The nature of the mechanical pulping process

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Abstract: Three independent properties must be optimized simultaneously for lightweight mechanical printing papers: scattering coefficient which is required for opacity, fibre length for strength, and density for printability. For a given wood species, there is a single relationship between scattering coefficient and fibre length, from groundwood to refiner pulps to kraft. Greater development of long fibres with less cutting, as measured by density, can be achieved by lowering the refining intensity or increasing either the chemical treatment or temperature.

The quality of mechanical pulp has improved steadily over the last few decades. Shortly after the introduction of thermomechanical pulp (TMP) it became the preferred furnish for newsprint and in recent years has become a substantial component of supercalendered and lightweight coated grades. With further improvement in fibre and pulp quality, by optimizing refiner operation and fractionation strategies, TMP could conceivably become the sole pulp in many high quality mechanical printing grades.

Extensive research has been done to determine parameters influencing mechanical pulp properties. Almost 30 years ago, Forgacs suggested that mechanical pulp could be characterized by two factors, one related to fibre length and the other to specific surface [32]. He proposed a groundwood control scheme based on on-line measuring of shives, fibre length and freeness. However, this control concept predicated suitable on-line sensors. Since then a significant amount of work has been done to better understand mechanical pulps and in particular the effect of operating parameters such as specific energy, consistency and raw material on fibre and pulp properties [5,6,9,12,17,19,26,33].

The wide particle size distribution in mechanical pulps contributes to improved optical and surface properties [3,7,15,23,30] making them suitable for low-cost, lightweight papers. Further cost saving could be achieved if minimum strength and opacity specifications could be met with fewer fibres per unit area of printing surface. Another opportunity would be to capitalize on either the inherent fibre properties of different wood species or employ fractionation strategies to tailor products for specific markets [1,2,11,12]. Even within species, variations offer significant options for cost reductions or quality improvement [4]. However, current refiner operating conditions limit this approach.

Mechanical pulping has been studied at Paprican for many years [14,18,24,25,29]. Work on stone groundwood, refiner mechanical and thermomechanical pulps has reflected the industry's adoption of the processes [8,10]. Both fundamental and practical approaches have addressed the potential to develop high-quality mechanical pulp and to reduce specific energy consumption [5,18,21,24].

The two key operating factors in refining are the specific energy and the intensity [18,24], defined as the specific energy per bar impact. Manipulating the refining intensity can have an effect on both energy consumption and pulp quality [8]. Increasing the refining intensity by either increasing the rotational speed of the refiner [27] or lowering the consistency [5] lowers the energy required to reach a given freeness but often reduces average fibre length and tear strength. The optimization of refining intensity to different wood species and wood of varying quality could lead to significant improvements in refiner operation and pulp quality.

This report discusses the factors that determine the energy/quality relationships in mechanical pulping. This understanding could unlock the potential value of each wood species, reduce process variability, and show how to make a mechanical pulp with optimized properties.

BACKGROUND

The basic concepts of mechanical pulping are evident in the evolution of the process. The first mechanical pulp was groundwood, which is characterized by low energy but low strength properties, Fig. 1. Groundwood must be mixed with chemical pulp to achieve adequate strength properties. With the introduction of refiners, mechanical pulps were stronger, but the addition of chemical pulp was still necessary for grades such as newsprint. Increasing the refining temperature by operating at higher casing pressure was expected to reduce energy consumption. In fact, thermomechanical pulp required more energy but produced a high-quality pulp that could be used as a single furnish for grades such as newsprint. The highest quality mechanical printing papers, lightweight-coated (LWC) and supercalendered (SC), now contain a large proportion of mechanical pulp but still require kraft for runnability. History suggests making these grades entirely from mechanical pulp would be the most cost-effective method. However, with current technology, sufficient energy cannot be
applied to the fibres to develop pulp properties.

Although there has been significant research effort worldwide to reduce energy consumption in mechanical pulping, experience has shown that the key to a longer, more developed fibre is being able to put more energy into the pulp. This can be done by softening the fibre by heat or chemicals, or by reducing the refining intensity. [Fig. 1]

Cross-sections of lightweight coated and supercalendered sheets provide an illustration of the type of fibres that are required for high value mechanical printing papers. [Fig. 2] The individual fibres are collapsed, giving a highly densified structure which provides a uniform printing surface. Density is a macroscopic indicator of the fibre characteristics such as flexibility [28], (Fig. 3), coarseness, (Fig. 4), and collapse [16]. Although calendering provides much of the densification, the pulp must respond to these forces. There must also be sufficient long fibre to maintain strength under this mechanical action and with the addition of fillers, which are required for opacity.

Three independent pulp properties need to be optimized for lightweight papers: scattering coefficient, which is required for opacity, fibre length for strength, and density for printability, (Fig. 5). Mechanical pulps are particularly suited for lightweight grades because of the inherent scattering by fines. This permits a reduction in basis weight without compromising opacity and showthrough. To maintain strength, the fibres must be developed without losing length. Flexible, conformable and collapsed fibres, which promote better printability, are characterized by a higher density. Examining pulp data plotted on these three axes can provide insight into the limits of mechanical pulping and the opportunities.

Pilot Plant Trials

A considerable quantity of such data was obtained when repeat trials were carried out on black spruce and balsam fir as part of a study of seasonal quality variations. Pulp from each species was produced on Paprican’s Bauter 36 in. double disc atmospheric refiner under the following conditions:
- RMP (1200 rpm, no chip pre-steaming)
- Low intensity RMP (900 rpm)
- Low intensity TMP (900 rpm, 10 min. of chip pre-steaming at 138°C).
The wood was carefully selected so that universal relationships could be developed. A common problem with many TMP studies noted by Corson [4] is that the relationships developed with small sample sites are overwhelmed by the inherent variations in the wood. In this case, trees of equal age were selected and chipping was carried out on a whole tree at a time. The large number of repeat trials done for this study also greatly enabled any variations to be smoothed by averaging.

**Scattering Coefficient and Fibre Length**

Averaging of the results over the nine trials produced the rather striking trend shown in Fig. 6. It is evident that the scattering coefficient is a well-defined function of the fibre length, expressed as the 'L' factor of the pulp and is completely independent of the process used to make it. Equally apparent is that the relationship is highly dependent on the species, with fir always yielding higher scattering coefficient than spruce at a given fibre length.

Adding data from trials for other processes suggests that the link between scattering and fibre length may be of a general

**FIG. 6.** Regardless of the refining process, the scattering coefficient is a well-defined function of the fibre length. At a given fibre length fir always yields higher scattering than spruce.

**FIG. 7.** Adding additional data to the plot of Fig. 6 shows that the relationship between scattering coefficient and fibre length extends all the way from stone groundwood to softwood kraft.

**FIG. 8.** For a given species scattering coefficient depends on the quantity of fines and is independent of the process.

**FIG. 9.** For a given species the energy needed for a given scattering coefficient is extremely dependent upon the process.
nature, (Fig. 7). Clearly, a convincing trend between scattering coefficient and fibre length extends all the way from stone groundwood to kraft. The implication is that the material needed to produce scattering is derived from the reduction of long fibre mass and the cutting of fibres during mechanical treatment. Therefore, a compromise must always be struck between the long fibre content required for strength and the cut material required for optical properties. As the plot of Fig. 8 shows, for a given species, scattering coefficient is a function of the quantity of fines and is independent of the process. However, for a given species, the energy input needed to achieve a certain scattering value is extremely dependent upon the process, as evident in Fig. 9, where the effects are shown for spruce and fir independently and also in combination. The difference arises because both pre-steaming and reduced refining intensity promote long fibre development with minimal cutting. This extends the specific energy which must be applied before a given fines content is reached.

Four operating parameters determine the position of the scattering coefficient/long fibre line for a specific wood species: specific energy, refining intensity, temperature and chemical treatment, (Fig. 10). The characteristics of the wood and physics dictate the relationship between scattering coefficient and long fibre but there are many different ways to move along this line. For instance, mixtures of kraft and groundwood lie on the same operating line, (Fig. 11). This was the traditional method of meeting chosen performance targets. In a refiner, changing the specific energy, refining intensity, temperature or chemical treatment will also change the position on the scattering coefficient/long fibre operating line. But none of these operating changes are able to move off this line. Electrical, equipment and chemical costs will determine the best set of operating parameters to achieve the required properties.

Sheet Density and Fibre Length
A common goal of most mechanical pulping studies has been the reduction of specific energy consumption. However, accomplishing this without compromising pulp quality has proven to be elusive. The challenge is demonstrated in the plot of handsheet density against long fibre content, (Fig. 12). In order to achieve good strength characteristics, the long fibres must be retained as the sheet surface is improved by increasing density. But, as Fig. 12 shows, this is a process-dependent condition. Moreover, the highest long fibre content at a given density is associated with the processes having the highest specific energy consumption. Traditionally, mechanical printing papers were made by combining groundwood with kraft. Refiner mechanical pulp provides a longer fibre but increasing the specific energy increases density at the expense of fibre length. Softening the pulp thermally or chemically increases the fibre length and increases the potential for density development in effect by operating on a different long fibre-density line. This operating line can also be changed...
by modifying the refining intensity. This suggests that lower refining intensities, perhaps combined with higher temperatures and chemical treatment, could produce a high-yield pulp with properties approaching those of kraft.

**IMPLICATIONS**

The foregoing observations strongly suggest that the specific energy needs for mechanical pulp depend to a large degree on both the quantity of long fibre and the extent to which it is developed. In fact, additional support for this was obtained recently in pilot plant trials carried out on a monthly basis using a Member Company’s wood supply. Each month’s trial included conventional as well as low-intensity refining and the results were interpolated to yield both the quantity of long fibre at 100 mL CSF and the specific energy needed to obtain that freeness. The plot, (Fig. 13), then shows very clearly the relationship between long fibre content and specific energy consumption. Moreover, low-intensity refining does not depart from the trend set by the conventional process, but merely extends the line towards more long fibre retention for a given freeness at a correspondingly higher energy demand. This is in marked contrast to the lower energy requirements at lower fibre lengths where the freeness is easily reached by fibre cutting.

The potential to obtain particular pulp properties is determined by the intrinsic characteristics of the wood fibres [1,2,5,11]; fibre length, diameter and cell wall thickness. The scattering of light by an individual fibre is related to the diameter of the lumen and thickness of the cell wall, when the fibre is collapsed [20,22,31]. For a given species, mature wood will tend to give longer fibres with thicker walls [13]. Juvenile wood, which has thinner cell walls, would be more appropriate for papers that require opacity but are not limited by strength. The age of the tree is an obvious factor, however any tree has a distribution of both juvenile and mature wood located at specific locations in the log [13]. For example, saw mill residuals tend to contain a higher proportion of the mature wood. This indicates that for optimizing the properties of a particular grade it is necessary to account for the source of material whether it be in the form of chips or roundwood or from old or new growth.

Plotting the diverse fibre dimensions of different wood species gives some insights into their best product applications. (Fig. 14). At one extreme are the short, thin-walled fibres of hardwoods such as maple and aspen. At the other extreme we have the pines and western firs with long, thick fibres.

The thin-walled fibres have the greatest potential to make an opaque sheet assuming the fibres can be sufficiently collapsed by either chemical or mechanical action. The short fibres and fragile walls of the hardwoods are best suited to filler grades intended to raise opacity and perhaps brightness. Aspen CTMP might have a niche as a filler pulp in high-quality newsprint, uncoated specialty ground-wood sheets, or as a supplement to coated wood-free sheets. Some under-utilized species could give pulps with greater strength assuming the fibres can be developed without breakage. If for example, we tailor the refining conditions to the characteristics of the wood, species like Douglas fir and southern pine probably have greater potential for strength development than at present. This is something that is not realized under conventional refining conditions. However, a large amount of energy would be required to reach this potential which could make this approach impractical.

Of more immediate interest would be balsam fir, which has relatively long fibres but thinner cell walls than jack pine and black spruce. This wood, although traditionally less valued than black spruce, has the potential to make a strong opaque pulp because of its thin-walled fibres. At the same long fibre content, balsam fir has a higher scattering coefficient than black spruce, (Fig. 6). This means that under the right refining conditions balsam fir could provide a more opaque sheet than black spruce at the same strength. Thus, there would be the potential to make a sheet of lower basis weight with balsam fir.

The quality of pulp made from balsam fir tends to be more variable than that from black spruce. In the plot of Fig. 15, the specific energy required to reach a freeness of 150 mL is shown for a series of pilot plant refining trials over a two-year period. The trials with lower energy are not a real energy saving but indicate the fibre has been cut leading to poorer strength properties. By lowering the refining intensity it is possible to put more energy into the pulp which can reduce this variation. Although
jack pine has a reasonable fibre length the pulp does not develop well under conventional refining conditions. With low-intensity refining, it is possible to make jack pine look like black spruce pulp, (Fig. 10). This demonstrates the potential to make mechanical pulp from wood species that have been under-utilized because of quality considerations.

**SUMMARY**

Examination of an extensive amount of data gathered from various mechanical pulping trials has identified the following two key features which all of these pulps appear to have in common:

1. For a given species, scattering coefficient is a well defined function of fibre length and can only be increased by fibre length reduction.

2. For a given process, density increases as fibre length decreases. The higher the fibre length at a given density, the higher the specific energy consumption of the process.

When these features are combined with the fibre characteristics of the wood species, a more optimal use of our wood resources should result.

**LITERATURE**


Résumé: Trois propriétés indépendantes doivent être optimisées simultanément pour les papiers impression mécaniques légers : le coefficient de dispersion pour l’opacité, la longueur des fibres pour la résistance, et la densité pour l’imprimabilité. Pour une essence de bois donnée, il y a une seule relation entre le coefficient de dispersion et la longueur des fibres, des pâtes mécaniques aux pâtes raffinées aux pâtes kraft. On peut obtenir un meilleur développement des fibres longues avec moins de coupures, en mesurant la densité, en réduisant l’intensité de raffinage, ou en accroissant le traitement ou chimique ou la température.

**Reference:**


**Keywords:** MECHANICAL PULPING, LIGHT WEIGHT PAPERS, PRINTING PAPERS, OPACITY, STRENGTH PROPERTIES, PRINTABILITY, REFINERS, VALUE ADDED PRODUCT