PULP FIBER QUALITY AND THE RELATIONSHIP WITH PAPER TISSUE PROPERTIES

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Introduction

Tissue papers include a wide range of products with different properties and quality demands. Key properties include: strength, absorbency, grammage, thickness (bulk), brightness, stretch, appearance and softness[1].

Recovered fibers now represent over 50% of the industry’s raw materials. However, using fibers from recovered paper makes it more difficult to maintain machine “runnability” and product quality.

Frequently, the relationship between tissue properties and pulp fiber quality (morphology) is counter-intuitive. It is also grade specific. Knowledge about this relationship holds the key to maximising tissue quality and lowering costs, whilst managing the variability of virgin and recovered fiber. This relationship is sufficiently important that most major tissue manufacturers have obtained patents on the means of generating and controlling fiber curl[15-19].

This report investigates the relationships between fiber morphology and tissue paper properties. This includes the impact on tissue properties of daily variations in fiber quality. The relationships are explained and guidance is provided as to the preferred method to measure fiber quality and how to modify it.

Fiber Morphology Definitions

Fiber quality is often defined in terms of fiber length and shape[2,3,4]. Fiber length is normally described as either the fiber contour length, L, or the end-to-end (projected) length, ℓ, Figure 1.

Two common measures of fiber shape are curl and kink. Curl is the gradual and continuous curvature of a fiber and is defined by[2,5]:

\[
\text{Curl Index} = \frac{L}{\ell} - 1.
\]

Kink is the abrupt (bend) change in the fiber curvature and is defined by Kibblewhite’s Kink Index[4]. This index is a weighted sum of the number, Nx, of kinks within a range of “x” kink angles:

\[
\text{Kink Index} = \frac{2N(21-45°) + 3N(46-90°) + 4N(91-180°)}{LTOTAL}.
\]

Fiber Morphology and Tissue Properties

Sheet Strength

The relation between sheet strength and fiber length is well known[6]. Increasing fiber length will tend to increase tensile strength (in-plane force) and tear strength (out-of-plane force). This arises from the longer fibers presenting more bonding opportunities/fiber. The relation holds over a range of sheet densities[2] as shown in Figures 2.

Figure 1: A diagrammatic representation of a curled fiber with 2 definitions of length

Figure 2: Increasing avg. fiber length from 1.47 to 2.70 mm increases tensile strength, at fixed bulk, for softwood Kraft pulp.
Fiber curl opens up the fiber network which reduces the opportunities for inter-fiber bonding and it places more stress on fiber-fiber bonds. Consequently, fiber curl decreases tensile strength\[^2\], Figure 3.

Conversely, increasing fiber curl increases wet web stretch, Figure 4. In the wet web inter-fiber bonding is negligible and the curlier fiber entangle more and resist being pulled apart.

Out-of-plane tear increases with increasing fiber curl\[^6\]. More energy is required to pull fibers out than to break them. Thus, out-of-plane tear increases with fiber curl.

Absorbency & Bulk
Absorbency and bulk are important properties for most tissue paper grades and perhaps the most important for products like paper towels.

Figures 2 and 3 reveal that increasing fiber length, or decreasing fiber curl, delivers the same sheet strength at a higher sheet bulk.

To increase absorbency and bulk, a more open fiber network is advantages. In the absence of other effects, increasing the fiber curl increases the sheet bulk, Figure 5, and absorbency.

Softness
Softness, often reported as a single value, is difficult to measure. It is considered a "compound" property subjectively combining several more basic properties\[^1\] such as surface smoothness\[^7\], bulk, and flexibility.

The relationship between fiber curl and tissue softness was reported by Borrego\[^8\], Figure 6. In general increasing fiber curl and kink tends to increase tissue softness.
Curl does increase the risk of fibers protruding out of the fiber network in the z-direction of the sheet. When fibers protrude out, it is important that these protruding fibers be soft and supple.

Accurately Measuring Fiber Length & Shape

Research performed at FP Innovations (Paprican), the University of British Columbia and OpTest Equipment Inc. resulted in a new design of cytometric flow cell that orients fibers precisely for proper analysis\(^9,11\) of length, curl and kink.

The flow cell, Figure 7, has a 33 mm\(^2\) cross section. The fibers flow in a thin (<0.5 mm) middle laminar layer which is flanked by 2 clear water layers. This design prevents flow cell contamination and plugging by highly curled and kinked fibers typically found in recycled pulps.

With the fibers correctly oriented it is essential that the entire fiber be measured without interference by air bubbles or dirt specks. This is best be achieved by using circular polarised light\(^9,10\).

Advanced image analysis software then measures the two dimensional morphology on fibers properly oriented and illuminated. This technology is embodied in a commercial device call the Fiber Quality Analyzer, FQA.

Process Variation of Length and Curl and Impact on Tissue Properties

Fiber length and curl was measured 8 times daily, for 18 days by a fiber quality analyzer, in a mill producing fully bleached Kraft softwood (FBK Swd) and hardwood (FBK Hwd) pulp. Figure 8 reveals the fiber length variation during this 18 day period. The 2-sigma Lw %-variation of the FBK Swd was about twice as large as the FBK Hwd.

However, the Curl Index %-variation, Figure 9, was over 3 times greater than the corresponding Lw variation. The impact of the Curl variation on tissue strength and bulk is estimated in Table 1.

Over the 18 day period the tensile strength would vary as much a 37% and bulk as much as 12% for tissue made of 100% FBK softwood.

<table>
<thead>
<tr>
<th>Time Period</th>
<th>Curl Index</th>
<th>Bulk</th>
<th>Tensile</th>
<th>Softness</th>
</tr>
</thead>
<tbody>
<tr>
<td>16 h</td>
<td>Lw</td>
<td>± 32%</td>
<td>± 32%</td>
<td>± 32%</td>
</tr>
<tr>
<td></td>
<td>% COV</td>
<td>± 13%</td>
<td>± 2.2%</td>
<td>± 9.7%</td>
</tr>
<tr>
<td>19 day</td>
<td>Range</td>
<td>± 32%</td>
<td>± 6.1%</td>
<td>± 18.5%</td>
</tr>
</tbody>
</table>

Table 1: The impact of fiber curl process variations on tissue made from 100% FBK Swd pulp
Changing Curl & Kink

Any mechanical action on fibers\(^{[12-14]}\) performed at high consistency (>10%) can introduce curl into chemical and recycled pulps. Even at lower consistencies changes in fiber morphology, brought on by refining, impacts tissue properties\(^{[8,12]}\). This behaviour is sufficiently important that most major tissue manufacturers have obtained patents on the means of generating and controlling fiber curl\(^{[15-19]}\).

It is often necessary to reduce excessive fiber curl. In general, low intensity-low consistency (LC/LI) refining helps remove curl and kink from chemical pulps as shown in Figures 10 and 11. The fiber quality analyzer results in these figures are for an 80% hardwood and 20% softwood bleached pulp.

![Figure 10: Effect on fiber length due increase in refining energy](image)

Figure 10 reveals that from 0 to 60 kWh/BDMT the fiber length changes by less than 1%. Then from 60 kWh/BDMT to 130 kWh/BDMT the average fiber length decreases by 6%. However, the reduction in fiber Curl and Kink is significantly greater from 0 to 60 kWh/BDMT.

![Figure 11: Effect on fiber Curl and kink due increase in refining energy](image)

Figure 11 shows that from 0 to 60 kWh/BDMT the fiber curl and kink decreases by over 16%. Then from 60 kWh/BDMT to 130 kWh/BDMT the fiber curl and kink decreases by about 7%.

The LC/LI refining study demonstrates how excessive curl and kink may be lowered without sacrificing fiber length. This method may be used to target curl and kink levels that provide desired tissue properties as discussed above.

The process stages of washing and bleaching a northern softwood Kraft pulp are presented in Figures 11 and 12. The fiber length, curl and kink were measured by a fiber quality analyzer.

![Figure 12: Northern softwood fiber length change during washing and bleaching](image)

Figure 12 finds that the reduction in fiber length over the entire process was less than 4%. However, there was significant increase in both curl and kink indices after each bleaching and washing stage. The Curl index increased from 0.075 entering the bleach plant to 0.175 exiting the last washer, or an increase of 131%.

![Figure 13: Northern softwood fiber curl and kink change during washing and bleaching](image)
The last stage of the process was the LC/LI refining which reduces the Curl Index to the target value of 0.12 (or 12%).

Conclusion

It has been shown that typical process variations may drastically change fiber curl and kink without significantly affecting fiber length. The investigations in this report reveal that changes in fiber curl and kink can significantly impact important tissue paper properties. Consequently precisely measuring fiber length, curl and kink is required to monitor and control the amount of curl and kink. This is the key to maximising tissue quality and lowering costs, whilst managing the variability of virgin and recovered fiber.

References

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Fiber Quality & Tissue Properties

Topics:

• Introduction & definitions
• Fiber morphology & tissue properties
• Accurately measuring fiber length & shape
• Impact of fiber variations on tissue quality
• Modifying fiber curl & kink
• Meeting the Int’l Standards
• Conclusion
Fiber Quality & Tissue Properties

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Fiber Quality & Tissue Properties

Introduction & Definitions

• Fiber length alone is a poor predictor of final product quality…

• Virgin and recovered fibers may have the same lengths, but different shapes will significantly affect tissue properties such as strength, bulk & softness

• Several US patents have been issued to major tissue manufacturers on the topic of fiber curl and tissue making
Fiber Quality & Tissue Properties

Introduction & Definitions

Definition of curl and kink:

• Curl Index = \( (L/l) - 1 \)
  \( L = \) Contour Length
  \( l = \) End-to-end [Projected] Length

• Kink is an abrupt change in curvature

• Kink Index = \( \{2N(21°-45°) + 3N(46°-90°) + 4N(91°-180°)\} / \text{Total } L \)
  \( N = \) Number of kinks counted within a range of angles
Fiber Quality & Tissue Properties

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Fiber Quality & Tissue Properties

Fiber Morphology & Tissue Properties

- Dry tensile strength as a function of length and curl:

- Strength loss with shorter & curlier fibers
Fiber Quality & Tissue Properties

Fiber Morphology & Tissue Properties

- Dry tensile strength & fiber length:
Fiber Quality & Tissue Properties

Fiber Morphology & Tissue properties

- Dry tensile strength & fiber curl:
  Curl & kink reduces effective fiber length

* Curl & kink place more strain on fiber bonds

* Curl & kink place more strain on fiber bonds
Fiber Quality & Tissue Properties

Fiber Morphology & Tissue Properties

• Wet web strength (~ 20% solids):
  • Wet stretch increases with fiber curl
  • Fiber bonding not a factor
  • Mainly fiber entanglement
Fiber Quality & Tissue Properties

Fiber Morphology & Tissue Properties

- Bulk & softness as a function of fiber curl

Curl & kink opens the sheet increasing bulk & softness

Burrego, Tissue World 2009-Nice
Fiber Quality & Tissue Properties

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Fiber Quality & Tissue Properties

3 Requirements to measure accurately:

1. Precisely orient fibers to correctly measure fiber length, width, curl, & kink
   Also, analyzes fiber bundles without plugging

2. Characterizes only cellulose

3. Measure all values simultaneously on each fiber
Fiber Quality & Tissue Properties

1. Precisely orient fibers to correctly measure length, width & shape values…

“sandwich” of 3 layers with cross section of 33 mm²
The thin middle layer is laminar and contains fiber

Clean water outer layer

Imaging area

Center layer with fibers

Clean water outer layer

cytometric flow cell
US Patent No. 5311290
2. Characterize only cellulose

Smallest air bubbles cannot be distinguished from fines!
Fiber Quality & Tissue Properties

2. Characterize only cellulose
- Using cross-polarized light causes air bubbles & non-cellulose contaminants to disappear...

There are 2 types of polarized light: Linear and Circular...
Fiber Quality & Tissue Properties

2. Characterize only cellulose

Circular polarized light gives true length in 2-d

same fiber, different polarization
Fiber Quality & Tissue Properties

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Fiber Quality & Tissue Properties

Fiber Quality Variations & Tissue Properties

- Fiber quality analyzer measured variations in Lw & CI over 18 days:
  - Curl Index variation is > 3x greater than Lw
  - The variability was greater for FBK softwood
Fiber Quality & Tissue Properties

Fiber Quality Variations & Tissue Properties

• Tissue made from this FBK softwood would be expected to have noticeable variations in quality.

• Using the relationships described earlier...

<table>
<thead>
<tr>
<th>Time Period</th>
<th>Curl Index</th>
<th>Est. 2-sigma property variation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Bulk</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16 h</td>
<td>Range</td>
<td>0.18 - 0.23</td>
</tr>
<tr>
<td></td>
<td>%COV</td>
<td>± 13%</td>
</tr>
<tr>
<td>19 day</td>
<td>Range</td>
<td>0.13 - 0.25</td>
</tr>
<tr>
<td></td>
<td>%COV</td>
<td>± 32%</td>
</tr>
</tbody>
</table>
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Modifying Fiber Curl & Kink

• Any mechanical action on fibers performed at high consistency (>10%) can introduce curl into chemical and recycled pulps.

• It is often necessary to reduce excessive fiber curl.

• In general, low intensity-low consistency (LC/LI) refining helps remove curl and kink from chemical pulps…
Fiber Quality & Tissue Properties

Modifying Fiber Curl & Kink

Fiber quality analyzer results on an 80% Hwd / 20% Swd blend:

<table>
<thead>
<tr>
<th>Energy Range</th>
<th>ΔLw (mm)</th>
<th>Δ Curl &amp; Kink</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 60 kWh/BDMT</td>
<td>&lt; 1%</td>
<td>&gt; -16%</td>
</tr>
<tr>
<td>60 – 130 kWh/BDMT</td>
<td>~ - 6%</td>
<td>~ - 7%</td>
</tr>
</tbody>
</table>
Fiber Quality & Tissue Properties

Modifying Fiber Curl & Kink

- This LC/LI refining study demonstrates how excessive curl may be lowered without sacrificing fiber length.
- This method may be used to target curl and kink levels that provide desired tissue properties.
- Consider the process stages of washing and bleaching a northern softwood Kraft pulp...
Fiber Quality & Tissue Properties

Modifying Fiber Curl & Kink

- Lw decreases <4% over the entire process

- Exiting the last washer, the curl & kink increased >131%

- LC/LI Refining brought the curl index to the target value of 12%
Fiber Quality & Tissue Properties

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Meeting Int’l Standards

- Std. Methods to measures **fiber lengths**: Tappi T271, PAPTAC B4 & ISO 16065-1 (Reproducibility ~3x better with polarized light!)

- Std. Methods to measures **fiber coarseness**: ISO 23713

- Common specifications:
  - flow cell orients fibers to <0.5 mm thin plane
  - light & detector spectral sensitivity match >90%
  - Use **cross polarized** light (>99% extinction) to detect only cellulose
  - calculate Ln, Lw, and Lww for each fiber
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Fiber Quality & Tissue Properties

• Typical process variations of fiber curl & kink may occur with no appreciable change in fiber length
• This report shows that changes in curl & kink can significantly impact important tissue properties
• Precisely measuring fiber length, curl and kink is required and best achieved with technology that:
  – correctly orients, without deforming, fibers for imaging
  – uses circular polarized light for “true” 2-d analysis
• Controlling fiber length & curl is key to maximizing tissue quality and lowering costs, whilst managing the variability
Thank you … Questions?