MILL SCALE DEVELOPMENT TOWARDS HIGH-PRODUCTION, LOW-ENERGY TMP REFINING LINE

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ABSTRACT

The main driving force in thermomechanical pulp (TMP) refiner development has been towards higher production rate refining lines. High production in the refining line offers both low investment and production costs for a paper mill. High production in the TMP line also produces pulp at lower energy consumption [1]. This has become increasingly important considering continuously rising energy prices and “real-time” electricity pricing.

Papier Masson was the first pulp and paper producer to build its new TMP line based on the single-refiner line concept in 2000. The refining line comprises two RGP-82 conical disc (CD) refiners followed by a low-consistency refining stage with three parallel refiners, screening and one RGP-82CD reject refiner. This line feeds one newsprint paper machine based solely on TMP pulp. Paper machine speed has been increasing continuously from its start-up and, accordingly, major efforts have been made to increase the TMP line production capacity. Production in 2000 was 640 BDMT/D. Recently, the production has exceeded 800 BDMT/D. Paper quality has not been compromised and pulp strength has been maintained at a high level.

This paper presents results from mill-scale development work focusing on main-line high-consistency refiners. Main improvements have been seen as a result of steam-separation technology, refiner-control strategy, and refiner segment developments.

A new refining efficiency formula [2], developed in Tampere University of Technology, for main line high consistency refining is also applied. This theory provides a new approach to analyzing the effects of refiner line operating conditions.

INTRODUCTION

The Papier Masson paper mill is located in Gatineau, Quebec. In 2000, the mill was the first pulp and paper producer to base its new TMP line on a single-refiner line concept. Refining line consists of two RGP-82CD conical disc refiners followed by a low-consistency refining stage with three parallel refiners, screening and one RGP-82CD reject refiner, as shown in Figure 1. All high-consistency refiners are equipped with 32 MW motors. This line feeds a newsprint paper machine based solely on TMP pulp.

Paper machine speed has been increasing continuously from its start-up and therefore lot of efforts has been used to increase production in TMP line. Production in 2000 was 640 BDMT/D. Recently, the production has exceeded 800 BDMT/D. Paper quality has not been compromised and pulp strength has been maintained at a high level.

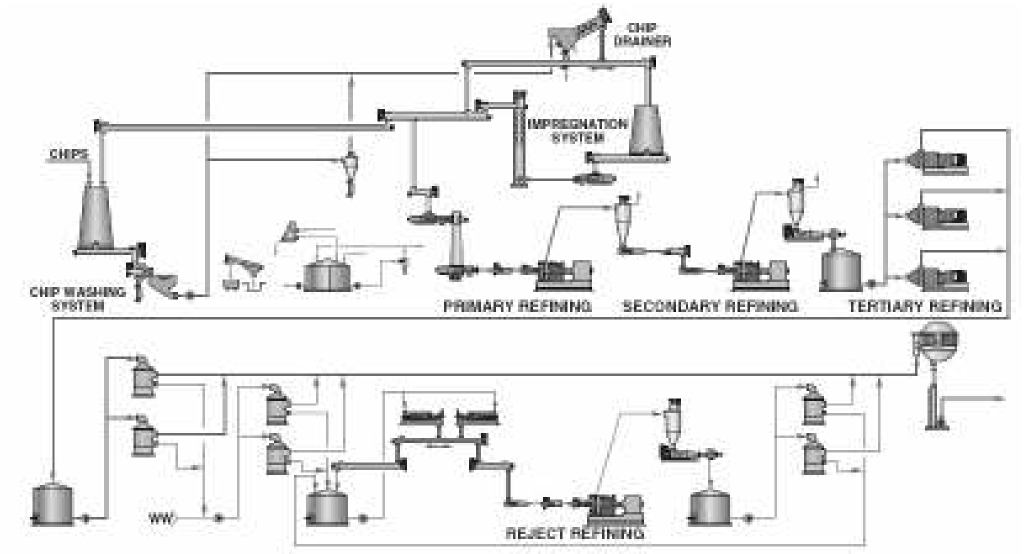


Figure 1. Flowsheet of Papier Masson TMP line.

Higher production lowers the refiner specific energy needed for the targeted freeness, as shown earlier [1, 3], but it might also have a negative effect on pulp quality. These phenomena are due to fact that higher throughput reduces residence time inside the refiner [4, 5]. Operating at high production while maintaining favorable pulp quality in refining, requires that the flow situation and refining intensity be adapted by changing refiner segment types or operating conditions. New intensity analyses, which will be presented later in this paper, provide a good tool for this work.

Another aspect in development of high production refiner lines is the loadability of the refiner. With high-capacity production, it is more difficult to apply as much specific energy in a refiner as in lower capacity production. Typical loadability curves for CD refiners [6] predict that in primary stage equipped with an RGP-82CD and a production rate of 600 tpd, 1200 kWh/T can be applied, but at 800 tpd it is difficult to apply more than 1000 kWh/T. These values are based on typical refining conditions and segment types and can be changed depending on the set up. Development efforts are needed to improve loadability above these curves.

In practice, a limitation for production rate increase in Papier Masson has been set by the strength of the pulp and paper. Tensile energy absorption has typically been the limiting factor. Therefore, development has focused on increasing pulp strength and reducing refining energy with ever-increasing production.

Figure 2 summarizes the results from Papier Masson's development work. Results based on the mill's production and quality follow-up system and typical TEA limit has set the maximum production rate at which the mill has operated its TMP line. From the start-up in 2000 and to 2003, a number of development efforts were made to achieve a fast start-up curve. Main improvements were achieved with the refiner's dilution water injection and refiner segment development combined with development in refiner measurements and controls.

This paper focuses on development after 2003 to increase the production of the line to 800 BDMT/D. Main improvements in this work were seen as a result of developments in refiner control strategy, steam separation technology and refiner segments. Results from these development steps are reported separately in the following chapter. As a result of these steps, Papier Masson's TMP line can now produce 800 BDMT/D pulp with good strength properties. In practice, tests at this high production rate have only involved short-term trials because of the limitations set by the current electricity supply contract.

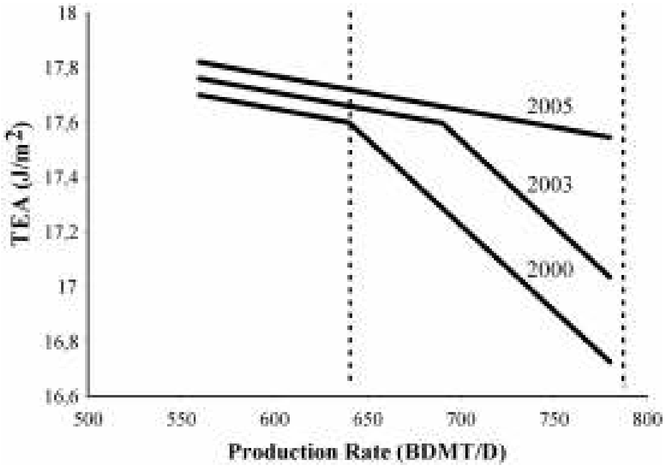


Figure 2. Final pulp quality TEA (J/m^2) as a function of TMP production rate after start-up.

MILL DEVELOPMENT

REFINER LINE CONTROL SYSTEM

Papier Masson has been working actively with refiner line controls [7]. For future work after this development was presented, it was planned to apply Model Predictive Control (MPC) for the refining line. In 2004, Metso Automation's Advanced Quality Control (AQC^{TM}) system was installed for the main refining line. Basics of this control system have been presented earlier [8].

The thirty-day performance tests for the system were done starting on March 22. Baseline was chosen to be one year from January 14, 2003 to January 13, 2004. The four-hour average data, along with the quality window, are shown in Figure 3 below. The quality window was determined by the permitted change in freeness by maintaining fiber length above the minimum value. The percent in the window for the baseline period was 66%.

Through a combination of primary blow-line consistency refiner control, primary cyclone consistency control, fiber length minimum control, and freeness target control/optimization, stable refiner operation and target pulp quality are achieved. By maintaining freeness on target and fiber length above minimum, the control system has permitted PML to achieve 95% within the quality window, compared to a 66 % baseline as shown in Figure 3.

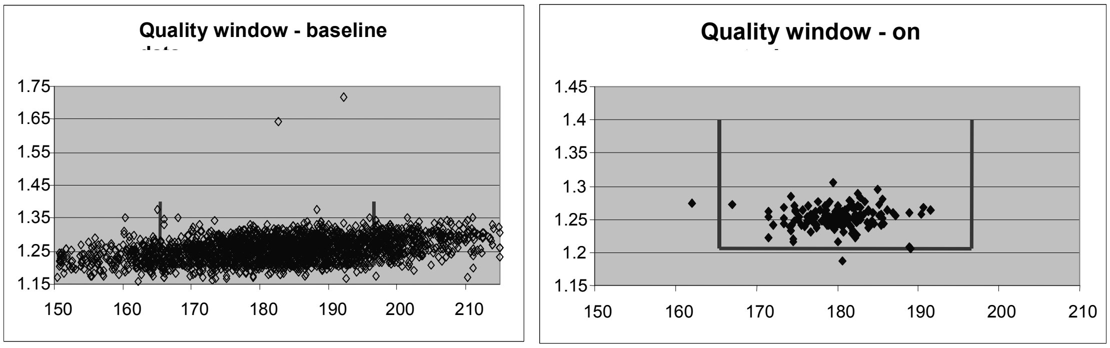


Figure 3. Graphs showing fiber length (y-axis) and Freeness (ml) after refining line during baseline period and period of AQC performance test.

The advantage of the Advanced Quality Control for Papier Masson was that when variations in pulp quality were eliminated it was possible to increase production while maintaining the pulp strength properties over the specified minimum limit for the paper machine. Control also minimizes specific energy consumption by continually producing the required pulp quality with minimized costs.

MECHANICAL STEAM SEPARATOR

Directly after implementing Advanced Quality Control, the steam separation cyclone between the refiner stages was changed to new equipment called Perisplitter™ from Metso Paper. This device uses mechanical energy to initiate the internal rotating flow. This has made it possible to reduce the size of the equipment. The difference between mechanical fiber separator and the conventional cyclone is presented in Figure 4.

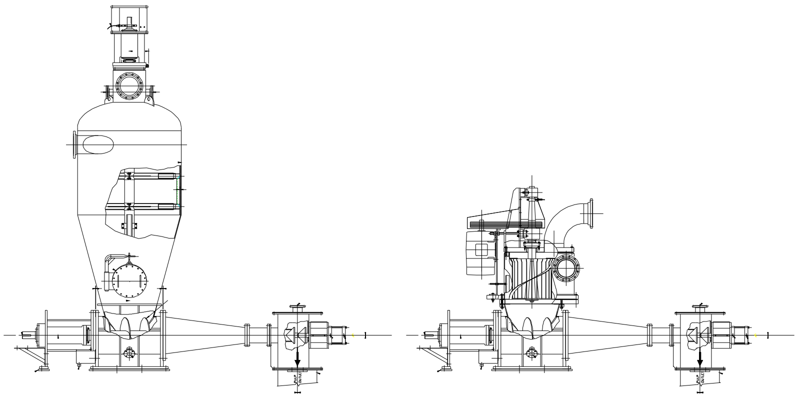
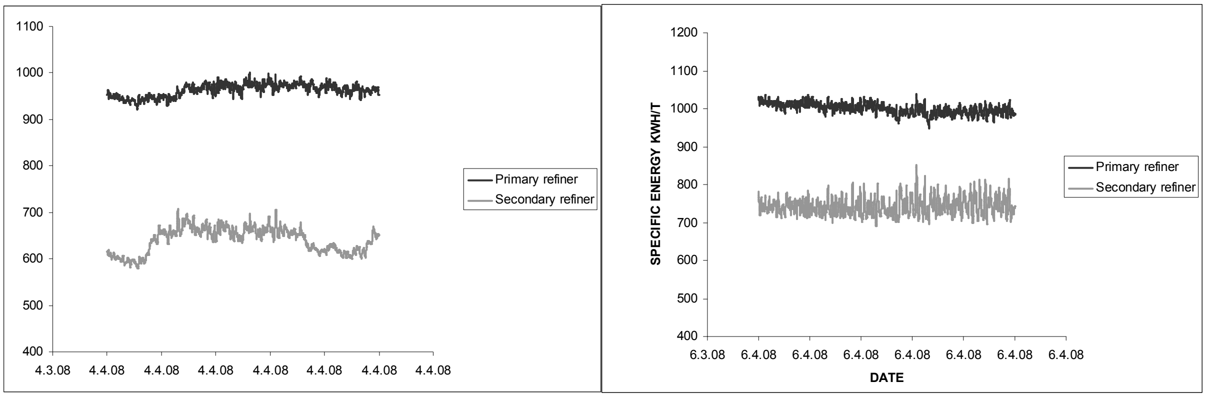


Figure 4. Cyclone and steam separator used between primary and secondary stage refiners to separate steam and fibers.

The background for this development was that it was evident that as a result of the high production rates the existing cyclones no longer worked optimally. The cyclone caused instability for the fiber feed to secondary refiner and also some fibers were carried out from the cyclone with the steam flow to heat recovery. This reduced clearly loadability and caused instability on the secondary refiner.

After installing the Perisplitter™ it was obvious that loadability of the secondary stage was clearly improved and fiber carry-over with the steam was reduced. Normal specific energies applied in the refiner stage at about 700 BDMT/D production are shown in Figure 5. The possibility to increase secondary stage load without stability problems again contributed to an additional increase in refiner line production. This development also made it possible to shift more specific energy to the secondary stage from the primary stage and, thus, to avoid higher intensity and possible strength reduction in the primary stage caused by increased production.


March 2004, Cyclone

June 2004, Steam separator

Figure 5. Specific energy applied to primary and secondary refiners when steam separation was made with cyclone (left) and mechanical steam separator (right).

REFINER SEGMENT DEVELOPMENTS

On January 19, 2005, the primary stage refiner segments were changed to feeding types to increase production further. The background for this was that at higher production rates the primary stage refiner's vibration level and instability increased. It was also suspected that pulp quality was reduced at high production rates.

The idea with this step in refiner segment development was to improve refiner feeding at high production rates. With improved feeding in the eye of the refiner, the goal was to increase the stability of chip feeding and minimize problems that a high amount of blow back steam in a refiner can cause. Center plate was designed using ideas of Turbine Segments technology [9] and flat zone segments were of unidirectional Low Energy Segment type [10]. During this development CD zone was not changed.

Results of this development were evident. Improved feeding provided a slight energy reduction at the primary stage refiner and by improving refiner flow conditions the instability seen in refiner with higher production rates was reduced. Load variations in the primary stage refiners were reduced by 30% and vibration level was reduced clearly at the higher production rates, as shown in Figure 6. At the highest production tested at the time, 725-750 BDMT/D, vibrations were reduced by 50%.

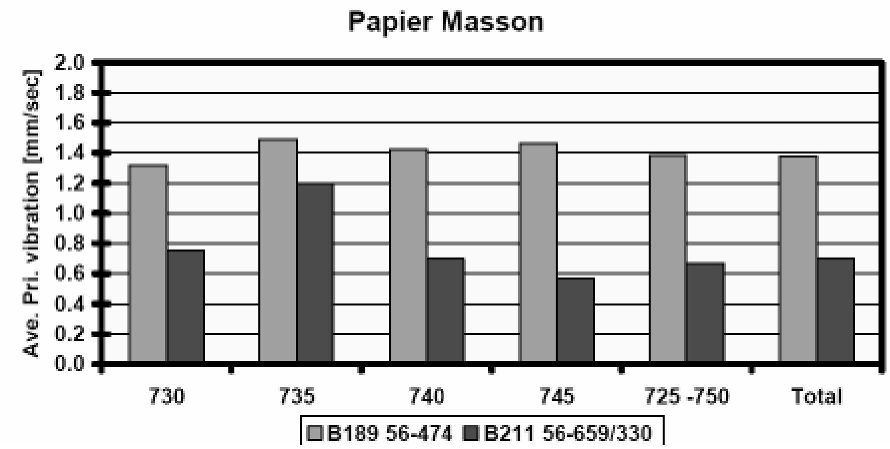


Figure 6. Average primary stage refiner vibration levels at different production rates when using standard type reversible refiner segments (B189,56-474) and new feeding type refiner segments (B211, 56-659/330) at the flat zone.

Papier Masson's TMP line can now produce 800 BDMT/D pulp with good strength properties. In practice, tests at this high production have only been short-term trials because of the limitations set by the current electricity supply contract. However, work to improve energy efficiency and to increase production rate further is being carried out continuously at Papier Masson.

TEORETHICAL CALCULATIONS FOR PRODUCTION RATE'S EFFECT ON REFINING

In order to understand the refining process, it is extremely important first to understand the flow phenomena inside a refiner. Secondly, it is important to be able to calculate or compute some basic values of flow field (fluid velocities, mass and volume fractions, residence time, etc.) and the thermo-dynamic state (pressure, temperature, latent heat, etc.) of flow medium. Moreover, it is important to be able to connect these values to the refiner's operating parameters (disc gap vs. power consumption and axial load, dilution water vs. steam production and consistency, etc.) and to have a measure to describe how these values and parameters are affecting the quality of the pulp produced. Accordingly, we applied a formula for refining intensity to evaluate the segments' refining efficiency in different refining conditions.

We have used the following formula to establish a numerical value for the refining intensity [1].

Intensity: $$I = \frac{P * 60}{N * n_b * t_r}$$ where

I is the intensity

P is the power consumption

N is the rotational speed (in rpm)

n_b is the number of bars

t_r is the residence time

When calculating refining intensity along the refining surface, values are calculated for unit radius by using actual segment geometry and simulated minimum fiber residence time as well as simulated power consumption. To get the correct figure for fiber residence time and power consumption in unit radius, the refiner's flow situation must be studied in detail. This has been carried out by using a 1-dimensional simulation model developed by Tampere University of Technology [2].

BASELINE SIMULATIONS FOR PRIMARY STAGE REFINER

Baseline simulations for the primary stage refiner are presented and analyzed to provide the background for calculated intensity values. This case is calculated using the following operating conditions.

Production	650 BDMT/D
Specific Refining Energy	1000 kWh/T
Flat Zone Disc Gap	2.5 mm
Conical Zone Disc Gap	2.2 mm
Dilution Water Flow Flat	300 l/min
Dilution Water Flow CD	300 l/min
Outlet consistency	60%
Inlet Pressure	240 kPa
Housing Pressure	350 kPa

As shown in Figure 7, results from this simulation are presented as a function of refining zone length from the center point. Both flat and CD zone are presented. Flat zone ends at a radius 710 mm, followed by the transition zone. Refining then continues in the conical zone, where stator bars are introduced at distance of 800 mm along the refining surface.

Dilution water is split 50/50 between flat and conical zones. As water evaporates to steam, consistency is increasing. At the end of the flat zone, consistency is somewhat above 50%, and water addition in the CD zone drops refining consistency again to level of 35%. At the outlet, consistency is above 60% (see Figure 7a).

Figure 7b presents cumulative power consumption along the refining surface. It is clearly seen, that only ¼ of the refiner's total energy is consumed in flat zone, and outer peripheries of both refining zones are the most important parts of the refining surface in respect to energy transfer.

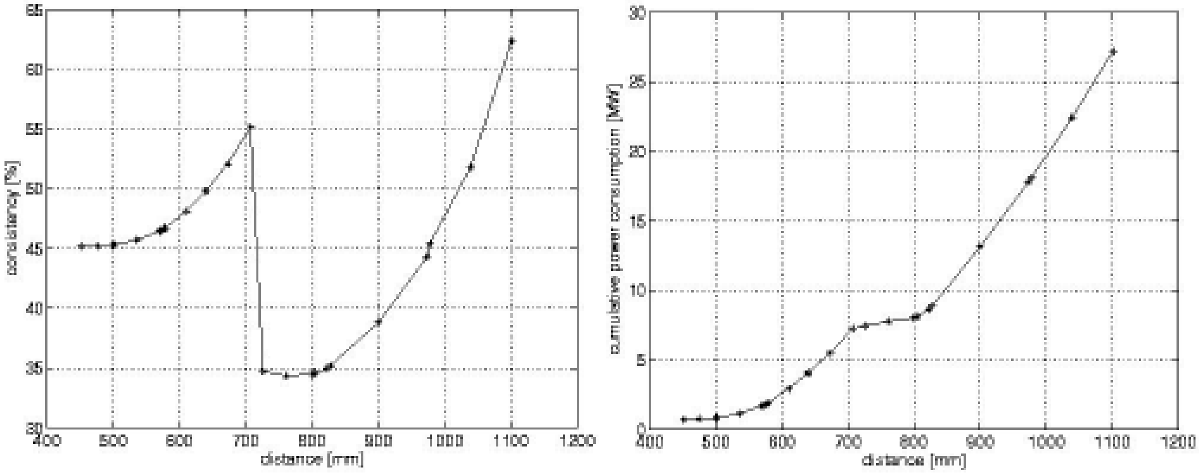
Figure 7c presents steam temperature along the refining zone. Although the baseline was simulated with "only" 650 tpd, it is obvious that high production rate and high specific energy generate much steam into the disc gap. Temperature level in the disc gap is high. There is a maximum in the area at which the conical zone bars begin.

A relatively large high temperature area forms close to the transition point from the flat zone to the CD zone. Radial velocities in the rotor side of the refiner are quite small in the beginning of the flat zone, due to the absence of steam. In the refining part of the flat zone, both steam and fibers are flowing faster. Steam velocity is higher than for fibers, because of the density difference. Speed is again reduced close to the steam pressure maximum and then accelerated towards the refiner outlet, where much of refining energy is applied to process.

Phase change from water to steam changes the refining environment along the refiner surface. Volume fractions (part of unit volume) for fibers, steam, and water are presented in the Figure 7e. In the beginning of the refining at the defibration stage, fibers cover a large part of the open volume, but the more steam is generated the more it needs space. In the transition point from flat zone to CD zone, the fiber volume fraction is again quite high. An obvious reason for this is that the open volume for flow is larger in this area and energy density applied to this zone is low. In addition, the large amount of dilution water fed to this area condensates as steam. At the periphery of the refiner, steam is again the main flow media between the segments.

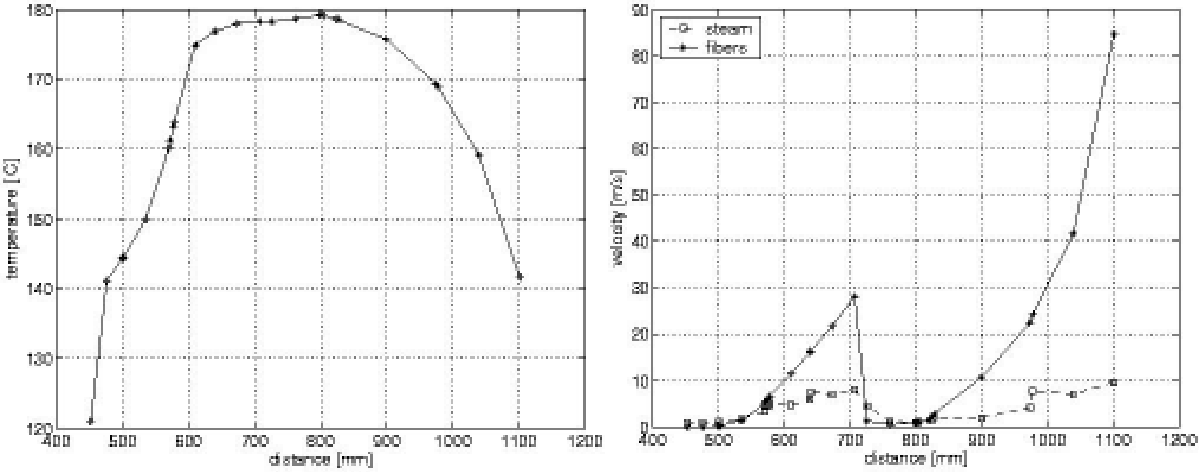
Fiber residence time is the most important parameter when comparing efficiency of the refining. All ways to reduce refining energy are made in one way or another by reducing residence time for fibers inside the refiner. Residence time is always a distribution in which some fibers are discharged rapidly directly through rotor, and some flow back towards the refiner inlet and rotate inside the refiner for a longer period. In this study, calculated residence time is based on fact that all fibers are moving forward. Consequently, these values would correlate to minimum residence time for fibers in the refiner. This is somewhat of a simplification but differences in minimum time with different segments or operating conditions are seen as much greater differences in mean residence times. Accordingly, the difference in minimum time provides a good base for comparing refining conditions.

In calculating refining intensity along the refining surface, values are calculated for unit radius by using actual segment geometry and simulated minimum fiber residence time. This is presented in Figure 8. Intensity is high in the areas in which fibers move fast and applied refining energy is high. In determining pulp quality, the outer peripheries of both refining zones are important.



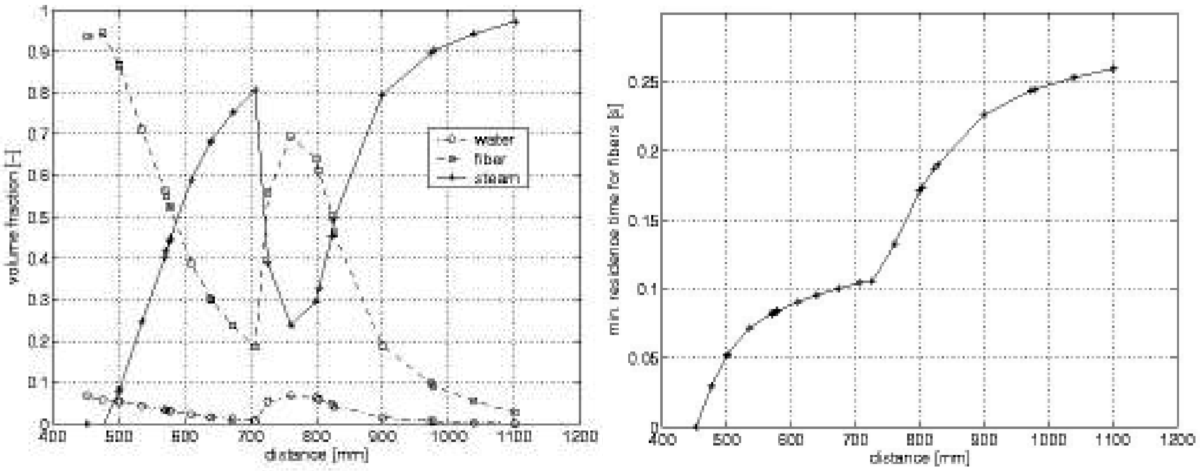
7a. Consistency

7b. Cumulative power



7c. Steam

7d. Radial velocity



7e. Volume

7f. Min. residence time

Figure 7. Results from baseline simulations for primary stage refiner

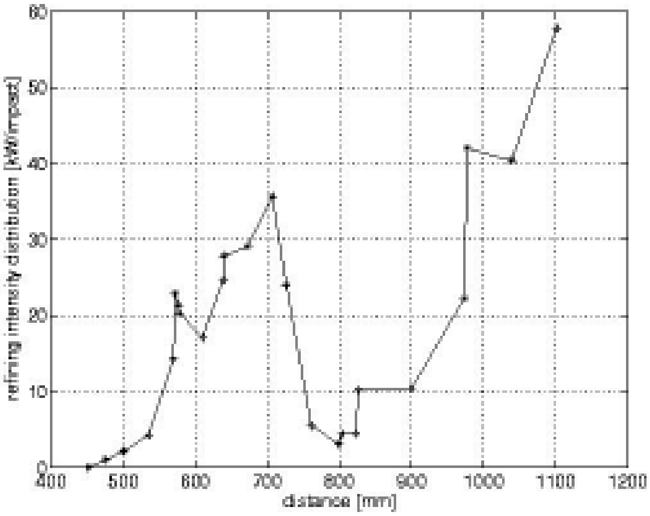


Figure 8. Calculated refining intensity in baseline simulations for primary stage refiner.

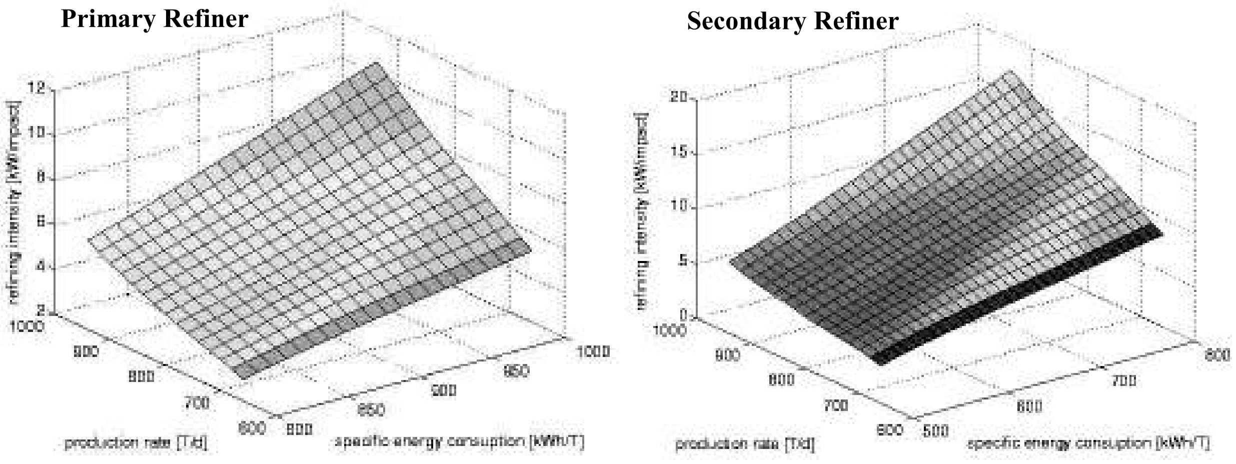
This detailed intensity information is used in refiner segment development work. The areas in the disc gap in which refining intensity reaches high local values is of main interest when developing new designs for high production rates.

THE EFFECT OF PRODUCTION RATE AND SPECIFIC ENERGY INPUT ON REFINING INTENSITY IN PRIMARY AND SECONDARY STAGE REFINERS

Simulations for both primary and secondary stage refiners were carried out with different production rates between 650 tpd and 950 tpd. At all these production rates, different specific energy levels were applied in the simulations. The energy levels studied in the primary stage were between 800 kWh/T and 1000 kWh/T and in secondary between 500 kWh/T and 800 kWh/T. Outlet consistency, water split, refiner pressures and type of refiner segments were not changed in studying the different operating conditions.

Results from this simulation are presented in Figure 9, in which refining intensity is shown as a function of production rate and applied specific energy for both primary and secondary refiners. This approach provides an explanation for the phenomena seen in the trial. Higher production with constant specific energy increases refining intensity due to changes in flow conditions and fiber residence time inside the refiner. Moreover, if the applied specific energy is higher, intensity increases. After passing a certain level, higher intensity also begins to effect fiber strengths, as seen in Papier Masson. In cases in which intensity is high, fiber residence time has also been short. This short residence time inside the refiner makes it more difficult to load the refiner.

Intensity is also higher in the secondary stage than in the primary stage, although the applied energy amount is lower. The reason is that a different flow characteristic causes shorter residence time in the secondary refiner and the segment geometry is different.


Primary Refiner

Secondary Refiner

Figure 9. Refining intensity as a function of production rate and applied specific energy for both primary and secondary refiners.

TARGETING 950 BDMT/D TMP LINE

In order to analyze possible development steps to increase production clearly above the 800 BDMT/D at Papier Masson, both the existing line at this high production and conversion to three-stage system were studied theoretically. A three-stage system has proven to be effective for production approaching 900 BDMT/D, with low freeness target after the third stage [12].

We studied refining intensity and compared the baseline and 950 BDMT/D production rate with a two-stage and three-stage refining production line. Applied energy amount in these processes has been the same in these simulations. Simulated cases were the following. Third stage is simulated here using the same segments and operating conditions as secondary stage.

1. 650 tpd, Primary SEC 1000 kWh/T, Secondary SEC 800 kWh/T
2. 950 tpd, Primary SEC 1000 kWh/T, Secondary SEC 800 kWh/T
3. 950 tpd, Primary SEC 800 kWh/T, Secondary SEC 500 kWh/T, Tertiary SEC 500 kWh/T

Calculated intensities for these cases are presented in Table 1.

CASE		1	2	3
Production	[bdmt/d]	650	950	950
SEC 1st stage	[kWh/t]	1000	1000	800
Intensity 1st stage	[kW/Impact]	5.051	10.72	7.613
Residence Time 1st stage	[sec]	0.275	0.19	0.225
SEC 2nd stage	[kWh/t]	800	800	500
Intensity 2nd stage	[kW/Impact]	8.155	17.45	6.786
Residence Time 2nd stage	[sec]	0.205	0.14	0.225
SEC 3rd stage	[kWh/t]			500
Intensity 3rd stage	[kW/Impact]			6.786
Residence Time 3rd stage	[sec]			0.225
TOTAL SEC	[kWh/t]	1800	1800	1800
TOTAL Intensity	[kW/Impact]	13.206	28.17	21.19
TOTAL Residence Time	[sec]	0.48	0.33	0.680

Table 1. Calculated intensities for the baseline, two-stage refining system at 650 BDMT/D production, and for two- and three-stage systems operating at 950 BDMT/D.

Intensity for a two-stage production line is doubled when production is increased from 650 tpd to 950 tpd. In practice, this combined with shorter residence time would reduce the refiner's energy consumption to a certain freeness, but probably this high intensity would also damage pulp quality.

A three-stage refining line, operating at 950 tpd production still has somewhat of higher intensity in primary stage than in the baseline 650 tpd but the following stages refine with much less intensity. In a three-stage system for 950 BDMT/D, it is possible to apply more energy to the second and third stage than 500 KWh/T without effecting pulp quality. This system could be tuned to about the same intensities as the baseline. It should as well be possible to load refiners more than 1800 kWh/T without increasing intensity excessively.

SUMMARY

This paper focuses on practical development made after 2003 to increase the highest possible production of the line to 800 BDMT/D and maintain pulp quality at a high level. Main improvements were seen as a result of development of refiner control strategy, steam separation technology and refiner segments.

When variations in pulp quality were eliminated, the advantage of the Advanced Quality Control for Papier Masson was that it was possible to increase production while maintaining the pulp strength properties over the specified minimum limit for the paper machine. After installing the Fiber Separator it was seen that loadability of the secondary stage was clearly improved and fiber carry-over with the steam was reduced. By introducing feeding type refiner segments in the primary stage refiner’s flat zone, primary stage refiners load variations were reduced by 30% and vibration level was reduced clearly at the higher production rates.

The theoretical approach provides an explanation of the phenomena seen in the practice. Higher production at constant specific energy increases refining intensity due to changes in flow conditions and fiber residence time inside the refiner. In addition, if the applied specific energy is higher, intensity increases. Moreover, after passing a certain level higher intensity starts to affect fiber strengths, as seen in Papier Masson. In cases in which intensity is high, fiber residence time has also been short. This short residence time inside the refiner makes it more difficult to load the refiner. Intensity is also higher in the secondary stage than in the primary stage, even though the amount of applied energy is smaller. This is due to a different flow characteristic causing shorter residence time in the secondary refiner.

A three-stage refining line, operating at 950 tpd production still has somewhat higher intensity in the primary stage than in the baseline 650 tpd, but the following stages refine with much less intensity. In a three-stage system for 950 BDMT/D, it is possible to apply more energy to second and third stage than 500 KWh/T without effecting pulp quality. This system could be tuned to about the same intensities as the baseline. It should, as well, be possible to load refiners more than 1800 kWh/T without increasing intensity excessively. This opens possibilities to reach even higher production rates in a three-stage refining systems based on RGP-82CD refiners.

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