Impact of refining intensity on energy reduction in commercial refiners: Effect of primary-stage consistency

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ABSTRACT

The specific refining energy required to obtain a given pulp quality can be reduced by increasing refining intensity. The simplest approach is to reduce refining consistency. Mill trials in a two-stage TMP (thermomechanical pulp) system showed a 7% reduction in total specific energy when consistency in the primary refiner was reduced from 50% to 38%. Target freeness in the discharge from the secondary refiner was 200 mL CSF. Similar results were obtained in a single-stage RMP (refiner mechanical pulp) system. Decreasing the consistency from 52% to 34% reduced the specific energy by approximately 15%. The results suggest that the magnitude of the energy savings depends on the mill's normal consistency level and on the final discharge freeness. The potential benefits are smaller for mills already operating at low consistencies, and savings shrink as the target pulp freeness decreases.

Application:

Specific refining energy for mechanical pulps can be reduced by reducing refining consistency.

BASIC RESEARCH INTO THE MECHanisms of material flow in chip refiners has led to the concept of refining intensity *(1)*. The underlying principle is that the parameters controlling the radial velocity of the fiber flow can be altered to vary the residence time of the material in the refining zone. A change in residence time implies a change in the number of bar impacts available to supply a given total specific energy. This, in turn, implies a change in the specific energy per impact, or refining intensity. The quality of pulp produced by a chip refiner would, therefore, be expected to depend not only on the specific energy expended, but also on the severity of energy application as governed by the refining intensity *(2)*.

Residence time decreases—and refining intensity increases—when the radial velocity increases. From a theoretical standpoint, refining intensity increases primarily through an increase in the centrifugal impulsion applied to feed the fiber relative to the restraining forces required for energy application. At a given rotational speed, the impulsion applied to each unit mass of fiber is dictated by its total mass and therefore is inversely proportional to the refining consistency. Thus refining intensity can be increased by reducing the consistency.

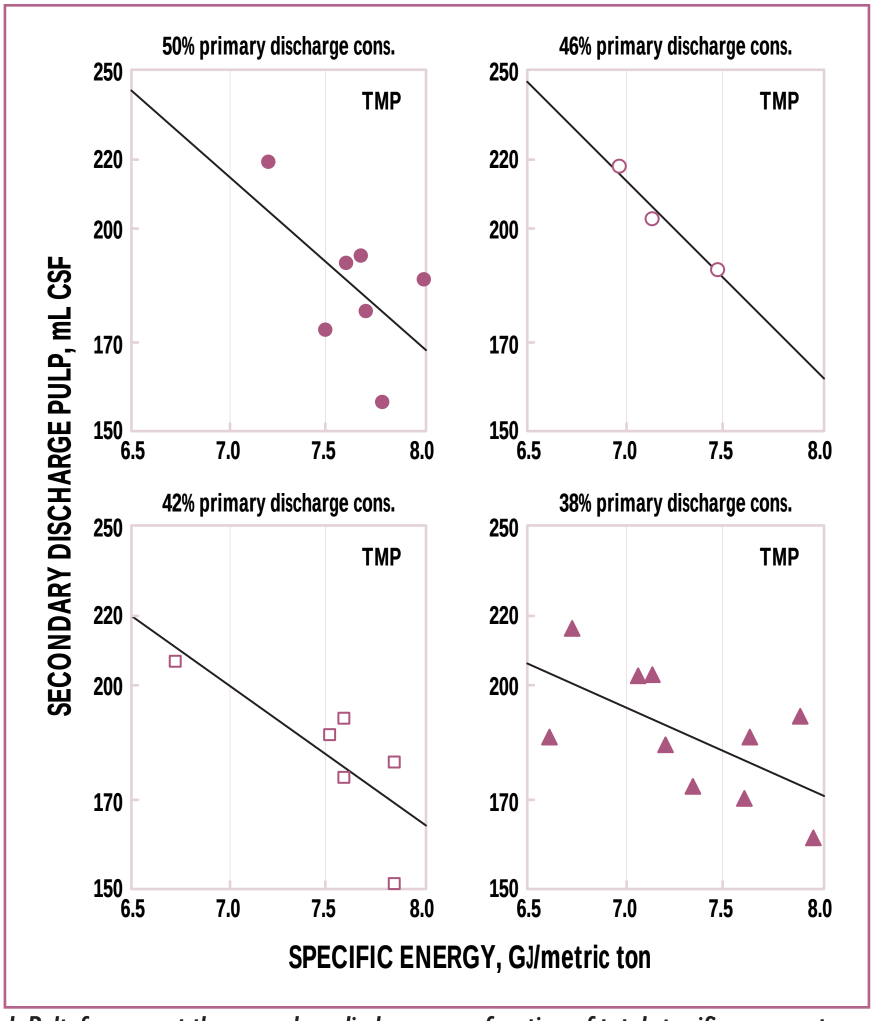
The high energy cost in the manufacture of TMP (thermomechanical pulp) has prompted research to explore refining intensity as a means of optimizing the relationship between refining energy and pulp quality. The approach, which has shown promise in pilot-plant trials, is to employ high-intensity refining in the first stage, where the high-impact energy can efficiently break down the material and separate the fibers *(3, 4)*. The second-stage refining is then carried out at a normal level of intensity to develop the fibers with minimal damage.

The commercial trials described here were carried out to examine the effect of reducing primary refining consistency on refining energy and pulp quality. Consistency in the secondary refiner was maintained at a constant level. The evaluation was conducted at Daishowa's Quebec City mill on one of their refiner lines [Andritz Sprout–Bauer (AS–B) Twin 60 refiners]. Each refiner has an installed capacity of 18 MW and normally operates at a discharge consistency of approximately 50%. In addition, the trial line was equipped with a consistency control system (ABB Auto TMP) incorporating a blow-line consistency sensor on both primary and secondary refiners *(5)*.

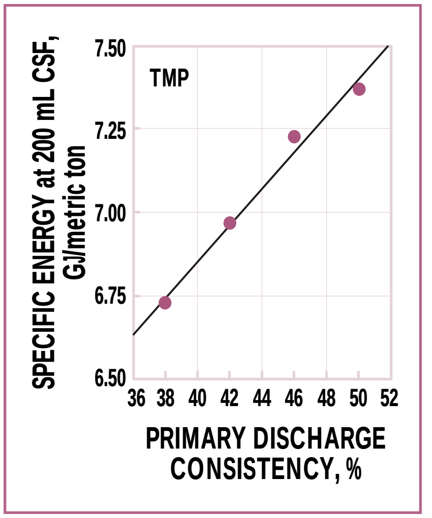
The work was done in two phases. The first phase, in June 1993, explored consistency control as a means of reducing energy consumption. The results indicated a beneficial effect of lowering primary consistency, but this work was not formally reported because of its preliminary nature. The second phase, in April 1994, was aimed at confirming and better delineating the previous findings. This paper presents the results of the second-phase trials and additional data from trials on another refining system.

EXPERIMENTAL

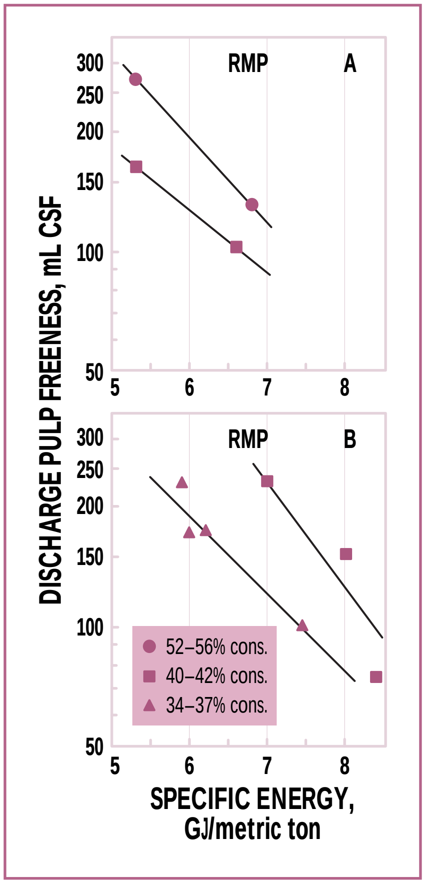
The second phase of the trials at the Daishowa mill was carried out over a five-day period. The trial was designed to determine the extent to which the primary-refiner discharge consistency could affect the relationship between specific energy and pulp quality. In the course of the trials, 26 runs were carried out. Four levels of consistency (50%, 46%, 42%, 38%) were explored. Secondary-refiner discharge consistency was kept constant at 48–50% throughout the trials. Target consistency levels



1. Pulp freeness at the secondary discharge as a function of total specific energy at four levels of primary discharge consistency



2. Total specific energy (at 200 mL CSF) as a function of primary discharge consistency



3. Pulp freeness at refiner discharge as a function of total specific energy. A: consistency decreased from ≈54% to ≈41%; B: consistency decreased from ≈41% to ≈34%.

were achieved and maintained using a closed-loop consistency-control system (Auto TMP) that automatically adjusts the dilution-water flow.

To vary the specific energy over a sufficient range, adjustments were made to both primary and secondary motor loads, as well as to production rate. The latter was determined from an unsteady-state mass balance around the latency chest, as described in the Appendix at the end of this report. The automated control system normally regulates the primary-refiner motor load by adjusting the chip feed rate. To facilitate the changes in specific energy, this control loop was disabled. Instead, the primary and secondary refiners were controlled by automatic adjustment of hydraulic pressure.

For each of the 26 runs, ten grab samples of pulp were collected from the secondary-refiner blow line over a period of 3–5 min. These were then blended together to form one composite sample that was tested in the mill's laboratory. Testing was carried out in accordance with standard CPPA procedures. Shive content was measured with a Pulmac shive analyzer equipped with 0.004-in. (0.106 mm) slots. The long-fiber content was determined in composite samples by means of a pulp quality (PQM) tester operated in a batch mode. Corresponding process data were obtained by averaging the distributed-control-system values from

Run	Blow-line consistency, % Primary	Secondary	Total specific energy, GJ/metric ton	Pulp freeness, mL CSF	Long-fiber content, %	Shive content (>0.106 mm), %
1	38	48	7.60	170	…	1.6
2	38	48	7.63	185	36	1.9
3	38	48	7.96	161	37	2.0
4	38	48	7.20	183	38	2.5
5	38	50	6.62	185	38	2.8
6	38	50	7.34	173	37	2.2
7	38	50	7.88	191	38	2.1
8	38	48	7.24	202	…	2.1
9	38	50	6.73	216	38	2.1
10	38	49	7.06	202	40	2.7
Avg.	**38**	**49**	**7.31**	**187**	**38**	**2.2**
11	42	48	7.60	175	…	1.8
12	42	49	7.85	179	38	1.8
13	42	48	7.85	151	38	1.8
14	42	48	7.60	190	40	2.3
15	42	48	7.52	186	39	1.9
16	42	48	6.73	206	43	2.4
Avg.	**42**	**48**	**7.52**	**181**	**40**	**2.0**
17	46	48	7.45	189	…	1.6
18	46	49	7.13	203	40	2.4
19	46	50	6.95	218	39	1.9
Avg.	**46**	**49**	**7.16**	**203**	**39**	**2.0**
20	50	48	7.78	156	…	1.7
21	50	48	7.70	178	45	2.0
22	50	48	7.99	186	37	2.0
23	50	50	7.67	192	37	1.9
24	50	50	7.49	173	37	2.3
25	50	50	7.60	190	36	2.1
26	50	50	7.20	219	38	2.5
Avg.	**50**	**49**	**7.63**	**185**	**37**	**2.1**

I. Operating conditions and pulp properties—Daishowa trials (two-stage TMP)

5 min before until 5 min after the pulp-sampling period.

The values of refining consistency reported here are those measured by the Auto TMP sensor. The sensor calibration was periodically verified during the mill trials (as would be done during normal mill operation) by laboratory testing of pulp samples collected from the refiner blow line.

Results from trials at a mill producing refiner mechanical pulp (RMP) are also presented. At the time of those trials, the former Domtar (now Alliance Forest Products) mill at Donnacona, PQ, was producing news-grade RMP in a single-stage operation. The refiners used in the trials (AS–B 45-1B and 42-1B) were each equipped with a feed belt, which facilitated accurate measurement of throughput and specific energy. More details regarding the refining system and procedures used in those trials can be found in the literature *(6)*.

RESULTS

Throughout the trials at the Daishowa mill, control of the Twin 60 refiners was greatly facilitated by the use of the Auto TMP system. Consistency targets were easily achieved and were accurate, as verified by laboratory measurements. The operating conditions and experimental results for the 26 trial runs are summarized in **Tables I and II**.

Consistency control

With a good calibration, the consistency sensor effectively controlled pulp consistency. This was verified with heat- and material-balance calculations (see Appendix) performed before and after setpoint changes in refining consistency. The dilution-water flow-rate changes implemented by the controller were in agreement with those calculated from heat and material balances.

Specific energy and pulp freeness

Figure 1 shows the decrease in pulp freeness from the secondary refiner with increasing specific energy at the four levels of primary consistency. The considerable scatter in the data is primarily due to uncertainties in measuring specific energy. Nevertheless, a plot of the specific energy required to obtain the target freeness (200 mL CSF at the secondary-refiner discharge) against primary-discharge consistency shows a reduction in total specific energy when first-stage consistency was reduced. As seen in **Fig. 2**, lowering primary-stage consistency from 50% to 38% reduced

Primary consis-tency, %	Freeness, mL CSF*	Apparent density, kg/m³	Burst index, kPa·m²/g	Tensile index, N·m/g	Tear index, mN·m²/g	Light-scattering coefficient m²/kg
38	170	364	2.14	41.4	10.9	…
	185	334	2.24	39.9	11.1	57.2
	161	327	2.13	38.6	10.9	58.5
	183	325	2.21	39.1	11.3	58.8
	185	311	2.11	37.5	10.6	59.3
	173	324	2.10	37.0	11.1	61.8
	191	345	2.25	41.2	10.2	56.6
	202	332	2.04	39.1	10.6	55.4
	216	328	2.06	38.0	10.7	55.8
	202	335	2.20	40.2	10.3	55.8
Avg.	**187**	**332**	**2.15**	**39.2**	**10.8**	**57.7**
42	175	346	2.11	42.5	10.7	…
	179	353	2.31	45.3	11.7	…
	151	333	2.15	42.5	11.9	…
	190	328	2.07	40.6	13.1	…
	186	339	2.09	40.5	12.6	…
	206	322	2.03	38.5	12.5	…
Avg.	**181**	**337**	**2.13**	**41.6**	**12.1**	**…**
46	189	342	2.14	40.8	10.9	…
	203	340	2.26	42.0	10.4	54.7
	218	364	2.35	45.2	10.8	52.7
Avg.	**203**	**348**	**2.25**	**42.7**	**10.7**	**53.7**
50	156	344	2.18	41.5	11.0	…
	178	340	2.39	40.6	11.1	57.0
	186	326	2.04	38.5	11.9	55.7
	192	382	2.30	43.9	9.3	52.9
	173	376	2.43	45.5	10.1	54.1
	190	382	2.16	41.0	10.0	52.9
	219	342	2.20	41.2	10.4	54.1
Avg.	**185**	**355**	**2.24**	**41.7**	**10.5**	**54.4**

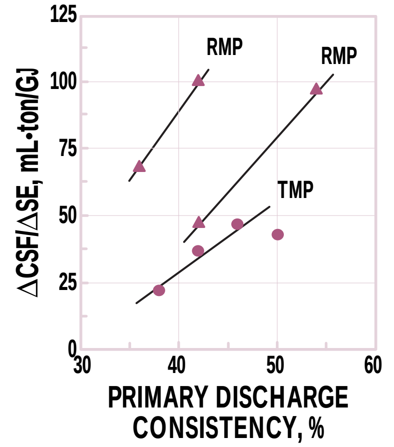
*Freeness at secondary-stage discharge

II. Handsheet properties—Daishowa trials (two-stage TMP)

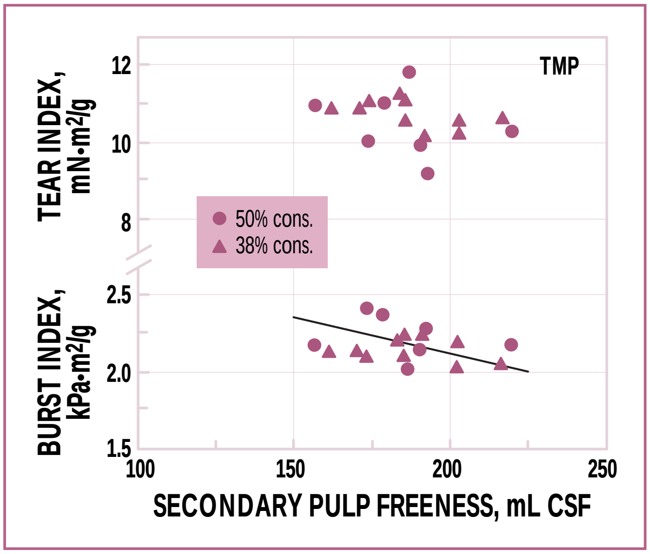
total specific energy by 0.55 GJ/metric ton (about 7%).

The difficulty encountered in measuring throughput (and specific energy) in these experiments resulted in some uncertainties regarding the reduction in energy when primary-stage consistency is decreased. However, there is enough information from pilot plant *(3, 6)* and commercial systems *(7)* to support the finding that specific energy drops when primary-stage consistency is decreased.

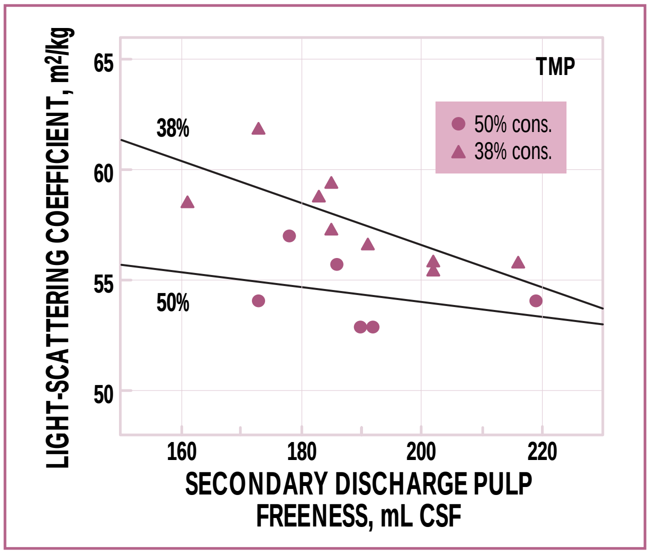
Table III and **Fig. 3** show the effect of consistency for a single-stage RMP produced in a 45-1B refiner. The experimental results are plotted in two figures because the trials were conducted at different times. Specific energy measurements were quite accurate because the refiners were fed by individual belt conveyors, which were calibrated at the beginning and end of the trials *(7)*. Figure 3A shows an 18% decrease in energy when the consistency was decreased from about 54% to 41%. Figure 3B shows a 15% reduction in specific energy when the discharge consistency was decreased from about 41% to 35%. The energy reductions shown in Figs. 3A and 3B are different because the wood characteristics changed and the specific energy needed to reach 200 mL CSF at about 41% consistency changed from 4.6 GJ/metric ton (Fig. 3A) to 5.9 GJ/metric ton (Fig. 3B), i.e., by about 25%. Such swings in energy requirements with variations in wood supply are not unusual *(8)*.



4. The change in freeness with specific energy as a function of primary discharge consistency



5. Tear and burst indexes of TMP as a function of secondary pulp freeness at two levels of first-stage discharge consistency



6. Light-scattering coefficient of TMP as a function of secondary pulp freeness at two levels of first-stage discharge consistency

Refiner	Discharge consistency, %	Specific energy, GJ/metric ton	Freeness, mL CSF	Tensile index, N·m/g	Tear index, mN·m²/g	Light-scattering coefficient, m²/kg
45-1B	40	5.3	163	41.4	8.0	54.2
	42	6.6	103	47.2	7.3	58.6
	52	5.3	271	33.5	9.0	49.4
	56	6.8	132	43.6	7.7	55.5
45-1B	34	6.2	172	38.0	8.0	55.0
	37	5.9	228	30.0	8.0	50.5
	37	6.0	170	35.8	7.7	55.4
	40	7.0	231	34.7	8.6	51.8
	41	8.4	75	46.3	7.0	59.3
	42	8.0	153	42.0	7.7	55.8
42-1B	25	6.2	163	36.1	8.6	54.4
	27	6.0	171	38.3	8.2	55.4
	28	6.7	132	39.4	8.0	55.7
	31	5.9	198	33.3	8.7	52.8
	33	7.3	90	44.2	7.4	60.2
	34	6.7	120	37.8	7.6	56.8
	38	7.0	124	34.3	7.4	55.1

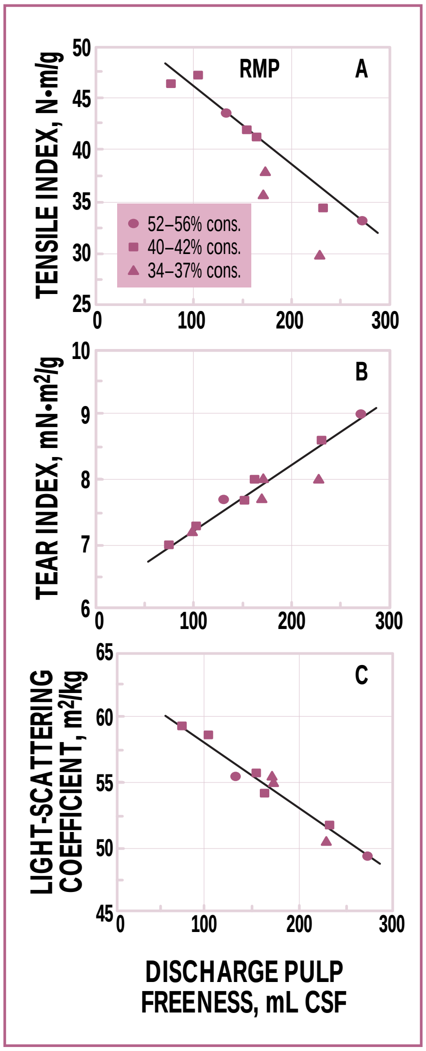
III. Operating conditions and pulp and handsheet properties—Donnacona trials (single-stage RMP)

Figures 1 and 3 indicate that the potential for energy savings declines with decreasing discharge freeness. The reduction in energy within a given freeness range seems to depend on the refining system. Inspection of Figs. 1 and 3 shows that in the range of 150–200 mL CSF, energy reduction in the Twin 60 varies from zero to 0.55 GJ/metric ton (Fig. 1), while in the 45-1B it varies over the range 1–1.3 GJ/metric ton (Fig. 3).

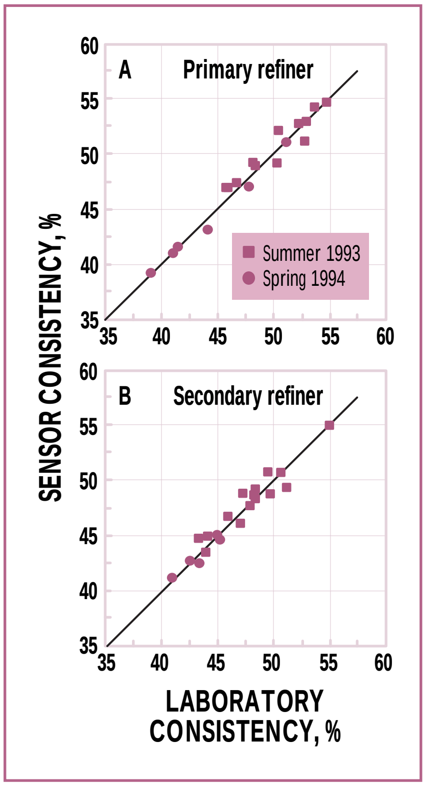
Figures 1 and 3 also suggest that the potential for energy savings decreases as the first-stage discharge consistency decreases. The slope of the line ΔCSF/ΔSE is plotted against primary-stage discharge consistency in **Fig. 4**. The result suggests that in the case of refiners already operating at lower levels of consistency, there is less potential to reduce the specific energy by decreasing the first-stage consistency.

Pulp and handsheet properties

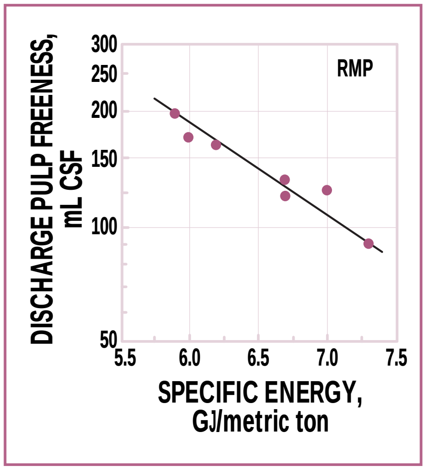
Tables I and II show that over the five-day trial period in the Daishowa mill, the pulp produced was of consistently high quality despite the variations in primary refining consistency. Pulp properties of TMP produced in the Twin-60 refiner are summarized in Table I, and handsheet properties are listed in Table II. Table III shows the pulp and handsheet properties of single-stage RMP



7. Tensile index, tear index, and light-scattering coefficient of RMP as a function of pulp freeness at refiner discharge over the consistency range 34–56%



8. Calibration curves for the consistency meter in A: primary refiner, B: secondary refiner



9. Pulp freeness at refiner discharge as a function of total specific energy over the consistency range 25–38%

produced in the 45-1B and 42-1B refiners.

The TMP trials were conducted over a limited range of secondary-discharge freeness. Indeed, the average freeness at three of the four consistency levels was in the range of 181–187 mL CSF. Because of the lower average discharge freeness, the average reduction in energy was 0.32 GJ/metric ton (Table I), as opposed to the 0.55 GJ/metric ton observed at 200 mL CSF (Fig. 2).

Figure 5 shows that the strength–freeness relationship for the TMP at 50% and 38% first-stage consistencies is very similar. However, there was a definite improvement in light-scattering coefficient for the pulps refined at the lower consistency, as seen in **Fig. 6.** Freeness–property relationships were also quite similar for the RMP, as seen in Table III and **Fig. 7**. These results demonstrate that within the given consistency range, pulps of very similar properties can be produced at significantly lower specific energy when the discharge consistency is low.

DISCUSSION

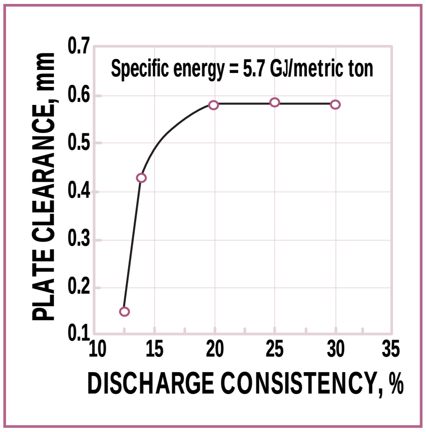
Consistency control

With a good sensor in place, pulp consistency control does not represent a technical challenge, and the control loop used in these trials performed adequately. Measured changes in consistency were close to those predicted from heat and material balances (see Appendix).

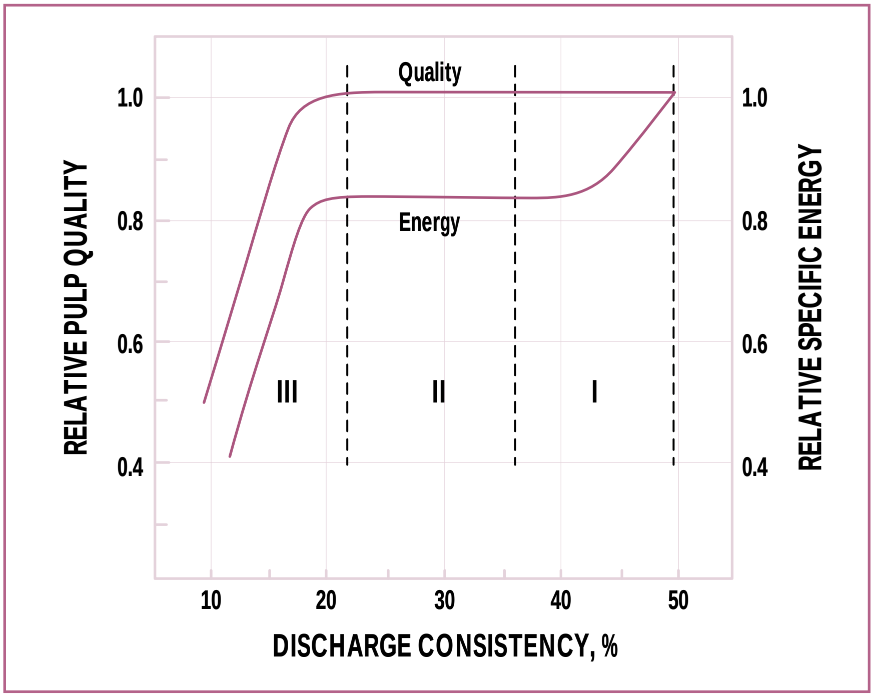
Discrepancies between sensor and laboratory measurements are likely to arise from the difficulty in obtaining a good laboratory consistency value. High-frequency variations in motor load cause rapid variations in pulp consistency. The difficulties in obtaining representative samples and subsequent pulp handling make this test particularly difficult. On the other hand, the optical sensing device performs a continuous measurement. The signal is filtered to eliminate the high-frequency consistency variations and provides an estimate of the minute-by-minute evolution of pulp consistency based on continuous measurements.

It was not possible in this study to evaluate the long-term stability of the sensor and its calibration. However, the same calibration curve was used on experiments performed almost a year apart. Results for the primary and secondary refiners are presented in **Fig. 8**. The calibration was performed by the vendor using averages of five laboratory measurements.

In most conventionally controlled refiner installations, there is a range of possible operating targets for primary-refiner consistency. The magnitude of a possible reduction in primary-refiner consistency varies with each operation. Automatic feedback control greatly facilitates adjustment of target consistency. Moreover,



10. At a given specific energy, plate gap remains constant until discharge consistency drops below 20%



11. Effect of discharge consistency on pulp quality and energy consumption (schematic)

the reduction in consistency variations with automatic control provides additional margin to lower consistency in the primary refiner.

In small refiners with relatively constant chip supply, consistency control is not critical. As refiners become larger and wood supply more variable, better consistency control is required. The consistency-control system performed well, responding adequately to changes in the dilution-water flow required to maintain the desired consistency (see Appendix).

Refining intensity

The Twin-60 refiners normally operate at relatively high consistency. This translates to a longer residence time in the refining zone and thus lower refining intensity *(1)*. As noted earlier, low intensity tends to hinder efficient application of energy, particularly during the initial stages of material breakdown and fiber separation.

The results obtained during these mill trials verified earlier pilot-plant experiments *(3, 6)* and results obtained with smaller commercial refiners *(7)*. The data show that the specific energy required to obtain a given freeness decreased with increasing refining intensity in the primary stage. Refining intensity was increased by decreasing the pulp consistency. However, the results also indicated some possible limitations of the process. It appears that the potential benefits in energy reduction are specific to the refining system, with the benefits becoming smaller when

- The second-stage discharge freeness decreases
- The normal operating consistency in the primary stage is already low.

Refining consistency

The chosen level of operating consistency is influenced by the refiner type and size, with larger refiners generally operating at higher consistency. Figure 4 indicates that, as the initial refining consistency decreases, the potential reductions in energy become smaller. At consistencies lower than about 30–35%, no energy reduction is to be expected. This is supported by the experimental results obtained in a 42-1B RMP refiner (Table III). In the range of 25–38% discharge consistency, there was no change in the relationship between pulp freeness and specific energy, as seen in **Fig. 9**. Pulp properties at a given specific energy were also the same (Table III). These results are in accord with those obtained in a 42-1A RMP refiner *(6)*, which showed that, at a given specific energy, freeness was constant in the range of discharge consistency 15–35%. However, at constant specific energy, freeness doubled when the discharge consistency increased to 50%.

At consistencies below 25%, pulp properties deteriorate. The required specific energy to obtain a given freeness decreases, but this is due to fiber shortening, which affects pulp strength properties. **Table IV** shows results at low discharge consistency for single-stage RMP produced in a pilot refiner. Fiber cutting occurs because of the decrease in plate clearance at low discharge consistency, as seen in **Fig. 10**. Small plate gaps significantly reduce the long-fiber content *(7)*.

With this information, the role of consistency can now be better understood. We can define three regions of consistency. In the example shown in **Fig. 11**, Region I covers the range 36–50% discharge con-

KEYWORDS
Beating degree, conservation, consistency, energy conservation, paper making equipment, refiners, refining, solids content, time, velocity.

Discharge consistency, %	Specific energy, GJ/metric ton	Tensile index, N·m/g	Tear index, mN·m^2/g	Light-scattering coefficient, m^2/kg
12.5	2.0	15	3.8	61
15	2.8	18	6.3	61
20	4.3	24	6.1	61
25	4.6	28	6.9	61
30	5.5	28	6.9	61

IV. Pulp properties at 200 mL CSF—Pilot-plant refiner (single-stage RMP)

Initial consistency, %	Final consistency, %	Feed rate, metric ton/day	Change in dilution-water flow (ΔW), L/min	
			Measured	Calculated
42	50	340	85	90
50	38	340	155	149

A-I. Measured and calculated values of change in dilution-water flow

sistency. In Region I, decreasing consistency decreases the residence time of the pulp in the refining zone, thus increasing refining intensity and decreasing the specific energy to a given pulp quality. In Region III, energy reduction is obtained at the expense of pulp quality. Low-consistency refining at relatively high energy input decreases the plate clearance and results in severe fiber shortening.

More difficult to understand are the reasons for the insensitivity of the energy–quality relationship to pulp consistency in Region II. It is conceivable that this is associated with the fiber saturation point, which may change the mode of refining in the presence of free water in the refining zone. Whatever the reasons may be, the results in Fig. 11 suggest that a refining system should operate in the middle of Region II. This will provide maximum energy savings while producing high-quality pulp, with minimum disruption from variations in consistency.

Optimizing refining consistency to minimize energy consumption without affecting pulp quality is one option for reducing energy, and it is easy to implement. Another option, based on the concept of high-intensity refining, is to increase the first-stage rotational speed. Commercial systems based on this principle are now in operation.

CONCLUSIONS

Decreasing the discharge consistency from the primary refiner of a two-stage refining system (Twin 60) reduced the specific energy required to produce TMP at a given level of freeness. The results presented here show that decreasing the primary-stage consistency from 50% to 38% led to a 7% reduction in the specific energy required to obtain a pulp of 200 mL CSF. In a single-stage system producing RMP (45-1B), decreasing the discharge consistency from 52% to 36% led to a 15% reduction in the specific energy required to reach 200 mL CSF. In both cases, energy reductions were obtained without adverse effects on pulp properties.

The energy savings become smaller when the normal operating consistency level in the mill is already low and when the final discharge freeness is less than 200 mL CSF.

Within the consistency range explored, the consistency control system greatly facilitated control of the TMP refiners. **TJ**

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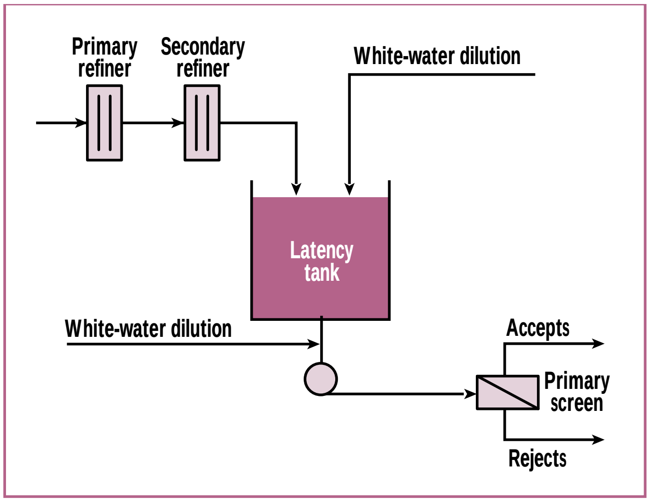
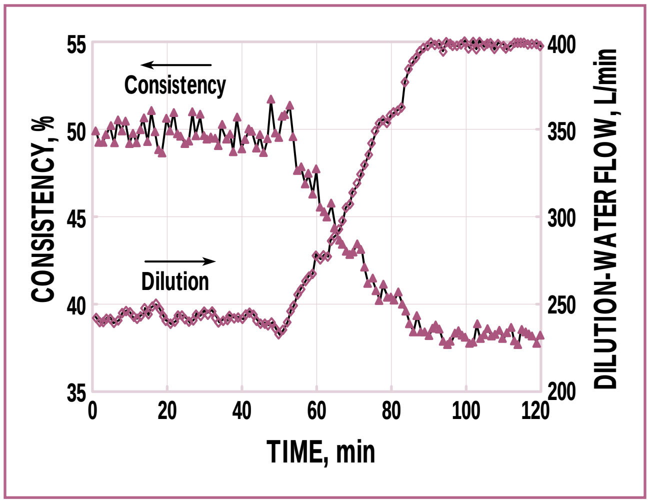


12. Schematic of the Daishowa refining line indicating the method by which the unsteady-state mass balance was used to calculate production rate



13. Performance of the consistency meter—a change in dilution water produces a change in consistency that is almost instantaneously recorded

APPENDIX

Determination of production rate

Production was determined from an unsteady-state mass balance around the latency chest, as shown in **Fig. 12**. The production, P, is given by

$$P = (P_A + P_R - P_W) + (C_L\, dV_L/dt) + (V_L\, dC_L/dt) \qquad (1)$$

where

P_A = fiber flow in screen accepts
P_R = fiber flow in screen rejects
P_W = fiber flow in white water
C_L = consistency in the latency chest
V_L = volume in the latency chest
t = time.

The transient terms dV_L/dt and dC_L/dt denote the change of volume and consistency in the latency chest with time. Both were evaluated via graphs of latency tank level and consistency vs. time

Heat and material balances

During these tests, motor load and feeder rpm remained constant. We assume that production rate, seal-water flow rate, and chip moisture also remained relatively constant. Furthermore, we neglect the change in heat required to bring the extra amount of dilution water to boiling temperature. Thus at constant motor load, the amount of steam remains constant.

By definition, pulp consistency, C, at the refiner discharge is

$$C = F/(W + F) \qquad (2)$$

where

W = water in the pulp
F = fiber throughput.

Rearranging, we obtain Eq. 3:

$$W = [F(1 - C)]/C \qquad (3)$$

Equation 3 allows the calculation of the change in dilution water, ΔW, when the consistency is changed. Calculated values of ΔW are compared with those measured experimentally in **Table A-I**.

Response of consistency meter

Figure 13 shows the response of the consistency meter to a sudden change in dilution flow from 245 L/min to 400 L/min. Consistency decreased from 50% to 38%. Feeder rpm was held constant, and the motor load was controlled and remained constant. Thus, the plate gap was adjusted in response to the consistency change. It can be seen from Fig. 13 that the consistency meter responded quickly and accurately to the changes in dilution-water flow.