and fiber flocs, refining effects are dependent on the magnitude and frequency of deformations. In the macroscopic world of commercial papermaking, we cannot directly control these factors. However, we can control them indirectly by making two broad assumptions.

We can first assume that the greater the number of bar edges available in the refining zone, the greater will be the number of fibers able to absorb a given refining load because fiber flocs are collected on bar edges. The average number of crossing points where flocs can be caught between opposing edges of the rotor and stator plates can be calculated based on the inner and outer diameter of the plates, bar and groove widths, and the average radial angle of the rotor and stator bars. While the term ‘bar edge length’ is generally used to describe this factor, it is mathematically proportional to the average number of crossing points.

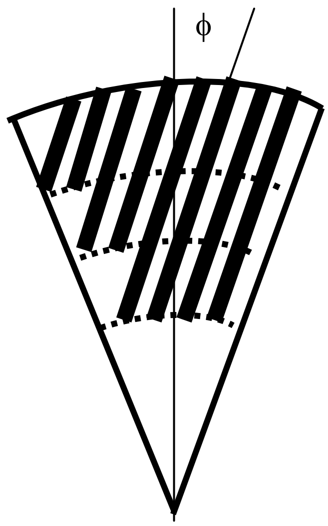
Second, we can assume that the torque applied by a refiner motor is directly proportional to the normal force acting to push a refiner rotor against a stator. This means that, with a fixed motor speed, the motor power is proportional to the normal force.

With these two assumptions, it is possible to conclude that the average magnitude of fiber deformation is directly related to the applied power divided by the product of rotating speed and edge length. This is the basis of the Specific Edge Load Theory which was first introduced back in the 1960's. The calculated variable is referred to as 'refining intensity' or 'specific edge load' (SEL), and is typically expressed in units of watt-seconds per meter (Ws/m).

In order to calculate the refining intensity, it is necessary to first determine the true load applied to the fibers. In a commercial refiner, there is significant power consumption resulting from hydraulic losses. The bars and grooves of the refiner filling accelerate and decelerate the fluid as it passes through the refiner, causing a heating of the fluid but no net refining effect on the fiber in the process. This is called the 'no-load power' and it must be subtracted from the total motor load in order to accurately define the net power actually applied to the fibers.

Given these relationships, the intensity, I, (Specific Edge Load, SEL) of refining may be calculated according to the following equation:

$$I = \frac{P - P_{No-Load}}{\left(\frac{RPM}{60}\right)\left(BarEdgeLength\right)}$$



$$BarEdgeLength = \int_{R_1}^{R_2} \frac{n_r n_s}{\cos\phi} dr \approx \sum_{i=1}^{N} \frac{n_{r_i} n_{s_i}}{\cos\phi} \Delta r$$

(Note: Bar edge length is sometimes called the 'cutting edge length')

Where ϕ is the angle the bar makes with the radial direction and n is the number of bars at the radius, *r*.

Bar edge length is the total length of bar edges that the fibres will see in one revolution. Note that for a double

Table: Typical intensities used for different pulp types

	SEL (Ws/m)
Unbleached SWK	2.0-3.0
Bleached SWK	1.0-2.0
Bleached HWK	0.2-0.6
Bleached Eucalyptus	0.2-0.6
Recycled Fiber*	0.2-0.8
TMP/GWD post-refining	0.2-0.5

*depends on fiber type

To define the refining process, it is not enough to know the magnitude or intensity of deformations. It is also necessary to know the frequency or, more accurately, the average number of deformations per unit mass. Computing the average number of deformations requires the assumptions that the deformation at any crossing point occurs over a finite time interval, and that the number of deformations per unit time is directly proportional to the rotating speed. Thus, the number of deformations per unit mass (N) is calculated according to the following equation:

$$N = \frac{\left(\frac{RPM}{60}\right)\left(BarEdgeLength\right)}{QC}$$

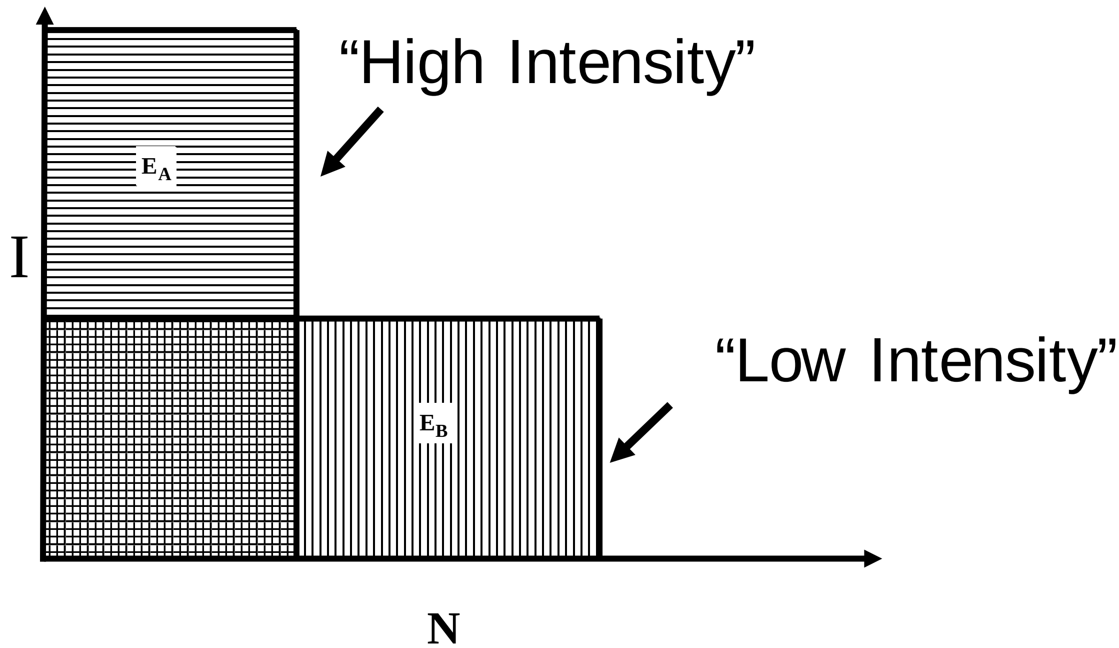
Note: TPD is the mass flow rate of pulp through the refiner

Since the amount of refining (P) is by definition equal to the product of the magnitude and the number of deformations, it can be calculated according to the following equation:

$$P = I \bullet N$$

Note that I is Power divided by a constant and N is equal to the same constant divided by F.

$$E = \frac{P}{K} \bullet \frac{K}{F}$$



The traditional application of refining theory usually refers to the specification of two parameters: Specific Energy (equal to P above) and Intensity (equal to I above). There is seldom any specific reference to N. However, a useful insight is gained by knowing that applied power determines the magnitude of deformations while throughput determines the number of deformations.

<u>C-Factor Analysis</u>. In recent years, the introduction and application of the C-Factor analysis by R.J. Kerekes et al. has lent substantial credibility to the notion of I and N. The C-Factor analysis takes the refining theory a step further by incorporating values for average fiber length and fiber coarseness in order to calculate I and N on a 'per fiber' basis.

C-Factor analysis also takes into account certain factors relating to bar and groove geometry which provide for a more accurate description of refining intensity.

It is appropriate to use both Specific Edge Load and C-Factor methods when analyzing a refiner filling application. It is important to recognize that SEL does not take into account fiber characteristics but does provide a benchmark value for which there exists a great deal of historical information.

The actual equation for the C-Factor calculation is too complex to include here. In fact, it is somewhat tedious to perform the calculation in the absence of a computer program. Virtually all C-Factor analyses are performed using a spreadsheet program that requires input information regarding refiner size, speed, no-load power and motor load. It also requires input on refiner filling configuration (including bar and groove widths, depths and radial angles), as well as input regarding pulp consistency, throughput, fiber length and coarseness. The output of the spreadsheet program includes a value called the C-Factor which of itself is not physically meaningful, and the two values I and N on a per fiber basis.

8. Refiner Plate Selection: *i) The Correct Amount of Refining (Specific Energy Input)*

The net specific energy consumption of a refiner or refining system determines the amount of refining that is applied to a pulp. Common North American units are horsepower per short ton per day, or hpd/t. The common metric units are kWh/metric ton.

Example calculations:

a) With a flow rate of 500 gpm and a consistency of 4.5%, the throughput is: t/d = 500 x 6.0 x 0.045 = 135 st/d

b) With a flow rate of 1200 lpm and a consistency of 5.3%: t/h = 1200 x 0.06 x 0.053 = 3.8 mt/h

c) If the motor load is 575 hp and the no-load power is 115 hp, then the net applied power is: 575 – 115 = 460 hp
and the specific energy input is: 460 hp / 135 t/d = 3.4 hpd/t

To convert from hp to kW, multiply hp by a factor of 0.746. The equivalent specific energy calculation for the flow rate of 1200 lpm would then be: (575 hp x 0.746) – (115 hp x 0.746) = 342 net kW 342 kW / (1200 * 0.06 * 0.053) = 90 kWh/t

According to these equations, if the applied motor load is increased or if the throughput is decreased, then the net specific energy will increase.

The specific energy required for a given installation is usually determined based on historical experience at a given mill. Even for the same or similar grades, and the same fiber source and pulping process, two paper mills may apply significantly different specific energy levels in the stock preparation refining system. Table 4 shows some typical energy ranges for different paper and paperboard grades.

Table 4

Grade		Net hpd/t
Fine Paper	HWD Kraft SWD Kraft Tickler	2-5 3-7 1-1.5
Linerboard	Base Top	5-7 10-12
News	SWD Kraft TMP/GWD	2-5 1-5
GWD Printing Paper	SWD Kraft TMP/GWD	3-7 3-6

An estimate of the specific energy requirement can be made for a given type of pulp if the unrefined pulp freeness and the target freeness level are known. By subtracting the target freeness from the unrefined freeness, the total amount of freeness change is calculated. Values in Table 5 can then be used to predict approximately how much energy should be required to achieve the desired freeness drop.

Table 5

Furnish	Freeness Drop / Net hpd/t
Bleached SWD Kraft	20-40 ml
Bleached HWD Kraft	60-100 ml
GWD	3-7 ml
OCC	40-70 ml
Mixed Office Waste	50-70 ml
News	20-35 ml

Note that this represents a rough guideline only. It is often the case that specific energy requirements are best determined based on paper quality checks during mill processing. It is therefore advisable that the available power for refining be around 25% greater than the expected nominal level.

5. **Refiner Plate Selection**:*ii) The Correct Intensity of Refining (Specific Edge Load)*

Determining “the best” refining intensity for a particular refining application can be considerably more difficult than specifying the required specific energy input. Even with a substantial background of mill operating data, designing a refining system to operate at optimal intensity involves several economic trade-offs. Hence, it requires a clear understanding of the economic impact of paper quality improvements.

If a pulp is only lightly refined, the refining intensity is usually not so important because there is not enough fiber modification taking place to make the difference discernable. An exception to this is the refining of unbleached kraft for sack paper applications for which the initial increase in tear with refining can only be assured if the intensity is sufficiently low (i.e. 1.5-2.0 Ws/m).

The benefits of low intensity refining for hardwood pulps and for mechanical pulp post-refining are quite widely acknowledged by papermakers. In the past, the lower limit of intensity had been established at 0.6-0.8 Ws/m due to the limitations of plate manufacturing technology. However, recent developments in this area have enabled intensities of 0.2-0.6 Ws/m to be achieved while maintaining efficiency and hydraulic capacity.

Low refining intensity has long been considered unnecessary for softwood pulps and deemed too costly in terms of potential increases in specific energy requirements. This view is changing as many mills are seeking gains in tear strength and toughness that lower refining intensity can provide. Many mill refiners currently operate in the range of 2.0 – 4.0 Ws/m. Any easily achieved reduction in intensity will almost always be beneficial to quality.

For hardwood pulps, low refining intensity results in greater bulk and opacity at a given level of most strength properties. There is no substantial evidence to demonstrate that refining intensity can be too low in the case of hardwood pulps. Most mill refiners currently operate in the range of 0.6-1.0 Ws/m, and nearly all applications could benefit from any reduction achieved by changing plate patterns. Another key benefit of low intensity refining for hardwood is the reduction in energy required to achieve a given pulp quality or drainage level. Figure 8 shows a compilation of pilot plant and mill data illustrating the impact of intensity on freeness drop for various bleached hardwood pulps.

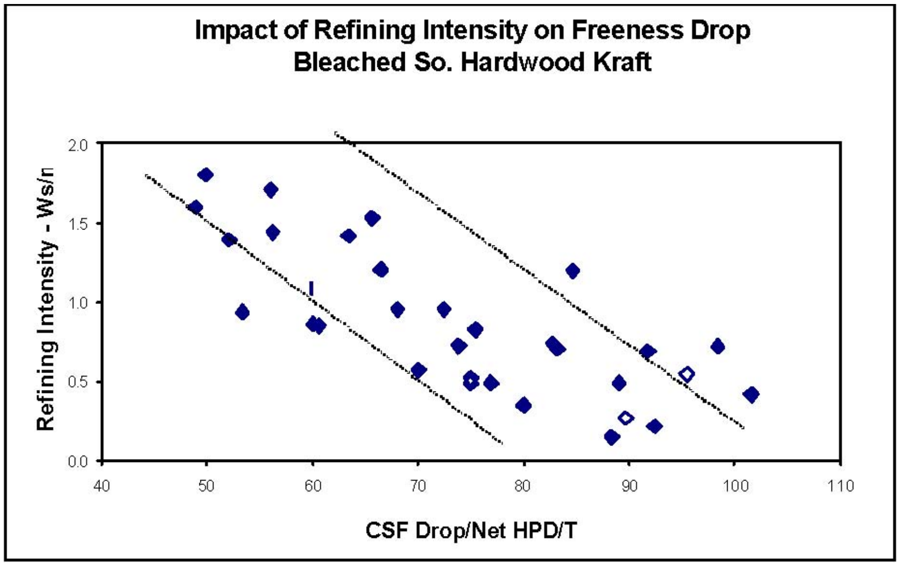


Figure 8

The data points clearly show a trend of increased freeness drop per net hpd/t applied as the refining intensity is reduced from 2.0 to 0.2 Ws/m. In other words, less energy is needed to achieve a given freeness. This can be taken as an operating cost reduction, or as an increase in power available for quality enhancement or to accommodate a higher throughput.

For mechanical pulp post-refining, low refining intensity will yield higher freeness, increased fiber length and improved tear strength at a given debris level and energy input. At an equivalent freeness (with higher specific energy input), reduced debris levels can be obtained.

Table 6 lists recommended ranges of refining intensity for various types of fiber. For most applications, refining intensity should be as low as is practically achievable in order to maximize pulp quality potential.

Table 6

Fiber Type	Refining Intensity (Ws/m)
SWD Kraft	1.0-2.5
HWD Kraft	0.3-0.8
Recycle	0.2-0.8
TMP/GWD	0.2-0.5

In certain softwood refining applications, reducing the total power consumption or increasing the power available for refining can be more beneficial than achieving the lowest possible intensity level. In these instances, it is often possible to reduce the active diameter of the refiner by using reduced periphery plates. The reduced active diameter will have a lower no load power demand. The relationship between plate diameter and no load is as follows:

$$\text{No load power} = k * \text{diameter}^{4.3} * \text{rpm}^{3}$$

Note: Diameter is in inches, power is in HP

Table 7 demonstrates the potential energy savings that would result from a reduction in the active diameter of refiner plates operating at typical speeds.

Table 7

Active Plate Diameter in	Reduced Active Plate Diameter In	Estimated Power Savings hp	Annualized Savings at $0.045/kWh $
46	43	83	$24,400
46	40	150	$43,800
42	39	90	$26,460
38	35	65	$19,100
34	31	75	$22,020
30	27	45	$13,275
26	23	45	$13,275

Depending on the specific circumstances, a mill may choose to take the economic benefit of the no load power savings, or they may use the additional available energy to achieve quality benefits.

Whether full diameter or reduced periphery plates are used, it is nearly always beneficial to use the narrowest practical bar width and groove width in any refiner. The practical limits of bar and groove width depend on the specifics of the application. The following guidelines apply:

Bar Width. In the absence of potential metal contamination and no-load power concerns, the width of bars would be only as great as required to rigidly hold the flocs of pulp that are being deformed. In real situations, the bar width is dictated mostly by the metal contamination potential of the application. Metal contamination introduces bending loads on the bars that far exceed the normal refining load. As a result, the minimum practical bar width is usually in excess of 0.050”. Experience has shown that in a refiner where baling wire contamination is likely, the minimum bar width should be in the order of 0.075”.

Groove Width. The minimum practical groove width is usually determined by the tendency for plugging of the groove, either by fiber or by a common contaminant. For post-refining of groundwood in a contaminant free system, a groove width of 0.050” would be possible. For hardwood pulps the groove width should be at least 0.075”. For softwood pulps the groove width should be at least 0.090” or 0.125”, depending on the average fiber length of the species being refined. Another factor to consider is that no-load power varies directly with the hydraulic section or open area of the cross section of the pattern. A plate with 1/8” grooves and 1/4” bars will have a higher no-load power than a plate with 1/4” grooves and 1/8” bars.

Minimum bar and groove widths create the lower limit of refining intensity for any given refiner size operating at a fixed speed. If there is a strong quality incentive to reduce intensity further, it can only be done be adding additional equipment.

6. Flow Considerations in a Stock Preparation Refiner

All stock preparation refiners are hydraulic machines with high speed rotating elements. That means that they operate in an incompressible medium (no appreciable air or other vapor present) and are subject to the considerable influence of fluid friction and centrifugal forces. They act much like centrifugal pumps, albeit with very leaky wear plates.

As discussed previously, the capacity of a refiner may be limited by the available net power which will limit the amount of refining that can be done. It is very important to recognize that the capacity of a refiner is also limited by its ability to pass a volumetric flow. The flow capacity of a refiner is determined by its disk diameter, its operating speed, and the hydraulic section and pumping angle of the installed refiner plates. Table 8 contains the recommended flow ranges for different sizes of double disk refiners. In most instances, the high end of these ranges is very optimistic and will result in poor refining with very short useful plate life. High flows are primarily encountered with tickler refiners where the entire flow of the paper machine stock must pass through the refiner.

Table 8

DOUBLE DISK REFINER CAPACITY CHART RECOMMENDED FLOW RANGES FOR VARIOUS SIZE REFINERS		
PLATE DIAM. INCHES	**MAX POWER HP MOTOR RPM NOMINAL NO LOAD HP**	**FLOW RATES -GPM LOW MED HIGH**
20	300 900 75	150 250 400
24	450 720 85	250 350 600
26	500 720 120	300 450 800
30	600 600 125	375 600 1100
34	800 514 135 1000 600 215	475 750 1400 550 875 1650
38	1250 514 215	650 1075 2025
42	1500 450 220 1750 514 330	775 1250 2400 900 1450 2800
46	2000 450 325	1025 1675 3275
52	3000 400 385 3000 450 550	1300 2150 4300 1475 2425 4850
54	3000 400 450	1475 2425 4850

General Bibliography

For additional information on this topic, a list of literature references can be found in the Resource Center at the FineBar website www.finebar.com. Also on the web site is a Stock Prep Calculator that can be used to calculate refining energy, intensity, and many

1. Isenberg, I.H.; Pulpwoods of the United States and Canada (1981)

2. Paulapuro, H.; Papermaking Science and Technology Book 8: Papermaking Part 1, Stock Preparation and Wet End; Finnish Paper Engineers' Association and Tappi Press (2000)
3. Scott, W.E. and Abbott, J.C.; Properties of Paper: An Introduction, 2nd edition; Tappi Press (1995)
4. Smook, G.A.; Handbook for Pulp & Paper Technologists; Tappi Press (1988)

Appendix A

No-Load Power in a Stock Preparation Refiner

In all pump-through refiner applications, a certain amount of applied power is consumed by the hydraulic pumping effect and the energy loss associated with viscous shearing of the fluid. This is called the “no-load” or circulating power. This energy produces no measurable change in the properties of the pulp being refined, except in the case of very sensitive pulps and/or very low relative throughput rates.

No-load power is mostly dependent on the diameter and rotational speed of the rotor, but it can also be significantly affected by the bar and groove configuration of the refiner plates. Factors such as flow rate, stock consistency and plate gap have a relatively minor influence. Contrary to frequent supplier claims, no-load is not dependent on the weight or mass of the rotating elements. The inertial mass of the rotating elements affects only the acceleration time for the motor-refiner system at motor start, and the resulting torsional loads on the rotating system.

Since all changes in pulp properties are determined by the “effective” power applied (i.e. total motor power minus no-load power), it is important to know what is the actual no-load power for any given refiner, installed plate pattern, and relative plate wear.
No-load can be determined by careful measurement or it may be calculated in accordance with theoretical formulas. A precise measurement of no-load power requires that the rotor be firmly held so as to prevent contact with the stators on either side. Because of the radial variability in the static pressure profile acting on each side of the rotor, it is often the case that instability exists which causes the rotor to lean against one or the other of the stators. If only water is present, it will result in noisy contact and a slight increase in

the measured load. The absence of a fiber mat will also result in a slight scarring of the bar surfaces of the refiner plates. If fiber is present, this instability can result in a significant increase in measured load and is usually the cause of incorrect no-load measurements. It is important to recognize that, for any given refiner with a given plate pattern, the no-load power will vary considerably from a maximum value when the plates are new to some much lower value (as much as 60-80% lower) when the plates are fully worn.

Since it is somewhat difficult to obtain an accurate measurement of refiner no load, it is often easier to rely on the calculated value. With an extensive collection of historical data, refiner and refiner filling manufacturers have developed quite reliable predictive models for this purpose.

Most formulas used for calculating no-load power are based loosely on the affinity laws used in pump design. Indeed, a refiner does behave much like a pump, albeit a very inefficient one. Every plate pattern will exhibit a characteristic curve that describes how the total head (pressure rise) varies with capacity (flow rate). The pressure rise will be at a maximum at zero flow, and will decrease as flow is increased, and actually become a pressure drop at a sufficiently high flow rate.

As with a pump impeller, pumping power (or no-load) in a refiner is proportional to the third power of rotational speed. However, unlike a homologous series in pump impellers, the no-load power for the refiner is proportional to the active plate diameter raised to the power of 4.3.

In addition to the effect of diameter and speed, the groove depth and hydraulic section ratio have a dramatic effect on no-load for a particular refiner plate configuration and wear condition. The hydraulic section ratio is the ratio of groove width to the sum of bar and groove width, accounting for any effect of tapered groove walls. Based on these relationships, a formula for the calculation of no-load power is:

$$NL = 102 \times (RPM/100)^{3} \times (D_a/100)^{4.3} \times H_s/0.45 \times G_d/0.25$$

where, NL = no-load (measured in horsepower)

RPM = rotational speed of the motor (revolutions/minute)

D_a = diameter of the active surface of the refiner plate (inches)

H_g = section ratio (dimensionless)

G_d= groove depth (inches)

Note: have to multiply by 2 if it is a double disc refiner…

Note: that most published no-load data for refiners is based on brand new cast refiner plate fillings with a typical section ratio of about 0.45 and an available groove depth of about 0.25”.

Case Study and Sample Calculations

A fine paper mill is refining bleached hardwood kraft under the following operating conditions:

One 34" DD refiner with a 1000 hp/600 rpm motor
700 hp applied motor load
900 gpm flow with no recirculation
4% consistency
500 ml freeness target
34" cast plates with a 2.0, 2.0, 4.5 pattern
30 km/rev bar edge length

Use this information to calculate the no load power, net hpd/t, refining intensity and freeness change per hpd/t applied.

STEP 1 -Calculate no load power

$NL = (102*(RPM/100)^{3}*(Diam/100)^{4.3})*(2*Groove\ Width/(Bar+Groove\ Width))*(Groove\ Depth/4)$

Motor speed 600 rpm Plate diameter 34 inches
Bar width 2.0 1/16 in Groove width 2.0 1/16 in
Groove depth 4.0 1/16 in

No Load = 213 hp

STEP 2 – Calculate applied power

Net Power = Applied Motor Load – No Load Power

Applied power 700 hp No load power 213 hp

Net Power = 487 hp

STEP 3 – Convert from hp to kW Net kW = 0.7457 * net hp = 363 kW **STEP 4** –

Calculate throughput

Short Tons/Day = Gallons per Minute * % Consistency * 6

Flow 900 gpm Consistency 0.04 Throughput = 216 t/d **STEP 5** – Calculate net specific energy

Specific Energy = Net Power / Tons per Day

Net power	487	hp
Tons per day	216	t/d

Specific Energy = 2.3 net hpd/t

STEP 6 – Calculate Specific Edge Load (refining intensity)

Specific Edge Load (SEL) = Net kW /(Bar Edge Length*Motor Speed* 1 min / 60 s)

Net kW 363 kW Bar edge length 30 km/rev
Speed 600 rpm

SEL = 1.2 Ws/m

STEP 7 – Calculate the freeness drop achieved per hpd/t applied

Δ CSF/ hpd/t = (Inlet CSF – Outlet CSF) / net Specific Energy

Inlet CSF 625 ml Outlet CSF 500 ml Specific
energy 2.3 hpd/t

Δ CSF/ hpd/t = 55 ml / hpd/t *(60-100 ml is typical for HWD kraft*)

STEP 8 – Assess potential benefits of reduced periphery Finebar® plates with equal groove volume and twice the edge length.

Reduced plate diameter	31	in
Bar width	1.0	1/16 in
Groove width	1.5	1/16 in
Groove depth	3.5	1/16 in
Bar edge length	59	km/rev
Motor speed	600	rpm

New No Load = 150 hp -*a savings of 63 hp based on plates as new*

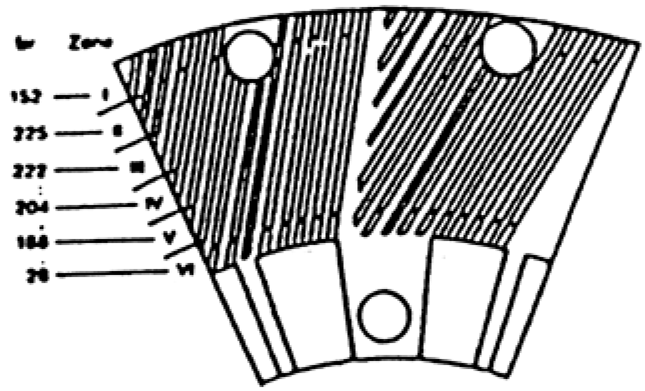
New SEL = 0.6 Ws/m - *in recommended SEL range for HWD of 0.3-0.8 Ws/m*

Annualized energy cost savings @$0.045/kWh = (63 hp*0.7457 kW/hp)*($0.045/kWh)*(24 h/day)*(365 days/yr) = $ 18,400

Note that additional energy savings would likely be realized from the improved efficiency achieved when refining hardwood kraft at low intensity.

Appendix: Sample calculation for bar edge length of a double disc refiner where the stator and rotor have the same pattern

IC/M Calculations for a typical Double-i refiner



Calculation: L = 1in. Rpm = 600

Zone	Br	Bs	Br × Bs
I	152	206	31.616
II	225	206	46.800
III	222	206	46.176
IV	204	192	39.168
V	188	176	33.066
VI	26	40	1.120
			197.968

$$IC/REV = 197.696 \times 2 = 395.934$$

$$IC/M = 395,936 \times 600 = 237.6 \times 10^6$$