Mill experiences of Evacuating Refiner Plates
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Abstract
The Thermo Mechanical Pulp process (TMP) has many advantages, but the recent worldwide increase in electrical energy cost threatens the existence of the process. The majority of the electrical energy consumed is applied in the refiners as mechanical energy put into the fibers through energy transfer which also produces an enormous amount of heat. For years researchers have measured and studied the impact of the temperature within the process on refining efficiency and pulp quality. It is clear that the process performance can be affected significantly by altering the operating temperature and pressures.

The concept of evacuating refiner plates was introduced at the IMPC 2005[1] conference. With this technology the unrefined particles take a separate path from the already refined particles and steam. This makes it possible to control and alter the temperature and pressure profile prevailing in the refining zone. As a consequence the refining conditions can be optimized for higher refining efficiency.

Pilot plant studies at the Ensis Papro plant resulted in significant improvements in refining efficiency, as well as creating the possibility for ultra low intensity refining. Since the pilot plant introduction a joint venture was established between Pan Pac Forest Products Ltd. (Pan Pac) and J&L Fiber Services, to explore if similar improvements could be achieved in a commercial size refiner system. Different filter configurations, plate patterns, and operating conditions have been explored and analyzed. Results from several full scale mill trials are reviewed and discussed in the paper, with emphasis on refining efficiency and pulp quality as well as operational issues.

Background
The Pan Pac mill is a Japanese owned market pulp mill operating in Hawkes Bay New Zealand since 1973. The primary refiner lines consists of five Defibrator RLP 54/58 pressurized single disc refiners operating at 1500 rpm. Ten atmospheric Defibrator RLP 50/54 refiners make up the secondary refiners, Figure 1.

![Figure 1. Pan Pac flow sheet](image-url)
Approximately 210,000 tons per year of standard newsprint pulp is produced from fast growing radiata pine, which is harvested locally. Over the last years, the cost structure for the mill has changed dramatically due to the deregulation of the national power grid, and today great emphasis is put on reducing the energy consumption for a given pulp quality. Approximately 65% of the electrical power in New Zealand is produced from hydro power, 25% thermal power, with the rest from geothermal wind power and biogas.

Electrical power is purchased on both long term agreement, and on the spot electricity market on a 30 minute basis. This can be quite challenging, since often the price can change by 500% or more depending on overall usage on the grid and longer term climatic effects (hydro dam levels). Figure 2 is a DCS screen shot of the pricing charts used on a minute by minute basis in the mill. The yellow line A represents the estimated purchase price. Depending on the price level managers will plan longer term production schedules, while the TMP operators will ensure lowest production costs on a minute basis.

Since more than eighty percent of the purchased electrical power is applied in the refiners, Pan Pac have implemented a continuous improvement program aimed at improving the overall refining efficiency. With today’s extremely high electrical energy cost in New Zealand, even a relatively small improvement in the refining efficiency will have a significant impact on the financial performance of the mill.

Refiner plate optimization is one component of this program, and a research and development partnership was established in 2005 between Pan Pac and J&L Fiber Services, Inc. The objective of this R&D effort is to find out if the results obtained with the E-Max technology at PAPRO could be duplicated on a commercial scale.

A team was organized with members from Pan Pac, J&L and Ensis PAPRO, each member having different responsibilities and tasks. A general project time line is given in Figure 3.

Traditional TMP Refiner System

A majority of the electrical energy applied to a TMP refiner as mechanical work is converted to heat as the fiber bundles are being strained between opposing refiner plate bars. As a rule of thumb, approximately 1.1 t/h of steam is produced for every 1 t/h of production. This energy transfer occurs between the refiner plates as shown in Figure 4.
Temperature measurements from the refining zones of several refiner types at different positions and different wood types, all reveal a classical temperature peak between the inlet and outlet of the disc, Figure 5 [2][3]. The fact that the pressure between the plates is higher than the inlet and outlet pressures forces the generated steam to flow in two directions; against the inlet and with the flow towards the periphery of the discs. The maximum temperature point indicates a turning point for the steam flow, for saturated conditions. This point divides the refining zone into two regions, the back-flow steam region, and a forward-flow region.

The divided steam flow often causes instabilities and recirculation within the refiner zone itself [4][5]. In addition, the requirement of not having the steam flow impede the fiber flow in the refining zone tends to work against the requirement of having the refiner bars transfer the mechanical work to the fiber at some optimum refining intensity,
Figure 6. As the number of plate bars is increased to reduce the stresses on the fibers, the open volume between the bars will decrease, and as a consequence the steam velocity increases. If the increase in steam velocity is large enough, the speed of the fibers will be so large that the additional bars in the refiner plates no longer have an impact.

**E-Max TMP Refiner System**

J&L’s E-Max refiner plate is a new approach to control the flow field within the refiner. By letting the steam and fine particles take a separate path from the coarse and unrefined fibers, the pressure (and temperature) buildup can be controlled. Figure 7 is a cross section of an evacuating refiner plate showing the steam and fiber flows. The energy is applied in a traditional plate pattern, and fifty percent or more of the generated steam passes through a filter. Depending on the size and configuration of the filter fines material (< 0.2 mm) will pass through the filter as well. For high freeness mechanical pulp, this can be as much as 30% of the production. Both the steam and fibers which are passed through the filter are forced by the centrifugal force and pressure drop through a cast channel within the plate, before being combined with the flow within the gap.
Computational Fluid Dynamic Models of the refining zone clearly reveal the difference between standard plates and the evacuating E-Max refiner plates. How much of the steam and fiber flow behind the plates is controlled by the sizing of the filters and the pressure differential between the refiner inlet and casing. In order to size the filters correctly for a given application, a combination of commercial CFD code and a specifically developed computer model for evacuating refiner plates are used.

**Steam flow through the filters**

The steam flow is driven by the continuous generation of steam and by the rotation of the rotor disc. For the radial distribution of the steam source, we are assuming the steam generation is proportional to the surface area of the differential annular ring at each radius, the rotor velocity at that radius, as well as the saturated steam evaporation heat at the corresponding pressure [6]. As the rotor with filter holes sweeps across the stator as a "vacuum cleaner" it depletes the steam layer in the refining gap.

Two main scenarios are at hand depending on the hole size and the number of holes per unit surface area of the filter. If the flow through the holes per unit surface area of the filter, as calculated from the pressures, is greater than the steam generated per unit surface area over the filter then the flow through the holes per unit surface area is limited to the steam generation and the pressure drops to a value very close to the case pressure of the refiner. The other scenario exists if the flow through the holes is less than the local steam generation. In this scenario there is a continuous flow over the filter surface as well as through the holes.

To date, the typical hole patterns used give us the first scenario for the flow, in which the flow through the holes is larger than the local generation of steam. In this configuration, the steam velocity is limited to 10-20 m/s. With this small steam velocity through the holes, the acceleration from drag force on a fiber is very small, except for very small fibers. Thus we can expect some of the fines evacuating through the holes, whereas almost none of the long fibers will go through the holes. Figure 9 shows the difference in refining zone temperature (and pressures) between plates with and without filter holes.

**Fiber flow through the filters**

By changing the hole diameter and pitch one can increase this velocity. At 50 m/s we get a significantly larger proportion of fibers and fines going through the holes. The fiber objects are basically moving over and across the filter area, and have to be imparted with a sufficient momentum change perpendicular to this travel in order to be able to enter the holes in the filter area. In order to estimate the removal rate through the filter area a "removal cross section" can be visualized as a surface area perpendicular to the velocity of the fiber, such that if a fiber hits within it, it will be completely removed from the fiber flow.
The larger the tangential velocity is in relation to the radial velocity, the larger the “vacuum cleaner” effect will be. In the extreme, at very high velocity aspect ratios this could result in the "clean sweep" effect, where the same fiber trajectory crosses multiple Filter areas, each removing some portion of fibers below the geometric length limit, with the result that non of these fiber classes would exit through the periphery of the refiner plates, but would all exit through holes in the Filter areas.

**Experimental**

**General trial setup**

The trials at Pan Pac were initiated in late 2005 by the installation of “experimental” E-Max refiner plates in the R5-0 primary refiner. To date, all trials have been conducted in this refiner, Figure 10. Samples are collected at the blow-line, and corresponding process data is collected from the DCS and PI information systems. In addition, the refiner has been fitted with a SmartPlates refining zone temperature measurement system, for analysis of the filter efficiencies.

![Image](image.png)

Figure 10. R5-0 refiner flow sheet.

For each trial setup, the response of the system is mapped out using design of experiments. The process variables used are: production, refiner plate gap, dilution, and pressure differential between the inlet and outlet of the refiner.

**Experimental plate trials**

**November 2005**

In November 2005, trials with experimental E-Max plates were initiated. With this design, different filter designs could easily be evaluated by making the filter a separate piece from the plate casting, Figure 11. Two different hole configurations were evaluated. After a few hours of operation, it became evident that the filters were plugged, Figure 12.
The SmartPlate temperature data was slowly creeping up to the traditional plates’ temperature profile, and the refiner was stopped after 20 hrs of operation. Upon removal of the steam boxes, it was clear that fibers were hung up on an edge within the box towards the periphery. The boxes were modified, and the experimental plates were re-installed, this time with smaller filter holes, and modified steam boxes.

With the modifications in place the filters were kept clean over time (right picture Figure 12). At the periphery of the filters on the draft side, some pitch was building up. This can be explained by the fact that the filter is slightly recessed below the plate gap, and the tangential movement of steam and fibers are significantly lower than in the plate gap. The initial plugging, although not desired, gave us an opportunity to compare the exact same refiner plate with and without filter holes, Table 1. The table compares two different E-Max plate patterns to the coarse pattern with a plugged filter, at three different freeness levels, 700 ml, 675 ml, and 650 ml.
Table 1. Experimental E-Max summary

<table>
<thead>
<tr>
<th></th>
<th>136 km/rev</th>
<th>136 km/rev</th>
<th>151 km/rev</th>
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<tbody>
<tr>
<td></td>
<td>Plugged</td>
<td>Open</td>
<td>Open</td>
</tr>
<tr>
<td>CSF ml</td>
<td>700</td>
<td>700</td>
<td>700</td>
</tr>
<tr>
<td>SEC kWh/ton</td>
<td>811</td>
<td>753</td>
<td>703</td>
</tr>
<tr>
<td>Fiber Length mm</td>
<td>1.95</td>
<td>1.94</td>
<td>1.87</td>
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<tr>
<td>CSF ml</td>
<td>675</td>
<td>675</td>
<td>675</td>
</tr>
<tr>
<td>SEC kWh/ton</td>
<td>875</td>
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<td>730</td>
</tr>
<tr>
<td>Fiber Length mm</td>
<td>1.92</td>
<td>1.91</td>
<td>1.82</td>
</tr>
<tr>
<td>CSF ml</td>
<td>650</td>
<td>650</td>
<td>650</td>
</tr>
<tr>
<td>SEC kWh/ton</td>
<td>935</td>
<td>840</td>
<td>780</td>
</tr>
<tr>
<td>Fiber Length mm</td>
<td>1.9</td>
<td>1.9</td>
<td>1.78</td>
</tr>
</tbody>
</table>

From the table it is clear that the filter holes trialed reduced the specific energy consumption by 7-10 percent against the same pattern with plugged filter holes. A reduction of 13-17 percent was possible with a slightly finer pattern to a given drainage, however at the expense of a reduction in fiber length by 4-6 percent. With these encouraging results, it was decided to go ahead with a “commercial product”, and new trials were scheduled for June 2006.

**Cast plates trials**

**June 2006**

The commercialized product has a cast channel inside the refiner plate, and the filter is an integral part of the casting. The evacuation channel is formed by placing a core in the mold for the castings. As the steel freezes, the core can be shaken out, and a channel is formed. Today, the filter holes are machined into the plates. By having one integral piece, the installation is made easy, and no modifications to the refiner are required, Figure 12.

A dramatic 30% drop in the applied specific energy was observed for the R5-0 refiner line after the E-Max installation, Figure 13. It should be noted that refiner plates installed prior to the E-Max installation were
bi-directional which typically require approximately 15% more energy than the uni-directional refiner plates used with the evacuating refiner plates. The savings from the E-Max contribution is thus approximately 15%.

![Figure 13. Applied specific energy vs time](image)

We continued with a comparison of the same uni-directional plate pattern (132 km/rev), with and without evacuation holes, Figure 14. At a freeness level of 710 ml the evacuation channel reduced the energy consumption by 12 percent without any adverse effect on fiber length. The operating window was explored using design of experiments, and the resulting pulps were analyzed using the Pulp Expert Fiber analyzer at Pan Pac. Selected samples where then forwarded to Ensis Papro for detail analysis.

![Figure 14 Freeness vs Specific Energy, and Pulp Expert LW Fiber Length vs Freeness](image)

With the majority of the steam bypassing the refining zone, plate patterns with significantly more bars can be used since the need for open volume within the plate is eliminated. One additional plate pattern with a 30 percent increase in edge length (183 km/rev) is compared in Figures 15 through 19. The open symbols represent reference samples from parallel refiner lines operating at very similar tonnage during the trials.
The specific energy requirement dropped approximately an additional 12% for the 183 km/rev pattern compared to the 132 km/rev reference E-Max refiner plate pattern. However, the pulp quality has changed as well, but is the quality worse? Rather surprisingly, with the additional edge length, a portion of the Bauer McNett R14 fraction has moved to the +50 and +100 middle fractions. There is no significant difference in the fines fraction (-200). This pulp will have a higher bulk than the reference pulps. There was no significant difference in Pulmac shives, Figure 17.
Figure 17. Pulmac Shives vs Freeness and R30

Figure 18 SmartPlates temperature data, converted to pressure

The SmartPlates pressure data is shown in Figure 18. From the graph it is clear that the traditional pressure peak in the middle of the plate is essentially removed with the E-Max refiner plates, with all steam moving forward with the pulp. Please note that there is a constant pressure drop of 0.5-0.8 bar over the E-Max filters towards the refiner case pressure (2.2 bar).

After approximately 90 hours of operation, the plates were removed due to burned pulp at the periphery of the plates. It is interesting to note that the burned area starts where the filter area ends. At the time we speculated that due to the reduced pressure drop over the plate, the drag forces are reduced and, as a consequence, the radial force on the material is less, Figure 19.
September 2006

The objective for these trials was to eliminate the burned pulp at the periphery of the plates. The patterns were modified by converting the full-height dams at the periphery of the plates to sub-surfaced dams in order to reduce the radial flow resistance at the periphery of the plates. Figure 20 is a graph of the refining zone temperature as a function of time. Note how the temperatures remains flat, indicating that the plates are kept clear. This was verified by inspection at 50, 120 and 190 hrs.

Although the plates were clear, the bar edges were severely worn already after 50 hrs of operation, and the plates were removed after 240 hrs due to poor quality. The severe bar-edge rounding can to a large extent be explained by the softer plate alloy we selected. The stresses in the E-Max refiner plates are slightly higher than in standard plates due to the cavity within the plates. Because of the uncertainty of the loads acting on the plates, we made a cautious decision when selecting the stronger but less wear resistant alloy for the initial trials.
February 2007-present

The objectives for these trials are to improve plate life and to monitor energy and pulp quality over time. In addition, the geometry of the filter holes has been changed to reduce the amount of free water that is allowed to pass through, which we now believe caused the burn in at the periphery of the plates.

Sedimentation tests

Blow-line samples were collected from the primary refiners, and compared using a sedimentation technique introduced by Ross Wakelin [7]. The characterization of mechanical pulp quality typically uses measurements on the whole pulp, such as freeness and handsheet properties. The problem with this is that similar values can be achieved through different combinations of quality and quantity of the fiber and fines components and, as a consequence, it is very difficult to pinpoint how the pulps differ.

With the sedimentation test, pulps with the same freeness can be differentiated in terms of degree of fiber development by removing the influence of fines content, Figure 20. Table 2 compares the different primary refiners.

![Figure 20 Sedimentation index of pulps of similar freeness, but with different fiber development](image)

Table 2 Sedimentation index and operating conditions

<table>
<thead>
<tr>
<th>Refiner</th>
<th>Plate Gap mm</th>
<th>Main Motor Load MW</th>
<th>SEC kWh/admt</th>
<th>Production T/h</th>
<th>Cons %</th>
<th>CSF ml</th>
<th>Fiberlength mm</th>
<th>Slope of graph S²A m²/g</th>
<th>s²A: 10.91</th>
<th>12.25</th>
<th>11.79</th>
<th>11.16</th>
<th>11.51</th>
</tr>
</thead>
</table>

A higher sedimentation index indicates a higher degree of fibrillation, which is desirable in terms of fiber collapsibility and bonding ability. To date it is very hard to draw any conclusions if there is any significant difference between the pulp produced with E-Max versus standard refiner plates. However, as more tests are done over time we may be able to draw some conclusions.

Concluding Remarks

The E-Max refiner plate concept shows great promise, with a 15-30% reduction in the required specific energy for a given pulp quality, depending on the reference selected. These results are in line with the findings at the Ensis-Papro pilot plant. However, new technologies have many unknowns associated with them, and the E-Max project at
Pan Pac is no different. We have struggled with plugged channels, burned plates, excessive wear etc, but over the last two years we have come closer to a new viable refining concept.

By allowing a majority of the steam and fine particles take a separate path from the unrefined fibers, new opportunities are opening up. The refining efficiency will improve because of reduced recirculation, reduced throughput in the plate gap, a more uniform residence time throughout the plate gap passage, and a controllable refining zone temperature. This is accomplished without any capital investment, using existing refiner equipment with the required modifications incorporated into the rotating refiner plates.

Trials are scheduled to verify energy consumptions and pulp quality on a mill wide basis. To date up to 33% of the produced pulp has been made with evacuating refiner plates, with no measurable adverse effects on the pulp quality or operation. Over time, we will increase this to 50 and 100% for periods of time to evaluate what impact the concept has on energy, quality and operations.

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References


