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Control of Chip Size Can Improve Energy Consumption and Pulp Quality in Refining

Developed by the Technical Group, J&L Fiber Services

OVER VIEW

- Chip size and uniformity significantly impact both refiner performance and pulp quality.
- Recent testing identifies the optimum size for mechanical pulping to be in the 3.5 mm to 6.0 mm range (13-19 mm screen range).
- Energy savings realized at the less-than-ideal range of 2-4 mm thickness risks a perceptible loss of bonding.
- Mills must ultimately balance one desirable effect against another to achieve optimum performance.

Even in the best designed chip refining systems, many system variables can have a profound effect on refiner performance and pulp quality.

Chip size and uniformity, for example, directly influence the amount of specific energy required, motor load stability and pulp quality.

Early Studies

In a series of studies involving *pinus radiata* chips for kraft pulping, Kibblewhite and Cown[1-4] established a definite cause-effect relationship between chip dimensions (and other raw material parameters) and pulp quality. However, they were unable to apply these parameters to predict the properties of mechanical pulps.

Other studies have revealed the following effects of chip composition and size:

- *Optical Properties* – Using sawmill residuals, such as fines and bark, will reduce desired optical qualities.[5-7]
- *Strength* – Consistently lower strength in mechanical pulps results when sawdust and shavings are blended with uniform, mid-sized chips.[8-11]
- *Yields* – Binotto[12] demonstrated that in high-yield bisulfate pulping, both yields and pulp strength increase as chip fines are removed. Shive and dirt counts are also reduced.
- *Energy Consumption* – Marton[13] and co-workers found that chip sizes in the range of 3-16 mm screen fractions strongly influence the energy required for initial defibering.

As chip size decreased, the energy required to reach 500 ml CSF also decreased. Chip size had very little influence on energy required to refine beyond 500 ml to 150 ml CSF. With the exception of a slight maximum at the 10 mm size and significant reductions for fractions under 5 mm, tear and tensile strengths were not affected by the size of chips.

Marton, Hu, Eskelinen and others obtained similar results.[14-16]

- *Feed and Motor Load Variations* – In a pilot plant TMP study, Eriksen et al.[17] found that when either overlarge chips or fines were *mixed* with homogeneous chips in the range of 10-23 mm length (3.6-4.9 mm thickness), poor pulp quality tended to be the result. Adding even small amounts of overlarge chips caused uneven feed and motor load variations.

Statistically Designed Pilot-Scale TMP Trial

While these studies showed the benefits of minimizing oversized or undersized chips, they did *not* show

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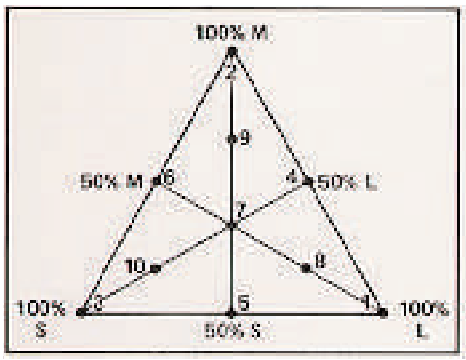
how “oversized” and “undersized” should be defined – or whether controlling chip size would lead to significantly better energy usage or pulp quality.

To address these questions, our research team* conducted controlled experiments in a TMP pilot-plant equipped with 36-inch refiners.

Experimental Design

The simplex design experiment used three chip-sized components in various combinations.

Fig. 1



Target chip mixture data points.
S=small chips, -4 mm thick;
M=medium chips, +4 mm to -8 mm thick;
L=large chips, +8 mm thick.

Figure 1 illustrates the distributions of these three components, with the sides of the triangle representing chip-size component axes. The most homogenous mixtures lie at the apices. The average chip size increases along the horizontal axis from left to right. (“Thickness” was used to define chip size since this is the smallest chip dimension and can be reliably measured.)[18]

A simplex design requires 10 data points to generate a response surface, using Scheffé’s special cubic model equation for this type of three-component experiment.[19] Data points 1-7 are used to determine the model equation for each response surface, while points 8-10 check their accuracy.

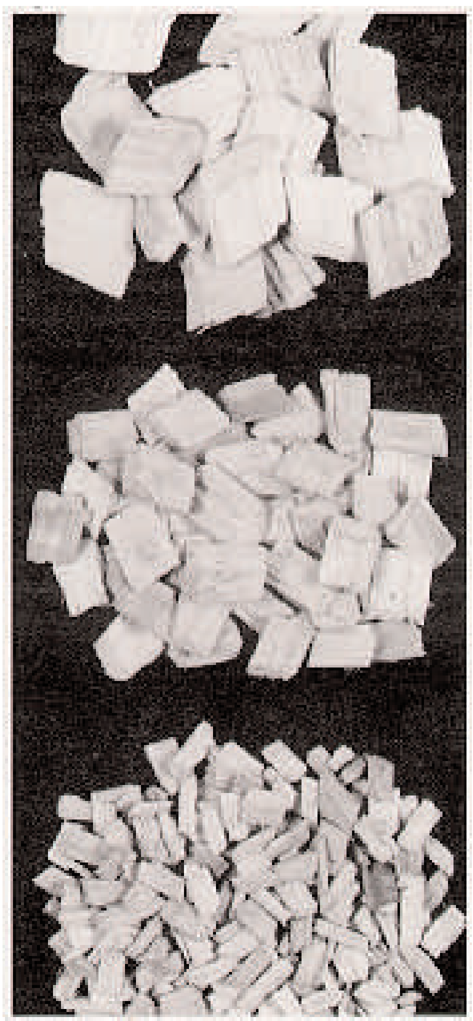
Procedures

- *Preparing the Chips* – Nine metric tons of debarked lodgepole pine *(pinus contorta)* were chipped in a pilot-scale chipper at two cut-length settings. Roughly 3400 kg of “short” chips were produced at a cut-length of 11.5 mm and 5700 kg of “long” chips at 22.4 mm cut-length. Later, at a pilot screening facility, they were segregated into the large, medium, and small thickness classifications (Figure 2). Then the three sizes were blended in various mixtures to approximate the ten data points of Figure 1.

Figure 3 shows the actual size of distributions of these mixtures. Note the approximate average thickness scale in the horizontal direction.

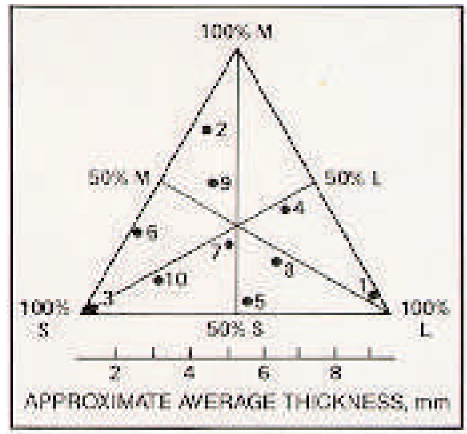
- *Preparing the Furnishes* – Several primary and secondary pulps were prepared. Primary pressurized refining was carried out after 3.5 minutes in 207-kPa saturated steam, applying 3200-3700 MJ/ton. From the primary pulps, several secondary-stage pulps were prepared at different specific energy levels.

Fig. 2



Typical appearance of chip size fractions.
Top: Large, +8 mm
Middle: Medium, -8 to +4 mm
Bottom: Small, -4 mm

Fig. 3



Size composition of actual chip mixture in TMP trial.

- *Applying Scheffé’s Equation* – Using TAPPI methods, the properties of each of the above pulps were determined and interpolated to 100 ml CSF. The properties at 100 ml CSF were then used to generate the three Scheffé’s model equations shown in Table I.

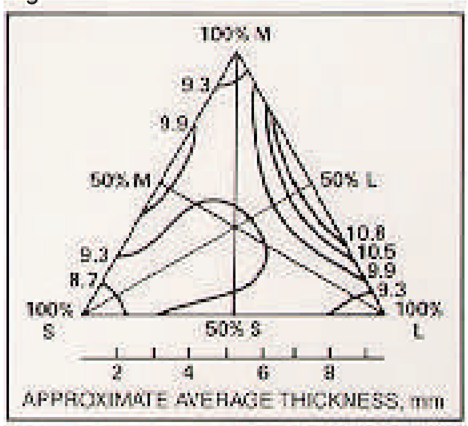
The R^2 values indicate that chip size is indeed the dominating cause of energy and property variations. This can be seen graphically in Figures 4-6, where response gradient values are imposed over the surface of the chip component triangles.

- *Establishing Confidence Limits* – Notice the high concentrations of data points at selected regions of Figure 3. These regions correspond to the areas of greatest confidence in the data. To check the significance of response differences from one area to another on the triangle, 90% confidence limits were determined for each of the three responses at each of the 10 target mixture data points (Table II).

Results

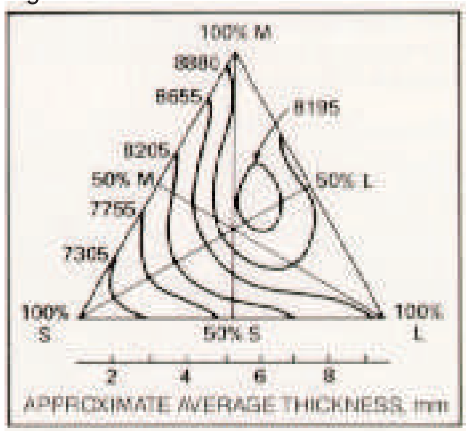
- *Specific Energy* – As shown on Table II and Figure 5, a significant increase in specific energy was required to reach 100 ml CSF as the thickness range moved from small to medium (1.6 to about 6 mm). There were very little

Fig. 4



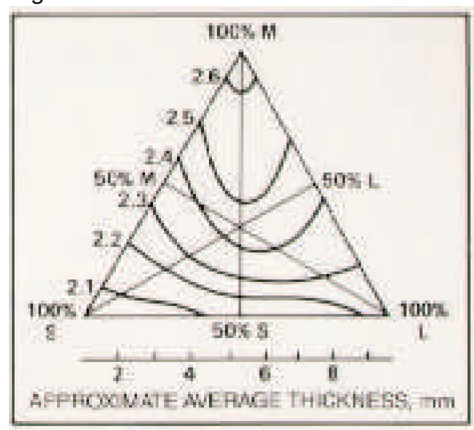
Iso-Tear lines at various chip size compositions, in mNm²/g at 100 ml CSF.

Fig. 5



Iso-Energy lines at various chip size compositions, in MJ/ton to reach 100ml CSF.

Fig. 6



Iso-Burst lines at various chip size compositions, in kN/g at 100 ml CSF.

differences in energy requirements in the medium to large range (up to 9.5 mm). This confirms Marton's impact energy work.[14]

Nonuniformity exerted no major influence on specific energy. The only significant differences were in the horizontal direction of the triangle (average thickness).

- *Burst Index* – Both chip thickness and uniformity had a significant influence on burst index:

a) *Effect of Thickness* – As shown in Figure 6, there was a significant maximum bonding at 5-6 mm chip thickness. (This size corresponds to nominal 17-18 mm Williams screen size.) The effect was much greater than Marton et al. observed[19] and it occurred with larger chips.

b) *Effect of Nonuniformity* – Figure 6 also shows the considerable influence of nonuniformity on burst index. For example, at a nominal 5 mm thickness, the most uniform composition (near the triangle apex) produced the strongest pulp, while very nonuniform mixtures of small and large chips were almost as inferior as 100% small.

- *Tear Index* – Figure 4 indicates that tear index trends toward maximum at 3-4 mm and also at 7-8 mm thickness. However, only small chips were shown to have a significantly deleterious effect.

Table I

$$Y = (Y_1 * L) + (Y_2 * M) + (Y_3 * S) + (Y_4 * L * M) + (Y_5 * L * S) + (Y_6 * M * S) + (Y_7 * L * M * S)$$

Response surfaces	Coefficients							
	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7	R^2
Specific energy	86.97	69.74	70.73	—	—	—	0.02080	0.62
Burst index	0.02218	0.02656	0.02050	—	—	—	—	0.87
Tear index	0.08781	0.08722	0.06242	0.00101	0.00494	0.0061	-0.00005	0.77

Scheffé's equation coefficients for three response surfaces.

Table II

Target mixture	Fraction of size components in mixture			Specific energy, MJ/ton	Burst index, kN/g	Tear index, mNm²/g
	S	M	L			
1	0	0	1	1002	0.12	0.9
2	0	1	0	924	0.11	1.5
3	1	0	0	661	0.08	0.5
4	0	½	½	708	0.09	1.7
5	½	0	½	585	0.07	0.7
6	½	½	0	498	0.06	0.7
7	⅓	⅓	⅓	583	0.07	0.4
8	⅙	⅙	⅔	522	0.06	0.4
9	⅙	⅔	⅙	502	0.06	0.5
10	⅔	⅙	⅙	413	0.05	0.3

90% confidence limits at 10 target mixtures.

The Probable Mechanisms Leading to Chip Size Effects

One could conclude the following regarding small chips/fines vs. large chips:

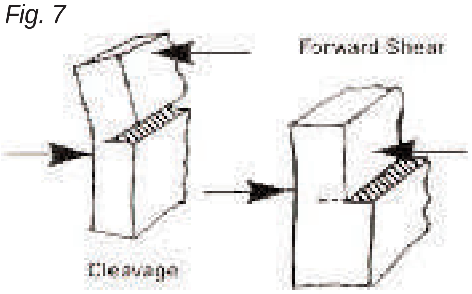
1. They require less energy to reach a given freeness or specific surface, since they have greater specific surface at the outset.

2. They yield weaker pulps, assuming that they would contain more damaged fibers, bark, dirt, etc.[19, 20]

Other characteristics of the starting material also affected technical pulp property differences:

- *Absorption of Energy* – When defibering impact energy is applied to thin chips, it apparently is absorbed in a different way than thicker chips.

Fig. 7



Modes of wood deformation under initial refining impacts, from Marton and Eskelinen(16)

Marton and Eskelinen[20] identified two modes of deformation and failure in defibering thin chips vs. thicker chips (Figure 5):

1. *Cleavage Failure* – The crack propagates as the wood is bent back – a typical result with thin chips and with wide gaps between applied forces.

The energy applied is more plastic (less elastic), with more of the energy going into bond-breaking, creating large amounts of surface area per impact. Thus the cleavage impacts would be more severe and cause more fiber damage and shattering. So, while thin chips require less energy to be reduced to a specific surface (freeness), they will yield pulps with more broken, less fibrillated fibers.

2. *Forward Shear* – This effect predominates with thicker chips and narrow gaps. The energy absorbed per unit of new surface area created is perhaps 4 times that absorbed in cleavage failure.

It is reasonable to assume that when the resilient, thicker chips undergo deformation – primarily by forward shear – the energy is more elastic. The energy would thus produce more reversible fiber compression, internal kneading and fibrillation, and heat generation.

The energy absorbed would increase with thickness, as less cleavage occurs and as the impact becomes more elastic. (Presumably, this elastic energy absorption would level off with very thick chips, possibly at 5-6 mm thickness where specific energy-specific surface relationships plateau.)

- *Effect of Chip Size and Uniformity on Motor Load and Plate Gap* – At a given production rate, feeding is much smoother with a large number of medium chips than with a small number of large chips. The same is true of homogenous medium-size furnishes vs. nonuniform mixtures.

Since unsteady motor loads and plate gaps can also lead to poor pulp quality, this may explain why large chip sizes, as well as nonuniform furnishes, can have a deleterious effect.

Summary

Chip size and uniformity can have a significant impact on refiner performance and, ultimately, pulp quality. Based on present results, the optimum chip size for mechanical pulping would appear to be in the 3.5 to 6.0 mm range (13-19 mm screen fraction). Ideally, the following sizes would be eliminated or minimized:

- Oversized Chips – Eliminate chips that are +29 mm screen size, or +10 mm thickness fraction. Minimize +22 mm screen size, or +7 mm thickness.

- Undersized Chips – Screen out -3 mm fractions and minimize screen fractions smaller than 7 mm.

Some commercial operations may decide upon the less-than-ideal range of 2-4 mm thickness for the energy savings that could result. However, doing so risks a perceptible loss in bonding and an increase in harmful undersized fractions.

Selecting the proper chip size for a specific mill is a matter of "balance" – weighing one desirable effect against another – to achieve optimum performance.

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