ELECTRICAL ENERGY CONSERVATION IN MECHANICAL PULPING AND OPPORTUNITIES FOR LOAD SHIFTING

Michael Jackson, Sunds Defibrator
George N. Ionides, Temanex
Dave M. Mackie, H.A. Simons

The Pulp and Paper Industry in Canada has mainly been involved in the production of commodity paper such as newsprint and market pulp. The industry has been focusing on attempting to reduce manufacturing costs. Reduction of the expensive kraft content in newsprint and other communication papers has been accomplished by introduction of thermomechanical pulp (TMP). A chip based product having significantly higher strength characteristics than stone groundwood.

Since its inception in the late sixties, the main focus of the research work on thermomechanical pulping (TMP) has been on how to improve the strength properties of the pulp and how to process different species. Today, the TMP process is capable of producing pulp from a wide range of softwoods and hardwoods. The unbleached pulp is suitable for use as a major furnish component in newsprint and associated grades of paper. TMP has been used as the sole furnish component in the manufacture of newsprint as early as twenty years ago.[1] TMP has also been used extensively to replace the more expensive kraft pulp in a number of different grades.

Mild chemical treatment followed by brightening of this pulp with peroxide, bleached chemi-thermomechanical pulp (BCTMP), has further extended its use into grades such as light weight coated, super calendered filled grades, printing and writings, board, tissue and fluff applications. Combination of a mild chemical treatment of the chips prior to the TMP process and subsequent brightening with peroxide has enabled the manufacture of a high bright, high strength pulp from aspen which has properties close to market hardwood kraft. Other hardwood species such as birch, eucalyptus and poplar can be used in the same manner.

The advantage of TMP over traditional mechanical pulping process, is that it is manufactured from chips, has a high yield from fibre, reduces the quantity of chemical pulp required in a furnish, and can be used in a wide range of products, Table 1.

Table 1 Potential Use of TMP and CTMP in Different End Products*

Product	Softwood TMP (%)	Softwood CTMP (%)	Hardwood CTMP (%)
Newsprint	95-100	80-100	70-80
SC Paper	65-80	70-90	35-50
LWC	50-65	35-75	40-50
Fine Paper	NS	50-80	50-60
Paperboard			
Solid Board	20-40	20-40	20-40
Folding Boxboard	20-25	25-35	15-20
Liquid Packaging	NS	20-25	15-20
Tissue	NS	20-40	20-40
Fluff	NS	80-100	NS

* % in product

The major drawback is that the manufacture of TMP requires significant quantities of electrical energy to comminute the wood chips into a useable pulp. This energy requirement is over 30% higher than for stone groundwood (SGW) and also higher than most other mechanical pulping processes, Table 2. This represents a major cost component in the manufacture of TMP particularly as electrical rates spiral upwards. In the past several years, considerable effort has gone into understanding the underlying mechanism behind the high energy consumption in the refining process and on how to reduce the energy input while maintaining pulp quality.

Table 2 Energy Requirement for Different Species

Species	Process	Energy kWh/t
Spruce	SGW 60 ml CSF	1650
	TMP 80 ml CSF	2350
Hemlock	SGW 60 ml CSF	1480
	TMP 80 ml CSF	2150
Pine	SGW 60 ml CSF	1850
	TMP 75 ml CSF	3290

A number of different approaches have been evaluated during recent years to reduce the energy consumption in mechanical pulping. These have included:

- chemical pretreatment;
- electron beam bombardment of chips;
- inlet or blowline consistency control;
- plate design modifications;
- increased refiner throughput;
- increased refiner angular velocity;
- post refining;
- high consistency screening;
- thermo-pulping.

The more important of these approaches are discussed below.

CHEMICAL TREATMENT

Chemical treatment of chips prior to refining has been studied in depth over the last decade. The main focus of most of these studies has been to extent the useful range of the species treatable by the TMP process and also to broaden the product spectrum for the use of this type of pulp.[2] With softwood species, impregnating the chip with a chemical such as sodium sulfite results in improved brightness and enhanced strength properties of TMP pulps. It also results in lower debris but usually increases the long fibre content, reduces the scattering coefficient and increases the energy requirement for a given drainage level. It has been found that treatment of a TMP or the screen rejects from a TMP with alkaline sodium sulfite at elevated temperature and pressure will significantly improve the bonding potential of the pulp and also result in a significant decrease in energy to obtain a given drainage.[3,4,5] These processes have been widely tried and developed in mills but have not been widely accepted because of:

- increased effluent load;
- dissolved organic carry over to the paper machine with subsequent adverse impact on pulp drainage;
- decreased opacity of the resultant pulp is due to the improved retention of fibre length and increased bonding of the pulp.

The dramatic decrease in energy in this process was attributed to the chemical modification of the fibre surface, substituting chemical "energy" for mechanical energy. It resulted in a minor yield decrease and to fibre modification brought about by the fibres being subjected to high temperature and pressure. In one experiment when the chemical was shut off a significant energy reduction was observed but the pulp was very dark because of the long retention time in the system at elevated temperature.

Increased refiner throughput
Overhung refiner plates have been used for a number of years in the industry to obtain improved pulp quality and reduced debris. To obtain desirable quality with overhung plates it was necessary to increase throughput and this combination of overhung plates and increased throughput reduced the energy requirement for a given freeness and quality by 100 kWh/t or about 5%.

A significant increase in the throughput resulted in a decrease in overall energy requirement of 200 kWh/t while maintaining pulp quality and freeness. This occurred on a commercial refiner system in N. America without using overhung plates.

Increase in angular velocity or high intensity refining
The initial concept for "high intensity refining"* came from the observation that in Europe there was a significant difference in the pulp quality from single and double disc refiners.[6] This was not observed to the same extent in North America. The reason for this difference is that in Europe, the single disc refiners rotate at 1500 rpm while in the double disc refiners both disc rotate at 1500 rpm. Thus a fibre between the discs of a double disc refiner is subjected to 3000 rpm. In North America, the single disc refiners rotate at 1800 rpm while the double disc refiners rotate at 1200 rpm: the difference between the two systems is 1800 rpm verses 2400 rpm, Table 3.

Table 3 Comparison Between Europe and North American Refining Systems

	N. America rpm	Europe rpm
Single Disc Refiners	1800	1500
Double Disc Refiners	1200	1500
Fibre Experiences in DD	2400	3000

A detailed study by the Finnish Research Institute,[6] found that the energy consumption in a single disc refiner was higher than in a double disc refiner and that increasing the rotational speed of both single and double disc refiners reduces the energy consumption. These changes in rotational velocity affects the following parameters:

- bar passing frequency;
- bar velocity and impulsive force;
- centrifugal forces within the refiner plat gap.

Naturally the design of the plates will also have an impact on the above parameters, such that the number of bars will affect the impact or impulse frequency and the loadability and degree of filling of the segments.

As the speed of rotation of the refiner increases the centrifugal forces increase. The centrifugal force is considered as the force that transports the wood material into and out of the refining zone. To a lesser extent this force also pushes the fibres towards the bars. Simply changing the bar impact frequency by increasing the number of bars appears to have the opposite effect of slightly increasing energy.

Thus it was concluded that by increasing the rate of rotation in both single and double disc refiners energy can be saved with greater potential of energy saving in the single disc machine. Increasing the rate of rotation from 1500 rpm to 1800-2000 rpm would mean a energy saving of about 5% for a double disc refiner and 10% energy saving for a single disc refiner. This is assuming that the tear strength can be kept constant. Most of the experimental work indicated that a loss of tear strength stemming from fibre length reduction at a given drainage occurred with increased rotational speed.

* High intensity refining may be a misnomer as increased rotation angular velocity for a given bar segment pattern decreases the energy input per impact, thereby reducing the refining intensity.

Subsequent work by Strand et al[7] investigated the effect of production rate on energy consumption concluded that as production rate increased in a refiner, energy consumption decreased by as much as 25% to obtain a given drainage. They argued that with a single stage conical disc CD refiner that increasing the rotational speed from 1500 rpm to 1800 rpm resulted in no energy saving unless this was accompanied by an increase in production rate. As the disc rpm is increased there had to be a corresponding decrease in plate gap to hold the pulp between the plates because of the increase in centrifugal forces. (Other authors[8] have reported a significant drop in plate gap at a given specific energy when going from 1200 to 1800 rpm.) Their data indicated at a constant production rate and at a given production rate and freeness there was no power saving, Table 4.

Table 4 Effect of Refiner Speed on Energy Requirement to Produce 175 ml Freeness at a Constant Production Rate on a CD Refiner

		1500 rpm	1800 rmp
No of Tests		91	5
Freeness	ml	175	175
Shives	%	0.89	0.92
Tensile Index	Nm/g	31.9	31.5
Tear Index	$mN.m^2/g$	7.7	7.7
Scattering Coeff	m^2/kg	44.6	44.1
Production Rate	ADMt/d	7.7	7.7
Specific Energy	kWh/ADMt	1892	1900

At an increased production rate, there was an decrease in energy at the higher rotational speed but also increased shive level Table 5.

Table 5 Pulp Quality Comparison at 175 Ml Freeness for a Single Stage, Conical Disc Refining Operated at 1500 and 1800 rpm

		1500 rpm	1800 rpm
Number of Tests		91	31
Freeness	ml	175	174
Shives	%	0.89	1.3
Tensile Index	Nm/g	31.9	30.3
Tear Index	$mN.m^2/g$	7.68	7.63
Scattering	m^2/kg	44.6	45.2
Production Rate	T/hr	7.7	9.4
Specific Energy	kWh/ADMt	1892	1687

Rotational speed effects on Single and Double Disc Refining

For double disc refining, Sundholm et al observed that increasing the rotational velocity of the refining device in the range 600-1900 rpm reduced the specific energy requirement to achieve a certain level of freeness. More specifically, refining chips to a pulp of 150 ml CSF at a rotational speeds of 1200, 1500, 1800 rpm required specific energy input levels of 1900, 1750, and 1600 kWh/BDMt respectively. With regard to pulp quality, increasing the rotational speed in this range resulted in reduced shive content and reduced long fibre content, the latter causing an observable reduction on the tear index of the pulp. While increase rotational speed did not appear to impact at all on the tensile strength of the pulp. It resulted in an increase or improvement in light scattering coefficient.

In the case of single disc refining, recent trials carried out in Europe have indicated that increasing the rotational speed of the primary refiner from 1800 rmp to 2400 rpm at constant production rate in a two stage TMP system resulted in energy saving of about 15% for refining to a secondary discharge freeness of 150 ml CSF, but only at the expense of certain quality aspects. Although the higher primary rotational speed resulted in pulp having improved density (8%) and scattering coefficient (6%), the pulp exhibited a significant 15% decrease in fibre length and corresponding 8% reduction in tear index. In addition, the burst and tensile indices if the pulp were both decreased by 12%. Some of these negative aspects could probably be rectified to some degree by appropriately modified segment design. In the meantime, quality reductions of these orders of magnitude are unacceptable.

Trials have been performed on a TMP system in Canada where one disc on a double disc refiner has had its rotational speed increased. Data from these trials have not been released but the unofficial word is that there was an energy reduction but a corresponding loss in pulp quality. At energy reductions of about 5% pulp quality is not an issue.

Hence the energy reduction obtained by a mill will depend on its particular situation. If the mill has already increased production and decreased energy, then the additional reduction in energy due to increased rotational speed will be about 5%. If the refiner system cannot increase through put even with the increase in rotational speed then the energy reduction will be negligible. If the mill can increases throughput and rotational speed at the same time then the energy reduction claimed may be as high as 25%. Opinions on the resulting quality differ however and quality will ultimately represent a deciding factor on refiner speed up.

Post refining

Post refining has been used in the industry for a number of years especially on mechanical pulps being used in the manufacture of specialty papers such as telephone directory, soft calendered and light weight coated grades. Post refining was recognized as having the ability to reduce debris and the overall fibre length. In this process certain strength properties of the pulp were reduced, particularly fibre length and tear strength. Recirculation around the refiner was required and the no load power on these original post refiners accounted for almost 50% of the connected horsepower. Newly designed post refiners enabled their installation with no recirculation on a stock going to the paper machine, Figure 1. This, coupled with improved control of the refiner, reduced no load power demand, and plate design has resulted in a reduction in energy demand for a given freeness, of about 200 kWh/t.[9] This reduction has been obtained at reduced debris levels but with little or no loss of in physical strength properties, Table 6.

Figure 1 Post Refining of TMP

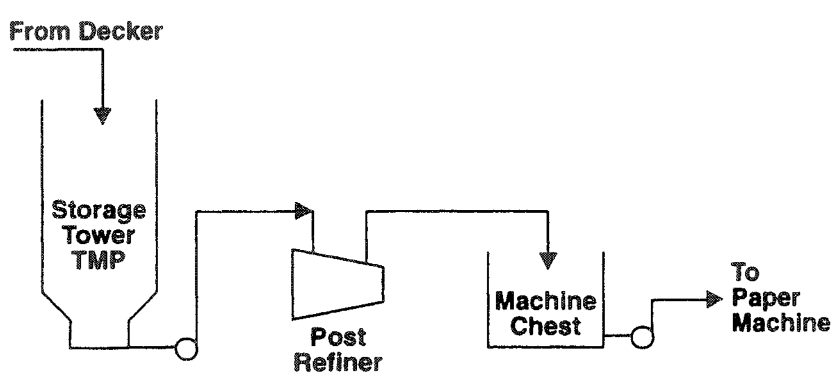
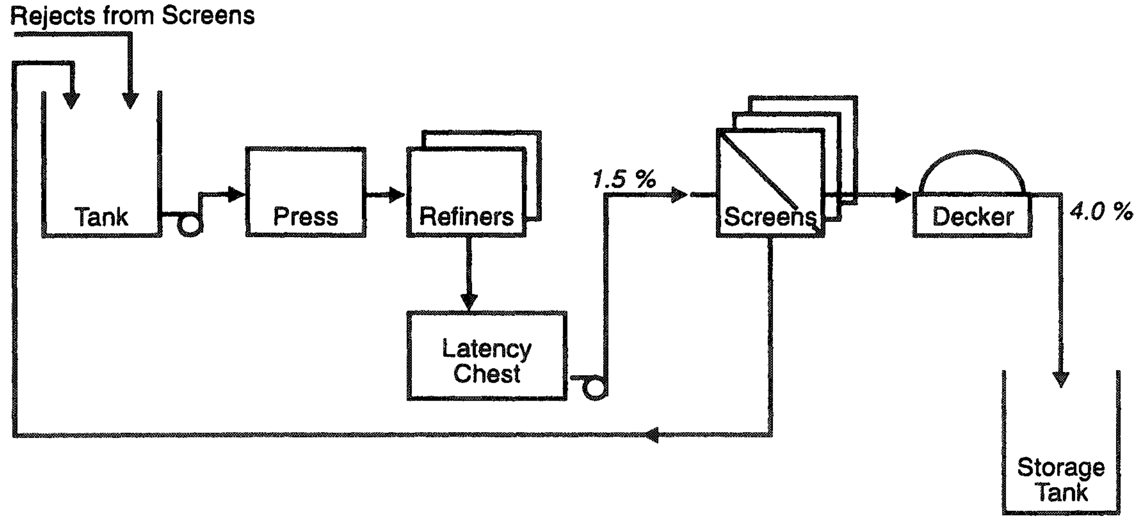


Figure 2 Reject Refining of TMP

A. Old System



B. New System

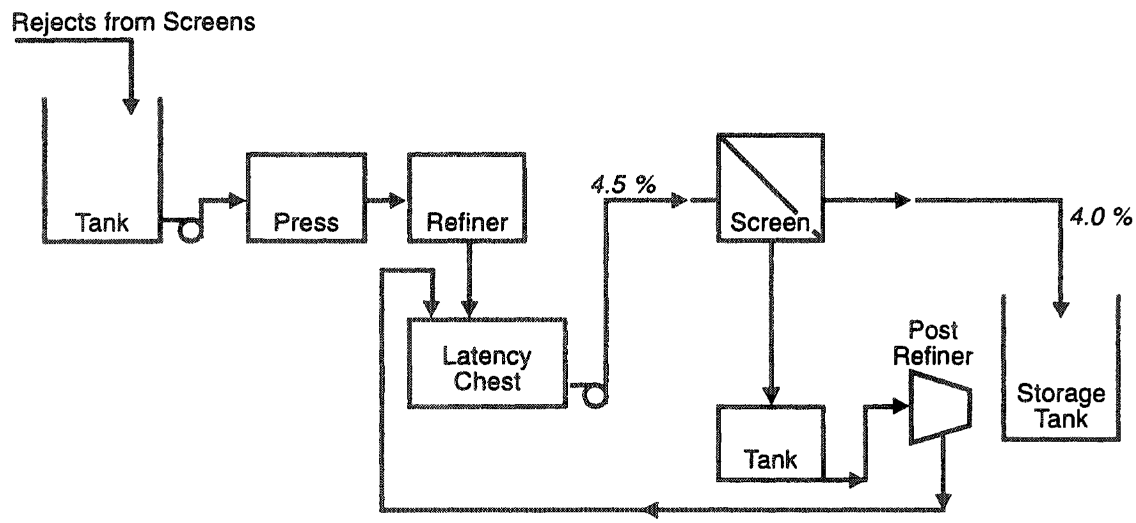


Table 6 Influence on Physical Strength Properties of Post Refining

Properties		No Post Refining	With Post Refining
Energy	kWh/T	2000	1850
Freeness	ml	116	110
Burst Index	kPa.m^2/g	1.8	1.9
Tear Index	mN.m^2/g	8.7	8.2
Debris	%	0.11	<0.05

Recently a new high consistency screening system (4-5% consistency) on a reject system was installed in a commercial plant. Rather than recirculate the rejects from this screen back through the reject refiner, they were processed through a post refiner, at about 4% consistency and then re-screened, Figure 2. This approach saved over 200 kWh/t in refining energy. Furthermore, because the screening was performed at high consistency, the mill was able to shut down one of the reject refiners and two old deckers, thereby eliminating saving the high maintenance cost of operating this equipment. Greater energy savings are possible by extending this low consistency approach in one of the following two ways:

- installing low consistency refiners possibly in series to perform all the refining of the rejects;
- terminate the high consistency refining at higher freeness then that currently practised and install one or more stages of low consistency refining prior to the screening process.

Recent work on production of hardwood pulps has indicated that a very suitable pulp can be produced by refining in the initial stage at high consistency followed by refining at 4% consistency.

Thermo-pulping

Thermo-pulping is a new process which has been recently developed in Europe which claims up to 30% reduction in energy.

The softening effect of wood lignin at elevated temperatures has been understood for a long time. At temperatures above the softening temperature, the forces to cause rupture in the wood structure decreases significantly.[10] While this phenomenon has been utilized effectively in the manufacture of fibreboard,[11] Figure 3, the production of a mechanical pulp for printing and writing grades by preheating chips to temperatures exceeding the softening point of lignin prior to defibration has resulted in high energy consumption and relatively poor optical properties with regard to brightness and scattering coefficient.[12] The main reason for this is related to the difficulty in creating fine material of suitable quality from the fibres that have initially been separated in the lignin rich middle lumella.[13] The fibres tend to be coated with a layer of this hydrophobic lignin material. However, many extensive studies now show that the difference in light scattering coefficient between different types of mechanical pulps can be related to differences in the quality of the long and intermediate fibre fractions. Long fibres created under conditions where the lignin is well softened, will exhibit low light scattering or specific surface area. This does not appear to be changed in a sufficiently effective manner by subsequent refining. It thus appears vital importance to make the initial separation of the chips into fibres under conditions which avoid the production of too many intact fibres having smooth hydrophobic surfaces in order to manufacture a high quality printing grade pulps. Once a primary pulp having suitable surface characteristics has been produced, Table 7, the temperature at which second stage refining is conducted can be increased well above the softening point of wood lignin in order to take advantage of the lower fracture strength of the wood structure at the higher temperature.

It ought thus to be possible to establish the final pulp properties in a primary refining stage after preheating the chips to a temperature below the softening point of the lignin and then achieve energy saving by conducting the second stage refining at a temperature well above the softening point of the lignin.

Figure 3 Refining Energy for Softwood Required at Various Temperatures

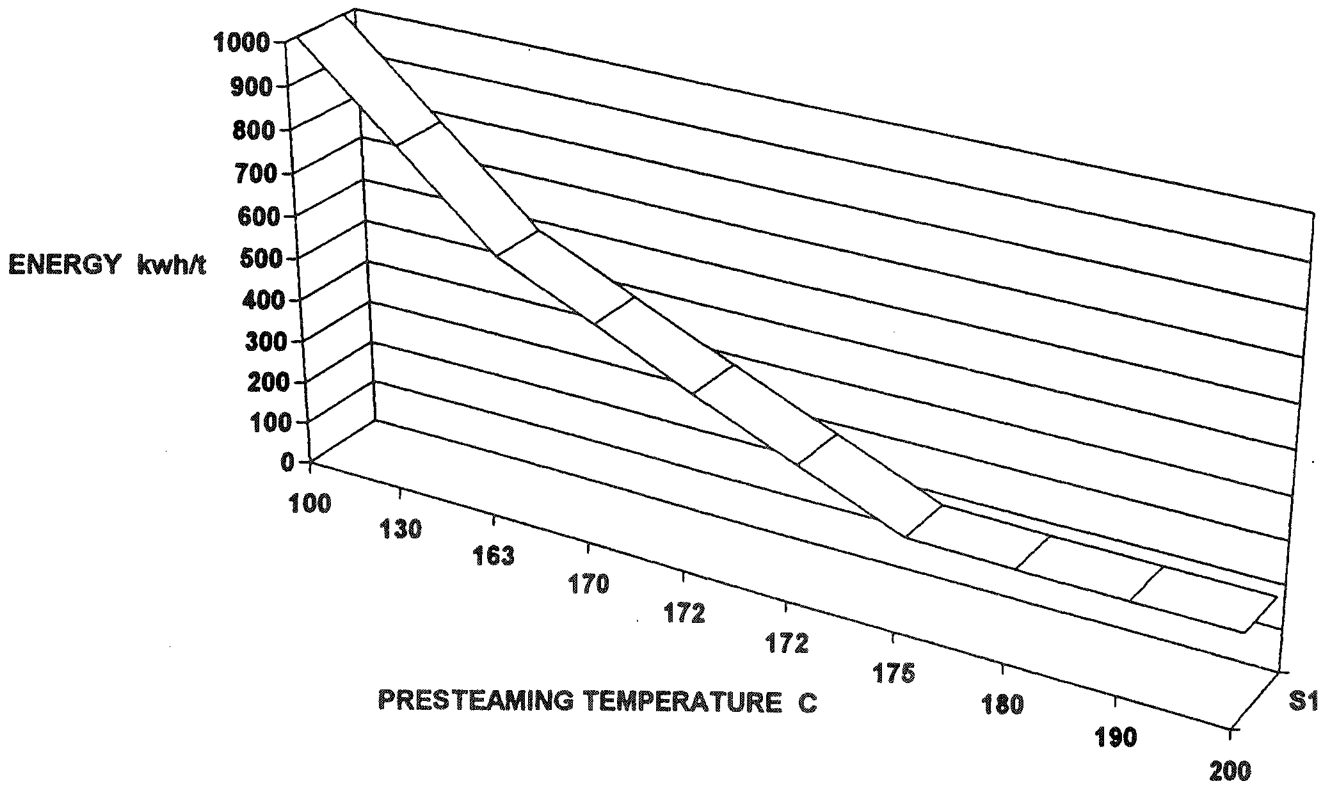


Table 7 Fibre Distribution from Primary and Secondary Refining

Bauer McNett Classification	Primary TMP % @ 355 ml CSF	Secondary TMP % @ 85 ml CSF
R14	18.9	6.9
14/28	27.4	25.3
28/48	16.5	21.3
48/100	9.3	11.0
100/200	7.8	9.6
P200	20.1	25.9

The concept outlined here has been evaluated in depth both in pilot plant studies and on full scale 350 t/d system in Europe. Pilot plant studies indicate energy savings in the order of 20-30%. Full scale studies on a two stage double disc system indicated energy savings of about 20% and using the reject refiner in the thermo-pulping mode also suggested energy savings of 20%.

Equipment modification required

Converting conventional TMP system to thermo-pulping requires additional equipment to be added to ensure a rapid but homogeneous temperature rise through the pulp mass. Modifications have to be made to the design of the secondary refiner to allow this refiner to operate at the higher temperature/pressure involved in the thermo-pulping process.

Energy savings

The energy saving predicted obtained in initial work has been about 30% or 500-650 kWh/t. This would reduce the energy requirement from to produce a TMP from 2200-2000 kWh/t to 1350-1700 kWh/t. There is significant evidence from trials in Europe that the energy reduction will be over 600 kWh/t. This will reduce the energy demand for TMP to equivalent to that of stone groundwood and if the recovered steam from the TMP can be used then TMP will become the most energy efficient mechanical pulping process.

Off-peak production

This decrease in energy requirement will enable an increase in production. If the increase in production is not required, and is sufficiently large, then the mill may be able to take advantage of off peak power where off-peak rates are available. This will offer the mill further opportunity to reduce electrical costs. It is envisaged that an additional TMP storage tank will need to be constructed. During off peak times the TMP system will be operated in such a manner as to fill this tank, while at peak periods, a portion of the TMP system is shut down and the level in this tank is drawn down.

CONCLUSIONS

1. Energy reduction technology in mechanical pulping will be implemented in the coming years.
2. Increased throughput and increased rotational speed will be implemented by a number of mill having the appropriate tackle.
3. Post refining technology will be more widely utilized.
4. Thermo-pulping technology, if successfully implemented in the coming months, will be widely accepted.
5. As electrical costs rise mills will consider adopting energy conservations strategies such as off-peak operations.

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