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REFINING CELLULOSE FOR AUTOCLAVED CELLULOSE FIBRE CEMENT COMPOSITES

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ABSTRACT.

In autoclaved cellulose reinforced fibre reinforced cement composites, refined cellulose acts both as a filter fibre in the Hatschek machine and as the major component of strength and ductility in the hardened composite. Retention of mineral particles is enhanced by greater refining of the fibre which may involve a significant production of fines and reduction of fibre length. Strength and ductility of the hardened composite is determined mainly by the longer cellulose fibres. So there is a potential conflict between refining for particle retention and maintaining fibre length for good hardened properties of the composite.

This article addresses the principles of refining, the significance of the standard drainage tests (CSF or Schopper-Reigler) and the means by which the best compromise between drainage and fibre length can be achieved for specific cellulose pulps.

Finally, this article briefly discusses how different cellulose pulps respond to refining to point out that each pulp or combination must be treated individually.

The article shows that with an appropriately designed refiner set, it is possible to establish a specific refining protocol without reducing the fibre length beyond a specified level while maintaining a desired production rate for refined pulp. The article also gives guidance for alternative methods for evaluation of desirable fibre lengths in the pulp.

Keywords: softwood fibre, refining, fibre length, mineral retention, fibre cement strength

INTRODUCTION.

Cellulose Fibre Fundamentals

Cellulose fibre for autoclaved fibre cement is mainly produced from softwood by chemical pulping processes such as the Kraft or Sulphate Process. Each fibre is derived from a single cell of the original wood of the tree as illustrated in Figure 1. It has the structure of a hollow tube and is composed of several layers of cross wound fibrils as shown in Figure 2. These structures are somewhat analogous to rope on a smaller scale.

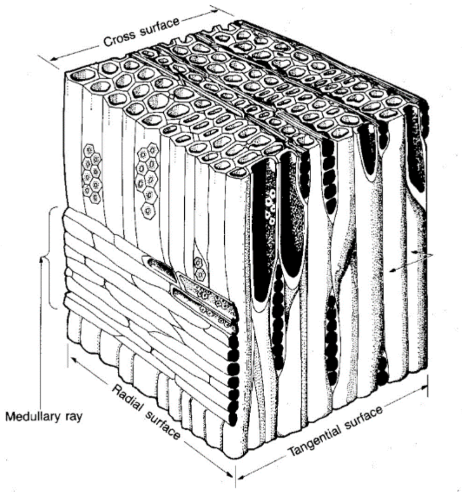

Figure 1: Idealised softwood section [http://www.buyqldtimber.com.au/news-3/Hardwood-vs-Softwood-Timber.aspx]

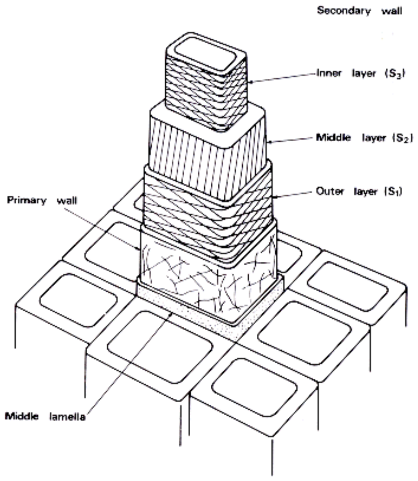

Figure 2: Idealised structure of softwood fibre [http://classes.mst.edu/civeng120/lessons/wood/cell_structure/cell_wall_big.gif]

To extract the fibres, the wood is cut into approximately 25 mm cubes that are then subject to the Kraft or other chemical pulping process where alkaline liquor at high temperature and pressure dissolves most of the middle lamina (ML in Figure 2). This is composed mainly of lignin which is a brittle thermoplastic material with a chemical composition that is closely related to cellulose. The fibres are thus released from their tight bonding with one another and after the chemical cooking process they are passed through a brief refining process in water to completely separate them from each other and convert them to a pulp slurry. They are then sent to a paper or board machine to convert them to a coarse paper or board and dried. It is in this form that they are delivered to the fibre cement manufacturer[1].

Refining

Paper board does not have the properties of a fine paper and if these boards were to be converted to paper they normally undergo a further refining process. This softens the fibres and increases their surface area to volume ratio. These softened compliant fibres can then contact each other more frequently and closely, thus making a strong hydrogen bonds with each other and this results in a softer but stronger paper. The compliance of the fibres also means that they readily form close nets in a paper machine and they trap fibre fines and mineral fillers. The net result is paper that has a close surface that may be suitable for printing without further surface

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[1] There may be additional chemical steps that can be used to remove all of the lignin by chlorine bleaching that occur before making the raw pulp into a board. Mostly unbleached pulp is used for autoclaved fibre cement but the principles outlined here do not change.

treatment. It should be noted that this is a brief outline of the papermaking process that in no way describes the full range of processes that can be used in modern paper mill.

Having said that, the fibre cement process also requires refining of the cellulose for much the same reasons as in paper making. Cellulose is refined to increase the fibre surface area to volume ratio so that fibres bond better to the cement minerals in fibre cement and to improve their ability to retain these minerals in the fibre cement manufacturing process.

Refiners

Refining is carried out on the fibres after they have been pulped in water usually at a concentration of dry cellulose of around 40g/litre of pulp. The most common type of refiner used in the fibre cement industry is the double disk refiner. A typical example is shown in Figure 3.

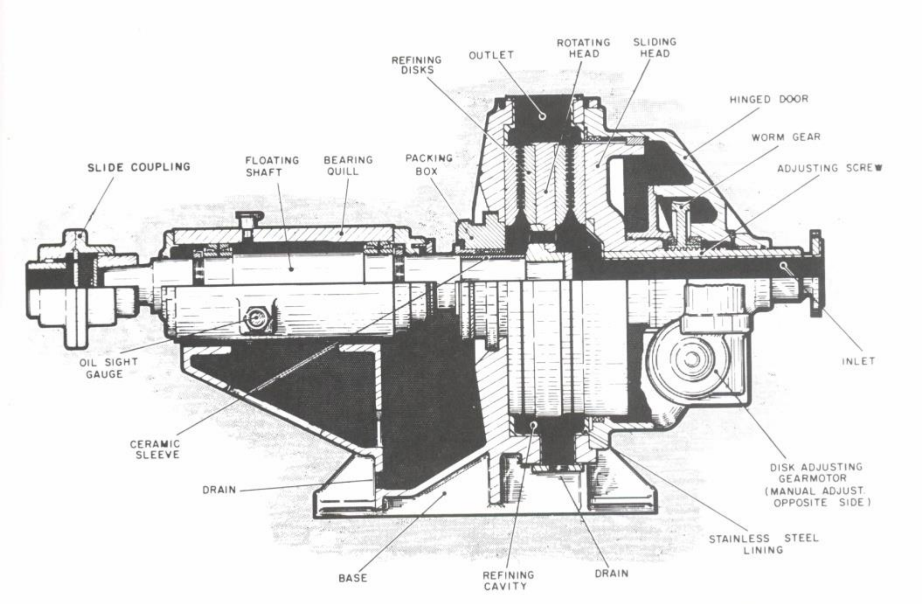

Figure 3: Double Disk Refiner [Smook (1999) p203]

The double disk refiner consists of three axially mounted disks – the inner disk (closest to the motor drive) is stationary, the central disk is rotated at high speed and the outer disk does not rotate but moves axially relative to the centre and the fixed disk.

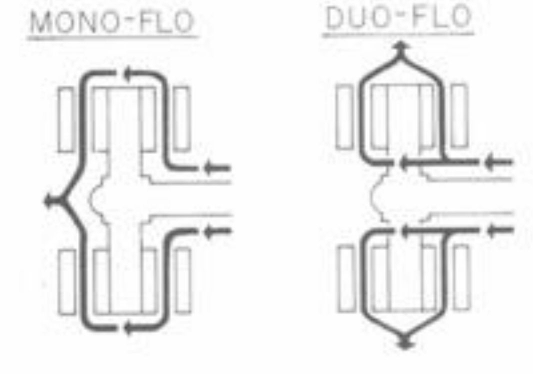

Figure 4: Flow Patterns in Double Disk Refiners [Smook (1999) p203]

Pulp is introduced under pressure into the centre of the refiner and flows between the stationary and rotating disks in one of the ways shown in Figure 4 as determined by the design of the particular refiner.

Each disk is fitted with a set of ribbed plates similar to those illustrated in Figure 5.[2]

Refining of the fibre occurs through rotation of the centre disks against the stationary disks as shown in Figure 6. Although it is commonly believed that refining occurs from the scissoring effect of the ribs of disks against each other, most refining occurs by the interaction of the fibres with one another.

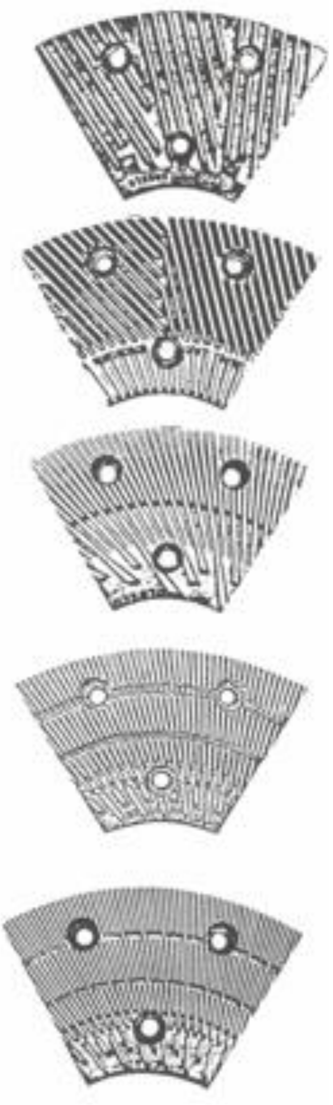

Figure 5: Typical Refiner Disk Patterns,
[Smook (1999) p204]

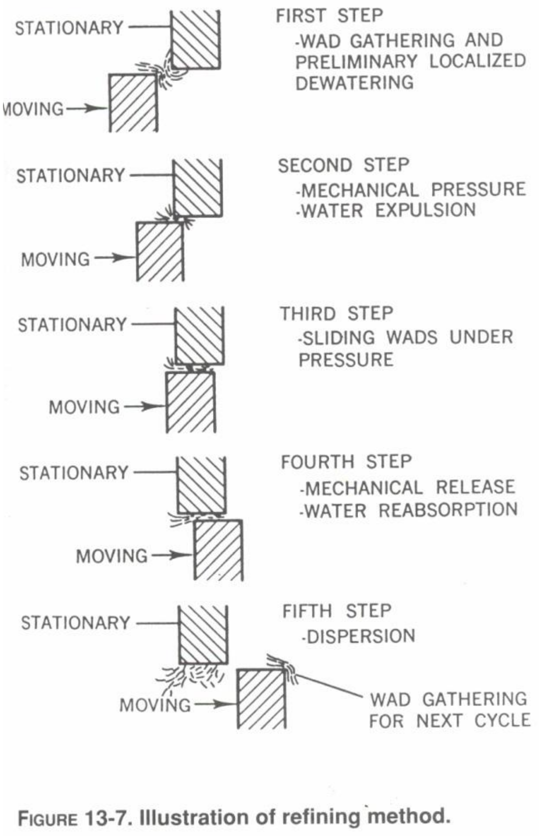

Figure 6: Refining Action,
[Smook (1999) p197]

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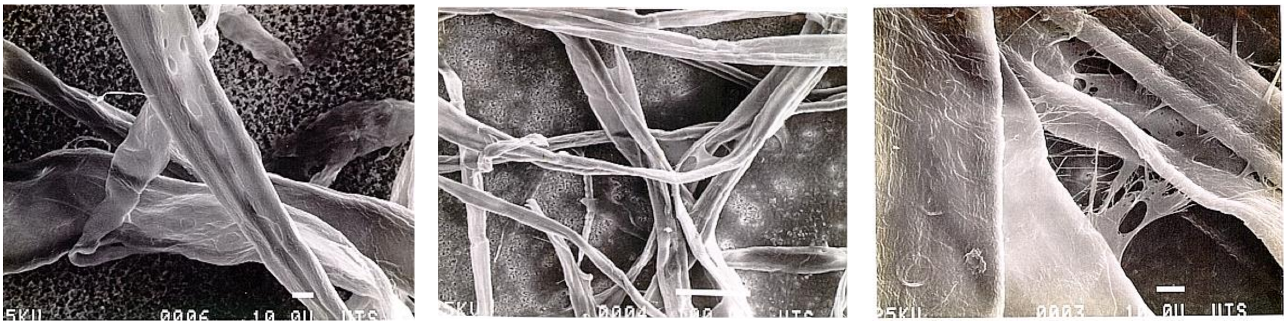
[2] Different plate patterns are used for different pulps and different purposes. Generally long fibred softwood pulps will be refined using coarse patterned disks and short fibre hard wood pulps will be refined using fine patterned disks.

Effect of Refining on the Cellulose Fibres

The effect of refining on cellulose fibres can be seen in Figure 7 where some P Radiata fibres are seen in the as received state figure 7(a) and progressively refined in Figures 7(b) and 7(c).

The fibres have collapsed like crushed drinking straws as seen in the first illustration. After refining they have first been split longitudinally at the 33 SR° stage but after further refining to 50 SR°it can be seen that their internal structure has been disrupted and the fibrils of their inner layers are exposed. The increase in specific surface by these processes enables the fibres to conform to each other, to form a filter layer and to retain cement, fines and other non-fibrous materials during the formation of sheets on the Hatschek machine.



a) Unrefined Fibre
760 CSF or 13 SR°

b) Refined
385 CSF or 33 SR°

c) Refined
213 CSF or 50 SR°

Figure 7: Effect of refining P Radiata cellulose fibres

Refining can also cut fibres thereby generating fines but this is not illustrated in this series of photos.

Refining Circuit

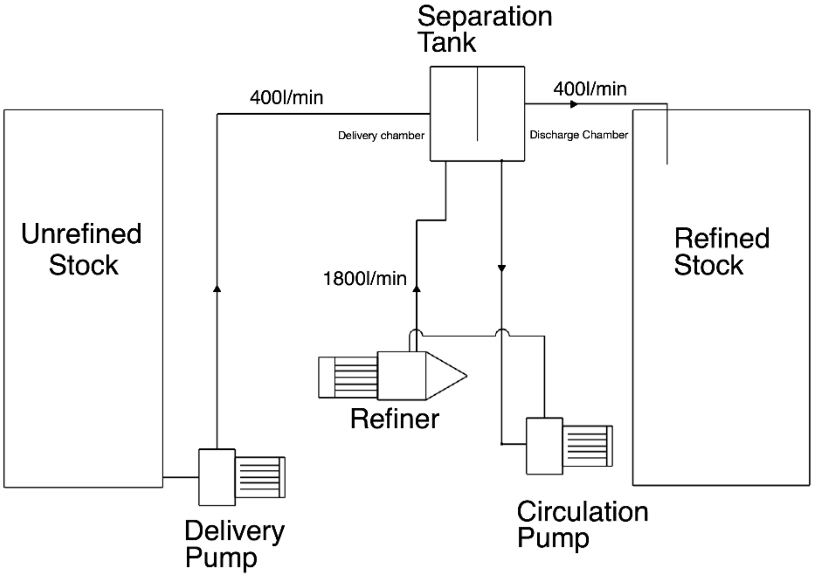


Figure 8: Refiner Circuit Principles

In this investigation the refining circuit was a recirculating circuit as shown below in Figure 8[3].

The refiner circuit operates as follows The heart of the circuit is the separation tank that is split into two chambers (delivery chamber and discharge chamber) by a partial dividing plate that allows pulp to flow between them. Unrefined pulp is delivered from the unrefined stock tank into the delivery chamber with a metering pump at a fixed rate – typically around 400 litres/min. The discharge chamber is connected to a circulation pump that removes pulp at a rate greater than the feed rate, passes it through the refiner and returns it to the delivery chamber. The circulation rate is typically around 1800 litres /minute.

Thus pulp is delivered into the delivery chamber at the rate of 400 litres/minute from the unrefined pulp plus 1800litres/min from the refiner and therefore the discharge from the Delivery Chamber to the Discharge Chamber must be 2200 litres/minute. As pulp is withdrawn from the discharge chamber by the circulation pump at the rate of 1800 litres/min then pulp must overflow the discharge chamber at the rate of 400 litres/min to maintain the balance. Therefore, the net effect of this circuit, is that the pulp is recirculated 4.5 times through the refiner before it is discharged from the delivery chamber into the refined stock chest. The recirculation ratio can be varied by changing the feed rate of raw pulp and/or the recirculation rate through the refiner set.

In practical terms this means that with appropriate adjustment of the power input, the pulp is fully refined when it discharges into the refined stock chest eliminating the need for cycling through a pencil tank system or cycling between two tanks for a fixed number of cycles. Thus from a few minutes after start-up, the freeness of the pulp being discharged into the refined stock chest can be measured and any adjustments can be made to the operating settings of the refiner to correct any discrepancies in the actual freeness required.

REFINING THEORY AND OPERATION OF REFINERS

Refining is accomplished by imparting energy to the pulp and a general relationship of the type:-

$$\Delta Freeness \propto Net\ Energy\ applied\ to\ pulp \tag{1}$$

is relevant. In this relationship the energy applied to the pulp is conventionally measured in kWh/tonne of dry cellulose equivalent. The refiner acts as a pump and some of the energy delivered to the refiner is used to pump the pulp however as an approximation the pumping power of the refiner can be considered to be constant even though the flow rates through the refiner may be changed. We can do this because adjustment of the flow rates

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[3] Figure 8 is a schematic of the refining circuit showing the principles of its operation. It is not an engineering drawing.

is obtained externally from the refiner by adjusting the pump and the valves in the pipes that feed it. Thus we can rewrite the relationship in 1 as follows.

$$P_{tot} = P_{net} + P_p \qquad 2$$

where $P_{tot} = Total\ Refiner\ power$

$P_{net} = Net\ Refiner\ powerapplied\ to\ the\ pulp$

and $P_p \ = \ Refiner\ pumping\ power$

We then determine the total energy applied to the pulp by dividing by the flow rate in tonnes per hour.

$$\Delta E = {P_{tot}}\Big/\left({M}/{t}\right) = {(P_{net} + P_p)}\Big/\left({M}/{t}\right) = E_{net} + E_p \qquad 3$$

Since Power = energy/time, and flow rate = Mass of dry cellulose/time, it will be seen that equation 3 can be simplified to

$$\Delta E = E_{net} + K$$

Where K is a constant and is independent of the mass flow rate through the refiner. Since E_{net} is proportional to the change in freeness we can use either the estimated net power or the total power to estimate the change in freeness because the pumping power provides a constant offset as will be demonstrated later.

There is a general relationship between energy input and change in freeness, however freeness is a measure of the drainage of pulp when tested in a defined manner (Canadian Standard Freeness – CSF or Schopper Reigler Freeness SR°)[4]. Freeness however being a measure of a bulk property of the pulp does not determine the state of the fibres and the same freeness can be achieved with short or long fibres or any combination of fibre lengths. It is well known however, that the intensity of refining influences the distribution of fibre lengths and high intensity refining tends to cut the fibres.

High intensity refining means that the refiners are adjusted to refine at high power. In the case of double disk refiners high power is achieved by closing the gaps between the rotating and the stationary plates by causing the external plate to move axially towards the floating/rotating centre plate. Luukkonen (2011) has demonstrated that the refiner motor power generally increases monotonically when the gaps are reduced.

As indicated above the change in freeness of the refined pulp is directly proportional to the energy input to the pulp and given that there is a constant pumping power requirement it can be seen that refining at high intensity refining is more economical than refining at low intensity. The time to refine will be less with high intensity refining than for low intensity refining but the net refining energy will remain the same so there will be a reduction in the energy for pumping. In addition, there may be a capacity constraint that means that refining must be completed more rapidly to maintain cellulose stocks.

INVESTIGATION

Specification for Refining

The refining plant specification in this report was required to refine the cellulose to 35 SR° without reducing the fibre length by more than 35%. The purpose of the investigation was to determine the set of conditions within the refining system that met this constraint.

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[4] For details of the methods of test and comparison between the methods see Sodinski and Doshi,1986.

Operation of the Refiner Set and Test Results

The pulp used was a mixture of 1 part bleached and 2 parts unbleached P Radiata softwood Kraft Pulp. The mean length weighted fibre length of the unrefined pulp was 2.4mm with fines content 3.2%, and mean width of 27 µm. Pulping was at a nominal 4.5 wt/vol.% i.e. 45 g of dry cellulose per litre of pulp equivalent. 16 tonnes of dry cellulose per day is equivalent to refining at the rate of 250 litres/min.

Samples of the unrefined pulp were collected from the refiner feed chest.

Batches of pulp were refined in equipment similar to that shown in Figure 8 except that two double disk refiners driven by motors of maximum power 315 kW, were used in series. Pulp flowrates and refiner power (or refining intensities) were systematically varied.

For each set of operating conditions, the refiner system was allowed to stabilise for 15 minutes and samples of refined pulp were collected at the discharge point. Each sample was tested for freeness using the Schopper-Reigler method, pulp temperature and consistency. A portion of the sample was taken for each condition and sent to an independent laboratory for length determination using the Kajaani FS300 Fibre Analyser. The laboratory reported the results according to several protocols but the length weighted distribution[5] was used to evaluate the results as this is appropriate for the evaluation of the presence of long fibres in the final pulp.

RESULTS

Table 1 lists the results obtained.

Table 1: Results

Refining Intensity J/m	*Refining Intensity Total kW*	*Refining Intensity Effective kW*	*Flow Rate litre/min*	*Total kWH/ tonne*	*Effective kWH /tonne*	*Freeness SR °*	*% Length Reduction*
1.50	440	300	350	433.80	295.77	27	29.52
			450	337.40	230.04	23	22.66
			550	276.05	188.22	16	15.13
1.75	490	350	350	483.09	329.31	34	35.79
			450	375.74	256.13	25	28.78
			550	307.42	209.56	22	17.34
2.00	540	400	350	532.39	405.70	56	55.19
			450	414.08	315.54	39	42.32
			550	338.79	258.17	30	31.12
2.25	590	450	350	614.10	468.38	59	58.09
			450	477.64	364.30	41	42.74
			550	390.79	298.06	28	35.27

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[5] For a discussion of the significance of the various interpretations of length distributions see Parham and Church, 1977

Discussion of Results

Table 1 shows the summary of the test results. Raw results are not included.

The details include the refining intensity in three columns expressed as Joules/metre, total refining power (kW) and effective refining power (kW) calculated by subtracting the free pumping power from the total power of the refiner(70kW per refiner). Expressing refining intensity as J/m allows comparison between refiners with different plate patterns (such as shown in Figure 5) and details of how this is calculated are included in Luukkonen. For completeness, we have included this measure but it is not significant for our purposes because we have reported results for only one type of refiner disks.

Columns two and three of table 1, express the refining intensity in terms of the refiner power. It will be seen that there is a constant difference of 140 kW between the effective power and the total power and this is because it was estimated that the pumping power of each refiner was approximately 70 kW. This is consistent with the argument presented earlier and can be seen in Figure 9 although there is some suggestion that pumping power is not constant with changes in flow rate. Since there are no standardised methods for estimating pumping power (Luukkonen, 2011), when estimating the likely refining power needs, it is simpler to use total power than some estimate of effective power.

In both cases however, the relationship between power and freeness developed derived from regression is quite strong (r^2=0.84 or 0.92) confirming that freeness is developed by input of energy to the dry cellulose.

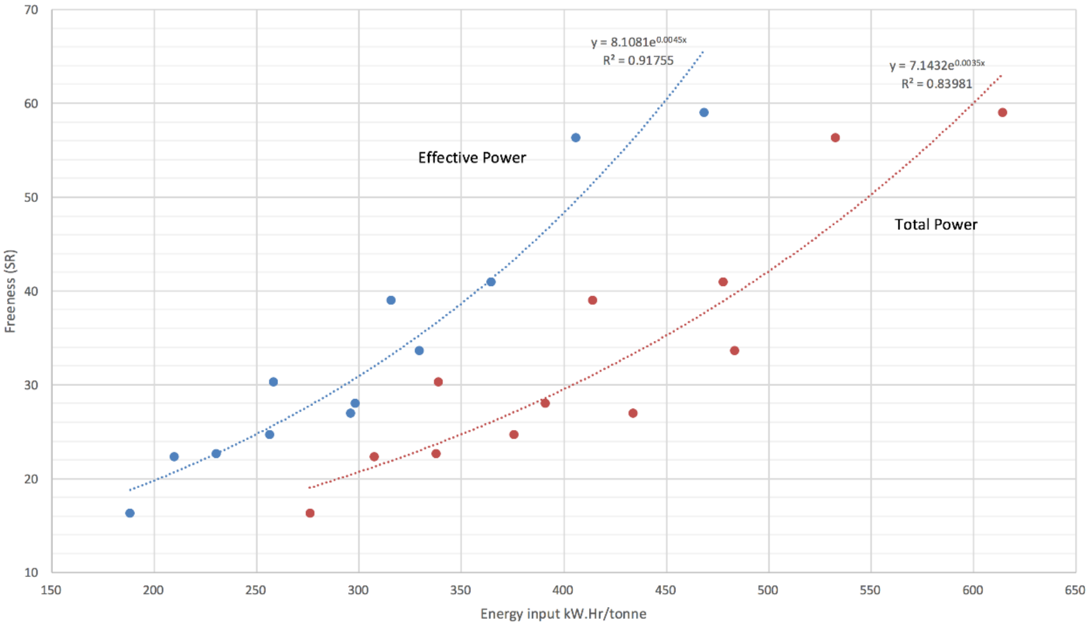

Figure 9: Freeness (SR) vs Input Energy kWh/tonne

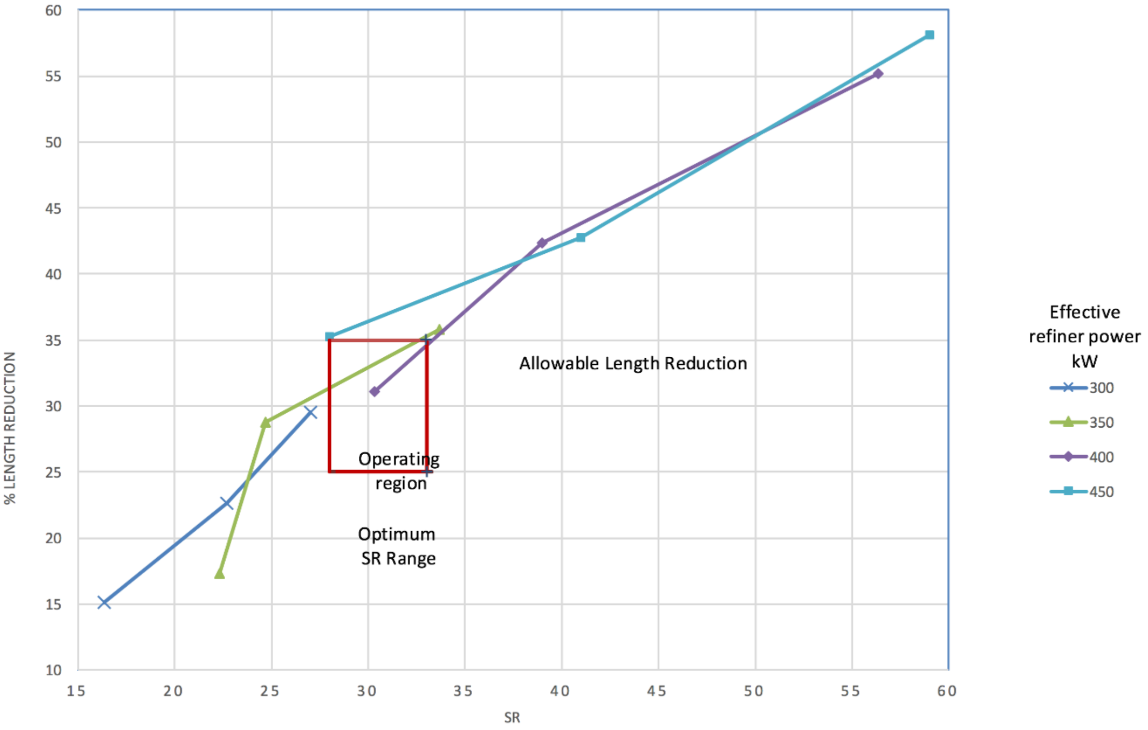

FIGURE 10: FIBRE LENGTH REDUCTION % VS SR

We now consider fibre length reduction due to refining as shown in Figure 10.

Figure 10 shows the reduction in length of the fibre as a percentage of its original length. The information from Table 1 is shown in four separate graphs representing the four levels of refining intensity with individual points being at different flow rates through the refiners. Within each group freeness and fibre cutting will increase with reducing flow rate as the total specific input energy increases.

A region is also outlined on the graph representing the normal operating parameters for refining:

1. The top and bottom lines define acceptable limits for length reduction
2. The two vertical lines are located at the usual limits of SR optimum for autoclaved fibre cement.

It will be seen that it is possible to operate within these specifications for the middle two intensity conditions i.e between 350 and 400 kW effective power input. It is also possible to come close with most intense refining although marginally exceeding the limit of cutting and being outside the optimum SR range.

We can now determine if the specifications for the refining system were met. Considering Figure 10 it will be seen that the conditions can be met directly by refining at either 350 or 400 kW effective input power and we can determine that the refining conditions listed in Table 2 will result in meeting the specifications.

Table 2: Specification Compliant Refining Conditions

Effective Power kW	SR	Length Reduction	Flow Rate litre/min	Specific Energy kWH/tonne
400	30	31%	550	250
350[6]	30	33%	400	260

It can be seen that it is possible to maintain fibre length and refine to the optimum freeness within the restraints of the refining system. It is also clear that although it is possible to refine more quickly this can only be done at the expense of reducing the fibre length and care needs to be taken to ensure that fibre cutting is not excessive.

Luukkonen (2011) working with mechanical softwood pulp, has shown that cutting of fibre is exponentially increased when the separation of the refiner plates is 0.3 mm or less. While it was not possible to determine the plate separation during this work, the shape of the refining curves here was similar to those reported by Luukkonen (2011). It seems reasonable therefore to assume that Luukkonen’s conclusions are relevant for the chemical pulps of this work.

It is this author’s experience that the response to refining is different for each species of pulp and that the response depends on the internal structure of the pulp fibre in question. Thus for example Douglas Fir (*Pseudotsuga menziesii*) has a friable outer layer on each fibre and that refining principally acts on this layer without changing the internal structure of the fibre. Thus it is necessary to evaluate each pulp individually with each refiner set to determine the necessary conditions to maintain fibre length with freeness.

Measurement of fibre length in this instance was done with a sophisticated measuring instrument and the results were evaluated using the length weighted fibre length. This emphasises the long fibre and effectively measures the development of fines. This suggests that it should be possible to use the simpler measure of fines using the residue method as an alternative to evaluate fibre length reduction.

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[6] Result by interpolation

CONCLUSIONS

We conclude that

1. it is possible to refine cellulose with a minimal change in fibre length with the appropriate choice of refining conditions.
2. Refining to higher SR levels increases the damage to the fibres and they experience a greater loss in fibre length.
3. While not proven, it seems that chemical pulps react to refining in a very similar way to the mechanical pulps as reported by Luukkonen.

ACKNOWLEDGEMENTS

The assistance of Mr Ivo Valka and Mr Jaromir Bucik of Papcel is recognised and the staff of Tepe Betopan in the performance of this investigation.

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