Lightweight, High-Opacity Paper: Process Costs and Energy Use Reduction


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Fiber loading is an environmentally friendly, energy efficient, and economical method for depositing precipitated calcium carbonate (PCC) partly within pulp fibers. Fiber loading can easily be done within the existing pulp processing system. This paper is a review of the process development from bench-scale to industrial-scale demonstrations, with additional experimental results showing the benefit of high consistency and high pH used in fiber-loading processing. Initially increasing the filler level without decreasing paper strength was the objective. Subsequently, substituting low cost PCC for higher cost fiber was evaluated. Finally, a fiber-loading method was developed that processes fiber at high consistency and pH, resulting in a high ash pulp without reducing freeness. A principal advantage of fiber loading is in applications for lightweight, high opacity, mechanical pulp containing printing grade papers. An example of this use of fiber loading is in adding 4% PCC and reducing grammage by 4 g/m² processing of 600 metric tons per day of newsprint. This example gave an estimated return on investment from 26.7% to 39.0%, depending on raw material costs for the PCC.

INTRODUCTION

A method to incorporate fillers within pulp fibers has been the subject of extensive research (1-3). The initial goal of this general area of research was to incorporate filler within fiber in order to have high strength fiber at high ash content. Another goal was to substitute low cost filler for high cost fiber using fiber loading. However, we now propose that in addition to filler for fiber substitution, it is possible to produce lightweight, high opacity, mechanical pulp containing paper by means of fiber loading.

Scallan and associates (1,2) reported the first studies (called lumen loading). These experiments focused on the use of titanium dioxide as filler. An excess of titanium dioxide was mechanically mixed with a pulp slurry depositing titanium dioxide within the fiber lumen. However, limitations of this method are that a large excess of titanium dioxide is required for lumen loading and a process to recycle this excess titanium dioxide is needed.

More recent studies on cell wall loading were reported by Allen and associates (3). Their approach was to saturate pulp fibers with, for example, sodium carbonate and react the resulting pulp mixture with a salt-containing calcium (e.g., calcium chloride). The resulting pulp mixture could contain high levels of calcium carbonate because the salt ions can easily penetrate into the fiber. This process has the advantage of using low cost filler in place of higher cost fiber. However, additional processing is required to remove salt remaining in the mixture.

The fiber-loading process developed in our laboratory is a two-step process (4). First, calcium hydroxide is mixed into pulp fibers. Then, the pulp mixture is reacted using a high consistency pressurized refiner under carbon dioxide pressure to precipitate calcium carbonate. This process uses conventional process equipment and has no byproducts.

In the following, we outline the FPL fiber-loading development and some general advantages of fiber loading in contrast to conventional PCC direct loading. There are three general areas of potential benefits to fiber loading:

- Improvements in product quality,
- Reduction in raw material costs, and
- Improvements in mill operating cost, including drying energy needs.

BENCH- AND INDUSTRIAL-SCALE EVALUATIONS

Initially, we examined fiber loading as a way to minimize a critical problem of recycling-hornification (5). We reasoned that if fillers could be precipitated within fiber voids, collapse of these voids during subsequent drying might be reduced. Although the impact of fiber loading on hornification remained unclear, other economic and environmental benefits became apparent. Not only
does incorporating an inexpensive filler extend the fiber supply, but also less sludge may be generated by this fiber-loading method.

Initial loading experiments indicated that rhombohedral calcite crystals in the 1-3 micron range were achievable. Cross sections of fiber-loaded softwood pulp and handsheet fibers examined by scanning electron microscopy (SEM) showed that PCC was deposited in discrete angular particles, i.e., crystals. Crystalline aggregates were seen in the lumen and on the fiber surface. The distinctive spectrum of calcium was found by x-ray microanalysis on the surface, in the lumen, and in the fiber wall. This information indicated that a portion of the calcium ions diffuse into the fiber wall and subsequently react with carbon dioxide, depositing PCC on both the internal and external surfaces of pulp and handsheet fibers.

Handsheet tests showed that at a given ash level strength properties were stronger for fiber-loaded pulp than for direct-loaded pulp (5). Also, at given ash levels, optical properties were poorer for fiber loaded than for direct loaded. This is understandable, because the fiber-loaded PCC in close contact with cell wall material (e.g., inside the cell lumen) may inherently scatter less. This is because the difference in the refractive index between filler and cell wall material is smaller than that between filler and air.

However, at equal strength, optical properties of direct loaded and fiber loaded are similar. Similar paper properties for fiber loading at higher ash content than direct loading has significant economic potential. Fiber-loading experiments were conducted using industrial-scale equipment for pulp preparation and papermachine evaluation (6). The pulp used was a bleached hardwood kraft. An atmospheric, high consistency refiner was used to mix the calcium hydroxide with the pulp followed by high consistency pressurized refiner under carbon dioxide pressure to precipitate the calcium hydroxide with the pulp before the fiber-loading process. Drying was increased, which we observed by the increased paper web solids in the dryer sections. Retention of PCC with either fiber loading or conventional direct loading was well within the control of conventional dual polymer retention aids. That is, the fiber loading plus a control using low consistency fiberization and conventional dual polymer retention aids. Apparent density was decreased but reduced wet pressing could offset it.

A second industrial-scale demonstration of fiber loading was performed at the Voith Sulzer Paper Technology Center at Appleton, Wisconsin, on recovered mixed office paper (7). The calcium hydroxide was completely converted to PCC. It was precipitated both within and on the fiber surfaces. Attempts to combine the mixing and reaction step were not successful, so it was concluded that separate mixing and reaction steps are needed. A handsheet study of recycled fiber-loaded paper using a recirculating handsheet mold showed that the process water contained about 50% less total suspended solids, total solids, and calcium ion concentration than did the direct-loaded pulps (8). This indicated about 50% less PCC filler would be present in deinking sludge. Because filler can be 50% or more of the deinking sludge, this is a significant finding.

Because fiber loading is conducted using high consistency, high pH processing, we reasoned that excessive curl could be created by fiber loading. Curl could adversely affect the dimensional stability of paper produced from fiber-loaded pulp. In a bench-scale study, the effects of high consistency, hot dispersion followed by conventional filler addition, and high consistency fiber loading plus a control using low consistency fiberization and minimal mechanical processing on fiber curl were evaluated (9). Although fiber loading increased individual fiber curl slightly more than that of the other two processing methods, most curl indices obtained were within the range considered relatively straight. Thus, no adverse effects as a result of curl from fiber loading are expected. In the same study, improved water removal of fiber-loaded pulp was indicated by both increased freeness after loading and lower moisture content after pressing when compared with conventionally filled sheets. Improved water removal could translate to faster papermachine drying, reducing drying energy needs, or both.

In another set of experiments (see Experimental), we examined the effect of pH and consistency on handsheet tensile index and freeness; the results of these experiments are shown in Table 1. The initial pulp was made into handsheets by fiberizing at low consistency and without any starch added. Next, we processed the pulp, but increased the pH to 12.0 with sodium hydroxide, and included 1.0% (based on oven dry fiber weight) cationic potato starch. Results showed an increase in tensile index from 27.29 to 41.25 N·m/g. The change in Canadian Standard Freeness (CSF) was from 670 to 620 ml. The CSF was small compared with the large change in tensile index.

In the same set of experiments, increasing the processing consistency from 3.5% to 15.0% further increased the tensile index from 41.25 to 49.31 N·m/g. The corresponding CSF decreased from 620 to 600 ml. This decrease was again much less than expected for a significant gain in tensile index.

The effect of changing the ash level and grammage of fiber-loaded pulp with respect to handsheet scattering coefficient and tensile index is listed in Table 2. Compared with direct loading at 7.9% ash, fiber loading at 6.2% ash and 8.7% ash resulting in
Table 1. Effect of Consistency and pH on Handsheet Strength and Pulp Freeness

<table>
<thead>
<tr>
<th>Sample</th>
<th>PH</th>
<th>Grammage (g/m²)</th>
<th>Tensile Index (N·m/g)</th>
<th>CSF (ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low consistency, no starch</td>
<td>7.0</td>
<td>45.0</td>
<td>27.29</td>
<td>670</td>
</tr>
<tr>
<td>Low consistency, starch</td>
<td>12.0</td>
<td>46.5</td>
<td>41.25</td>
<td>620</td>
</tr>
<tr>
<td>High consistency, starch</td>
<td>12.0</td>
<td>45.8</td>
<td>49.31</td>
<td>600</td>
</tr>
</tbody>
</table>

Table 2. Effect of Fiber Loading on Tensile Index and Scattering Coefficient

<table>
<thead>
<tr>
<th>Sample</th>
<th>Grammage (g/m²)</th>
<th>Ash (%)</th>
<th>Scattered Coefficient (cm²/g)</th>
<th>Tensile Index (N·m/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct load</td>
<td>44.5</td>
<td>7.9</td>
<td>627</td>
<td>18.90</td>
</tr>
<tr>
<td>Fiber load</td>
<td>43.7</td>
<td>6.2</td>
<td>523</td>
<td>42.18</td>
</tr>
<tr>
<td>Fiber load</td>
<td>48.2</td>
<td>8.7</td>
<td>589</td>
<td>36.97</td>
</tr>
</tbody>
</table>

increased tensile indexes. These experiments show that with fiber loading, ash levels can be considerably increased, grammage reduced, or both while still maintaining strength. We have also observed improved formation of handsheets with increased fiber loading, ash levels, which are usually the case for conventional increased filler. Improved paper formation is helpful in reducing basis weights. Similar results have been obtained for producing lightweight, high opacity newsprint by fiber loading (10).

**PROCESS ECONOMICS**

As a consequence of the preceding results, we examined the economics of producing lightweight, high opacity newsprint. The process economics for a specific set of conditions are reported in Table 3. We assumed the following:

- 600 metric tons per day were being produced from an 80/20 blend of thermomechanical pulp (TMP) and deinked pulp (DIP)
- Fiber fractionation resulted in 300 metric tons per day of the long fraction being required for fiber loading
- $5,860,000 for the installed fiber-loading equipment
- $50,000 per year for additional manpower for operating fiber-loading equipment
- $0.04 per kW for electricity
- 798 kWh for operating fiber-loading equipment

At a reduced grammage of 4 g/m² from 49 g/m² and increased ash of 4%, we estimated a savings of $115,000 per year from reduced drying. For raw material savings from reducing grammage and substituting PCC for fiber, we obtained values for an assumed cost of PCC at both $75 per ton and for PCC at $150 per ton. The cost of PCC varies depending on the availability of carbon dioxide at the mill site as well as availability of calcium hydroxide. We did not attempt to estimate the impact of the many factors involved in the PCC raw material costs, merely using a cost at both the high and low ends, i.e., $75 and $150 per metric ton of PCC.

At $75 per ton PCC, we obtained a savings in raw materials of $2,750,000 per year, and at $150 per ton PCC, a cost reduction of $2,150,000 per year. The return on investment (ROI) at $75 per ton PCC is 39.0% and for $150 per ton PCC, the ROI is 26.7%.

**EXPERIMENTAL PROCEDURE**

**Materials**

A fully bleached northern softwood dried market kraft pulp was used for the experiments as shown in Tables 1 and 2. Calcium hydroxide used for fiber loading was Mississippi Codex hydrated lime (Mississippi Lime Company, Alton, IL); comparative direct loading of pulp was done with papermakers grade (HO) pre-
precipitated calcium carbonate obtained from Specialty Minerals, Inc. (Bethlehem, PA).

**Equipment**

A Hobart (Troy, OH) mixer was used to mix dry calcium hydroxide into high consistency pulp. Subsequent reaction with carbon dioxide was carried out in a 305-mm-diameter pressurized disk refiner manufactured by Sprout Bauer (Springfield, OH) using refiner plates at a 0.6-mm-wide gap.

**Methods**

For fiber loading, 500-g batches of pulp at 20% consistency were mixed for a few minutes with dry calcium hydroxide in a Hobart Mixer. The pulp mixtures were then reacted with carbon dioxide in the holding chamber of the refiner pressurized at 207 kPa. After 10-min. retention, the pulp was passed through the refiner at wide (0.6-mm) plate gap. Exit temperature was less than 40°C.

Handsheets for comparative direct loading included adding papermaker’s grade PCC into the doler tank during handsheet manufacture. A cationic potato starch was added at the doler tank at 1% to help with PCC retention for both fiber-loaded and direct-loaded handsheets.

**Pulp and Paper Tests**

Low basis weight (40 to 50 g/m²) handsheets were prepared from the pulp blends by a modification of Tappi method T205. Tappi method T220 was followed for physical testing; pulp freeness was measured by T227; paper ash was measured at 400°C by T211.

**CONCLUSIONS**

- Fiber loading, by precipitating PCC partially within fibers, results in increased strength at a given ash level.
- Fiber loading substitutes low cost filler for high cost fiber.
- Both high pH and high consistency processing contribute to pulp handsheet strength development without significantly reducing the pulp freeness.
- Fiber loading permits lightweight, high opacity paper production.

- For newsprint production, a return on investment from 26.7% to 39.0% is estimated, depending on the price of PCC ingredients.

**LITERATURE CITED**


