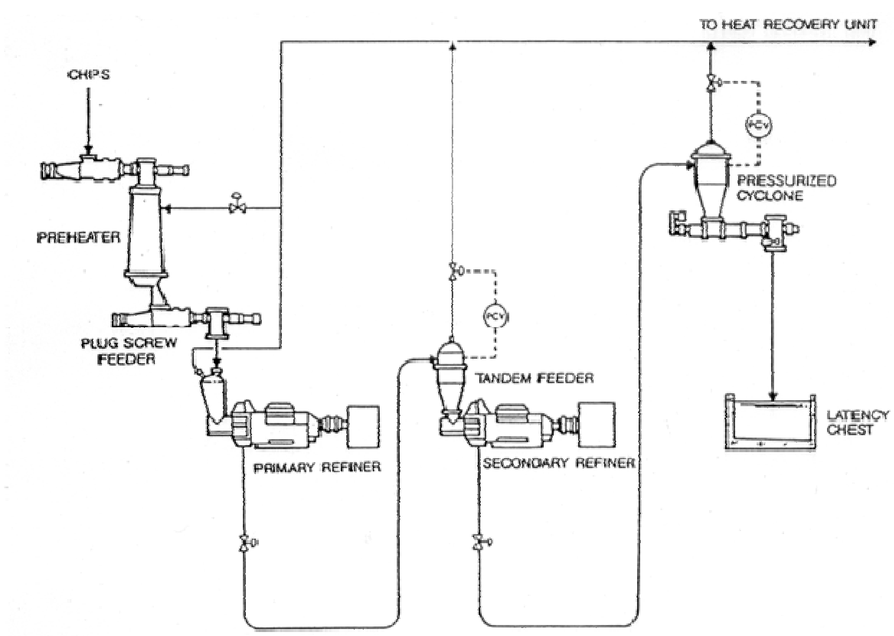
MECHANICAL PULPING – TMP / CTMP

1 Thermo-mechanical Pulp (TMP)

Mechanical pulping consumes a great deal of electrical energy. Much effort has been spent over the years to reduce this. A major early approach was the use of higher temperatures to "soften the lignin". This occurs in RMP by the steam generation in the process.

In thermomechanical pulping (TMP), pressurized steam is applied before and during refining to raise the wood temperature to soften the lignin. The TMP process reached commercialization in the 1970s.

The process has evolved slightly over the years, to a typical one shown below. Chips are preheated and refined in a pressurized refiner called the "primary stage". The pulp from this stage is then refined in a "second stage". In the early days, the second stage was an open discharge refiner (RMP). In more modern systems, both stages are pressurized, below

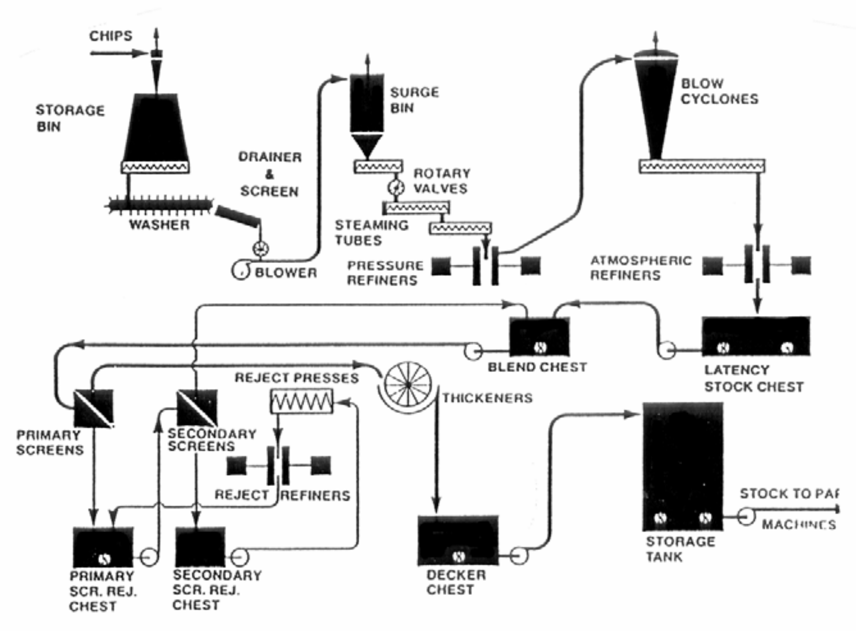


It should be noted that TMP did not lead to the anticipated reduction in energy consumption. It did not do so because, upon lignin softening, fibres break out of the wood matrix through the middle lamella rather than the P1 layer, leaving lignin-rich fibre surfaces. These give stiff, poorly bonding fibres. To make suitable papermaking fibres, much of this lignin must be removed in the fibre development step. This requires increased energy consumption.

Other comparisons of TMP, SGW, and RMP are shown below. The TMP requires higher energy, but gives longer fibres, fewer shives, and less fines. As a result, TMP produces stronger paper, to the extent that in many cases newsprint can be made from 100% TMP without any chemical reinforcement pulp needed.

	SGW	RMP	TMP
Energy required (GJ/ton)	5.0	6.4	7.0
Freeness	100	130	100-150
Burst index	1.2	1.6	1.8-2.4
Tear index	3.5	6.8	7.5-9.0
Breaking length (km)	3.2	3.5	3.9-4.3
Shive content (%)	3	2	0.5
Long fibre content (R48)	28	50	55
Fines content (P100)	50	38	35
Brightness (unbleached)	61.5	59	58.5

A typical TMP process also contains a “latency removal” step (below). Latency refers to a high curl developed in fibres during refining which is frozen in upon cooling after refining. This in effect reduces the length of fibres, diminishing their ability to make strong pulp. The curl is removed in a “latency chest” in which the pulp is heated at low consistency in a stirred tank. During this process, the fibres straighten out to a large degree.



Screening and cleaning system which follows all mechanical pulping processes. This is an important component of mechanical pulping because the process does not break down all of the wood to individual fibres. It is necessary therefore to separate the fibres from the fibre bundles (shives). This is accomplished in screens and cleaners (hydrocyclones). The separated fibres then pass on to a thickener and then to the paper machine. The “rejects” are further refined in a “reject refiner”, and then screened again. We will talk a lot more about screening in upcoming lectures.

Modern chip refiners are a marvel of mechanical engineering. They are large in size, operate at high speed, but have a gap less than 1mm between the rotating plates.

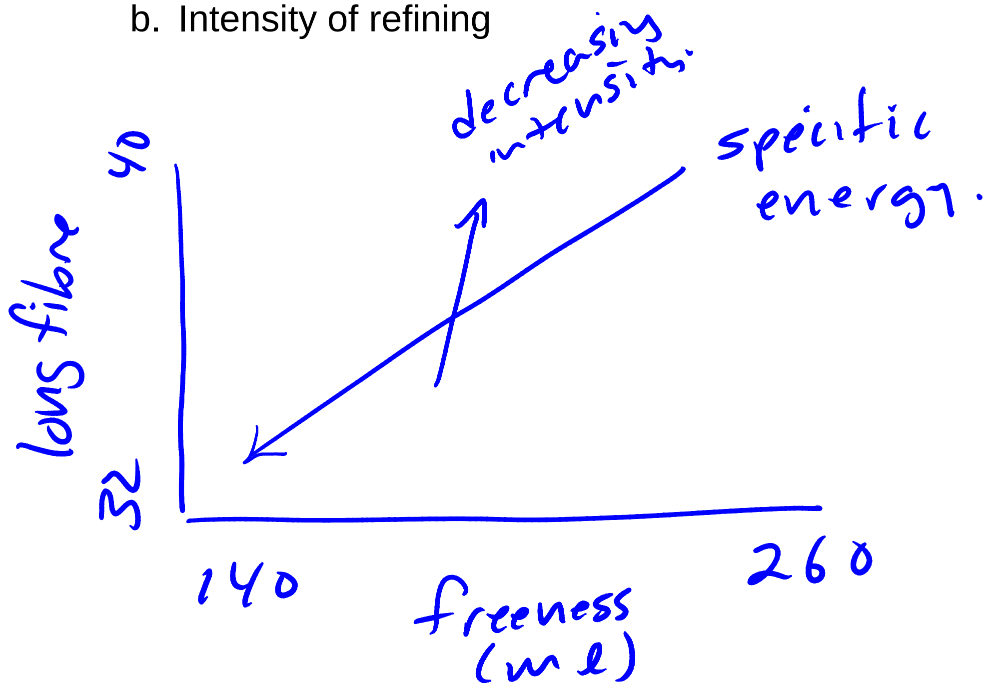
Typical Production Rate	300 Bdt/d
(of one refiner)	800 Bdt/d - modern
Typical gap between plates	0.5-1 mm
Typical Specific Energy	7 GJ/t
Typical Power to Refiners	20 MW

(Note: 20MW = 27,000 horsepower ~ 10 train diesel locomotive)

2 Refining parameters and their effects on pulp quality

We have two independent parameters:

a. The amount of energy applied to the pulp (Specific Energy)
b. Intensity of refining



Refiner Speed

Increased refining speed:

c. increases intensity at the same power
d. lower energy consumption to get same freeness (quality?)
e. lower fibre length
f. lower tear, higher scattering at same CSF.

Consistency

Increasing the consistency of the pulp in the refining zone:

g. increases moisture content which increases fibre length
h. increases wet mass, therefore, inertia which lowers the refining intensity which lower fibre length
i. increased dilution (lower consistency) reduces the gap between the plates due to lower steam volume.
j. Decrease power consumption by 7% when 50% consistency → 38% consistency.

Note: refiner consistency is usually reported as discharge consistency.

Production rate

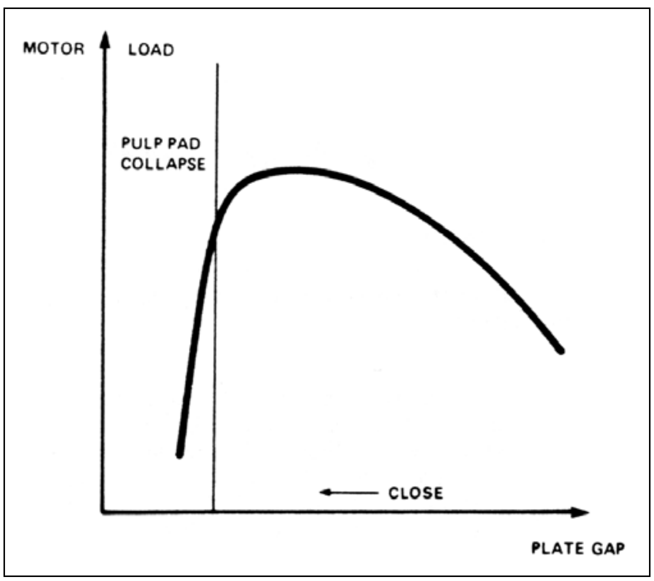
Increased production will reduce energy consumption (at a constant CSF), however it will lower fibre length and strength

Preheating and steaming (Temperature)

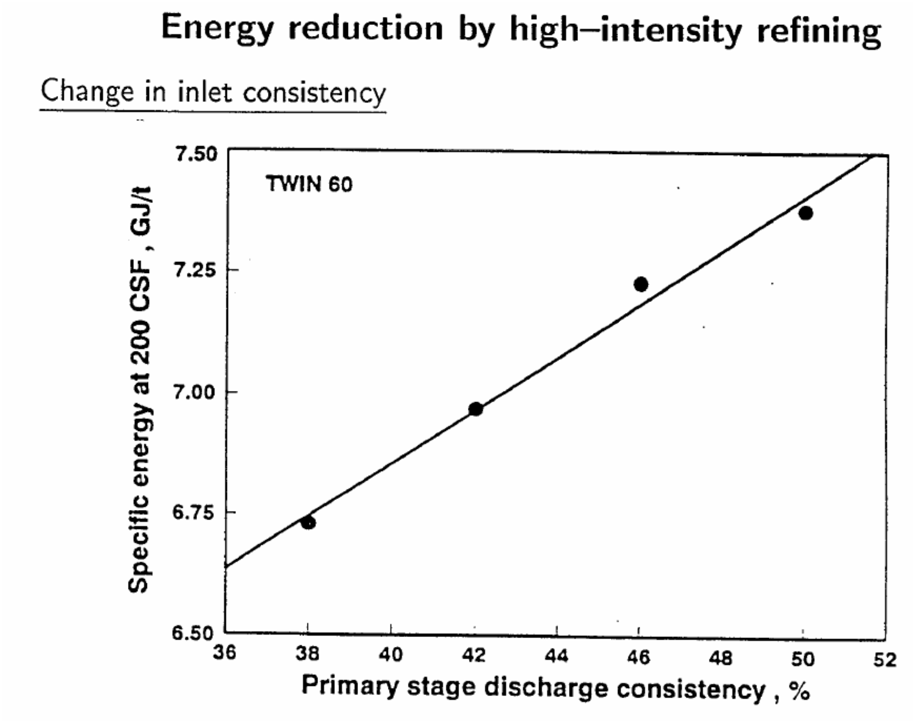
Found that preheating is not too important but temperature in refining is. Increases refiner temperature (pressure of saturated steam) increases fibre length and strength.

Plate gap

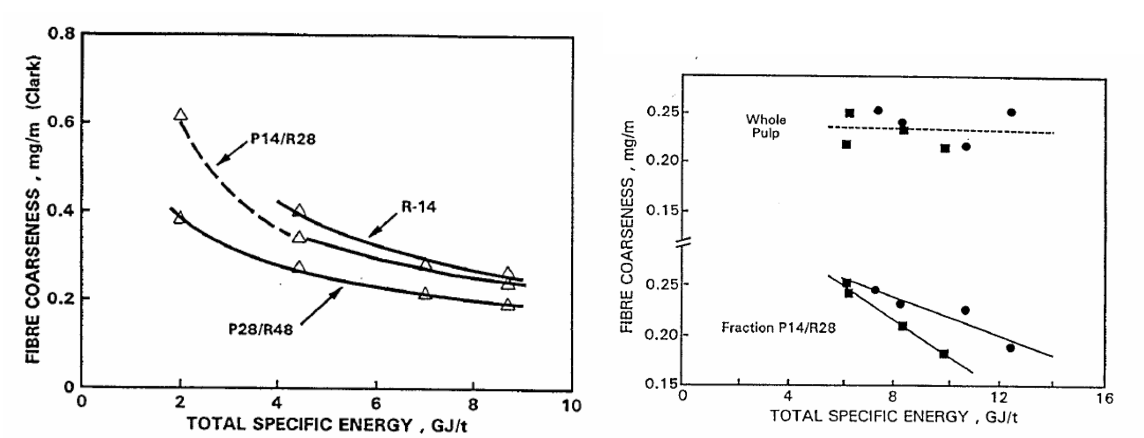
Closing the plate gap increases power consumption. If the feed rate remains constant, this increases the specific energy. It also increases refining intensity. However, if the gap becomes too small, the pulp pad separating the plates collapses and the power drops drastically, possibly leading to plate clash.



Effect of various parameters on pulp quality



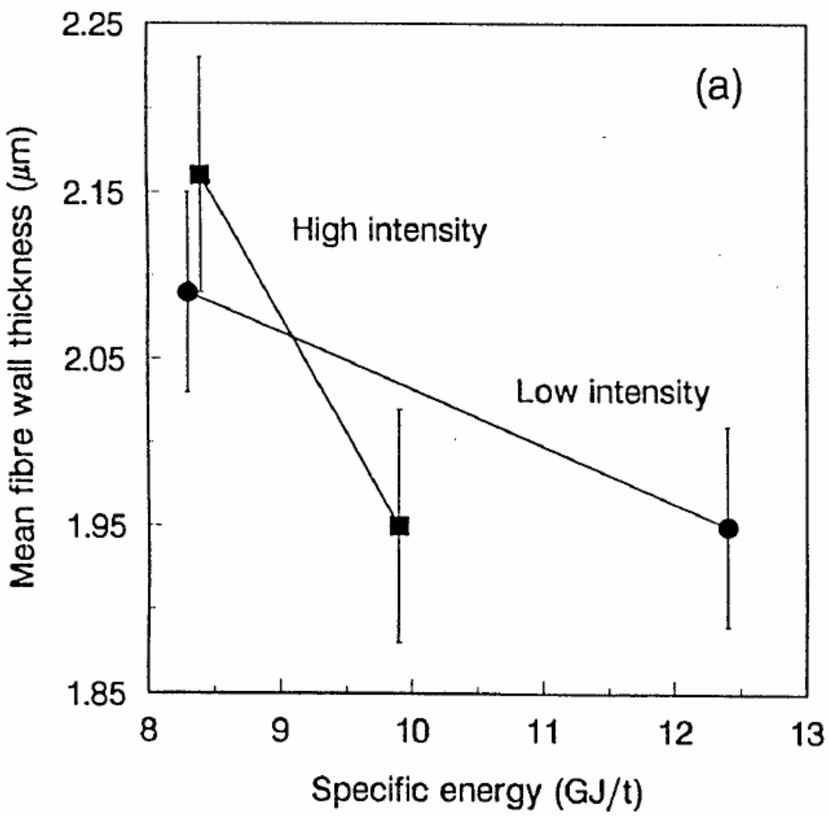
The above figures shows that as the consistency at the discharge of the refiner decreases the specific energy required to make the same freeness pulp (200 CSF) also decreases.



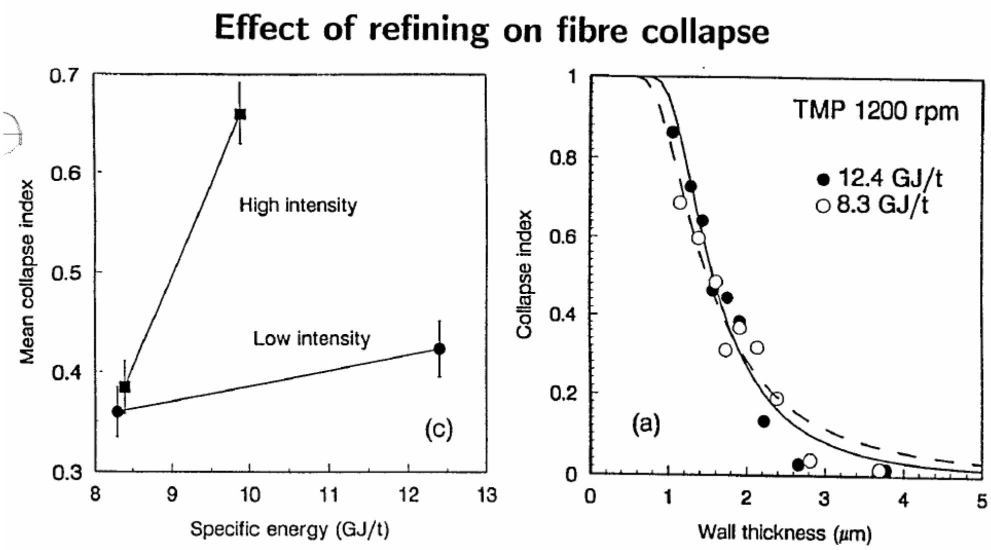
(a) (b)

As specific energy increases the outer layer of the fibre is delaminated. This results in the fibre wall becoming less thinner and the coarseness (weight per unit length of fibre) also decreases. The figure (a) above shows that coarseness of the long fibres (those retained on a 14 wires/inch mesh) are coarser but lose more of their outer wall during the development step of refining. The middle fraction of fibres (those that pass the 28 wires per inch mesh but are retained on 48 wire per inch mesh, P28/R48).

The figure (b) indicates the same thing. However, we see also see that this trend isn't always evident if we measure the coarseness of the whole pulps using modern fibre analysis equipment, such as kajaani FS-200. The reason is that these optical instruments do not accurately measure the right amount of fines.

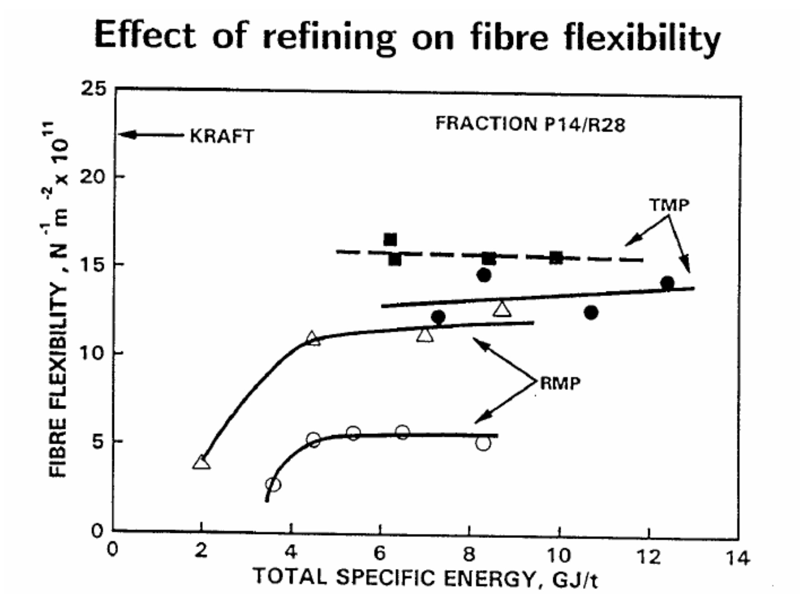


The mean wall thickness of the fibres has been directly measured using confocal microscopy. Here we see that as specific energy is increased the wall thickness decreases. We also note that the specific energy required to lower the wall thickness is less for high intensity treatments. The lower wall thickness results in more collapsible fibres that result in stronger bonds and stronger paper. Also, it results in more fibres per gram and therefore more bonds per gram thus stronger paper.



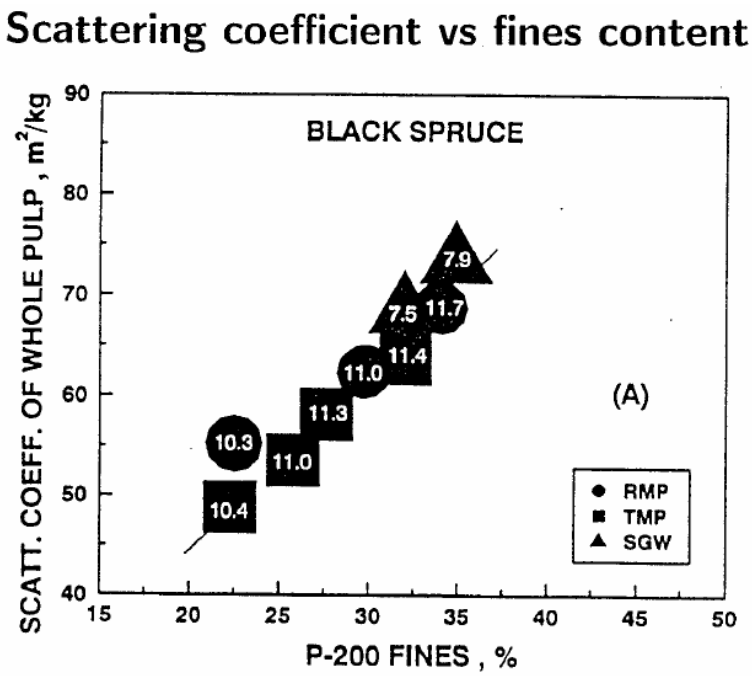
Collapse Index: $CI = 1 - \frac{A_{lumen}}{A_{lumen_0}}$

The above figure shows that the wall thickness results in a more collapsed fibre. That is the fibres will look more like ribbons than hollow tubes. The right hand side graph shows the relation between wall thickness and collapse index for the two treatments: they are the same. This indicates that the flexibility of the fibre wall is about the same for high and low intensity treatments.



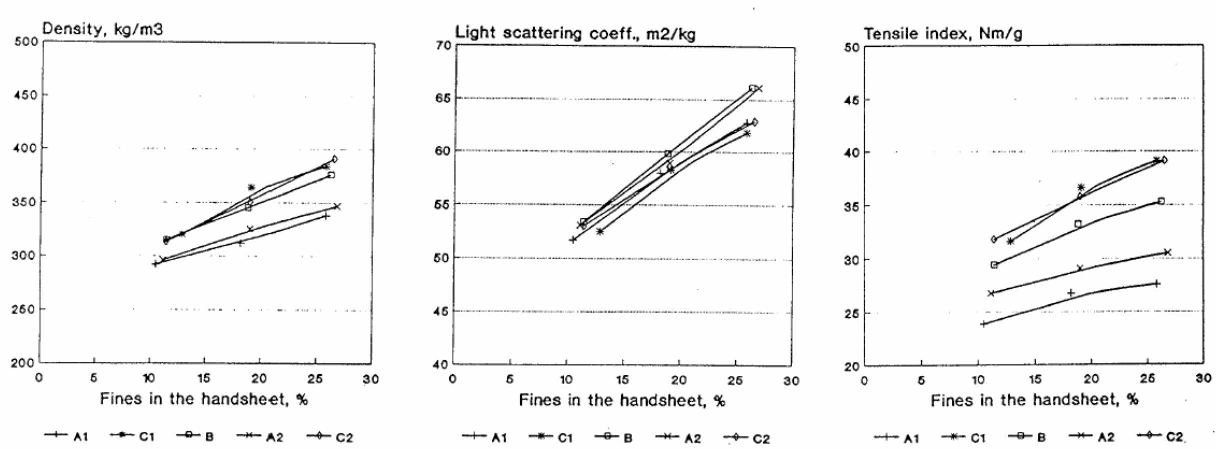
This conclusion is further supported by the graph above. For RMP there appears to be a increase in flexibility at low energies but at moderate specific energies the flexibility of the wall is about the same.

This indicates that fibre development in refining is mostly through the removal of the outer wall and not through internal delamination of the wall i.e., it changes the thickness of the wall but not the elastic modulus of the wall material.



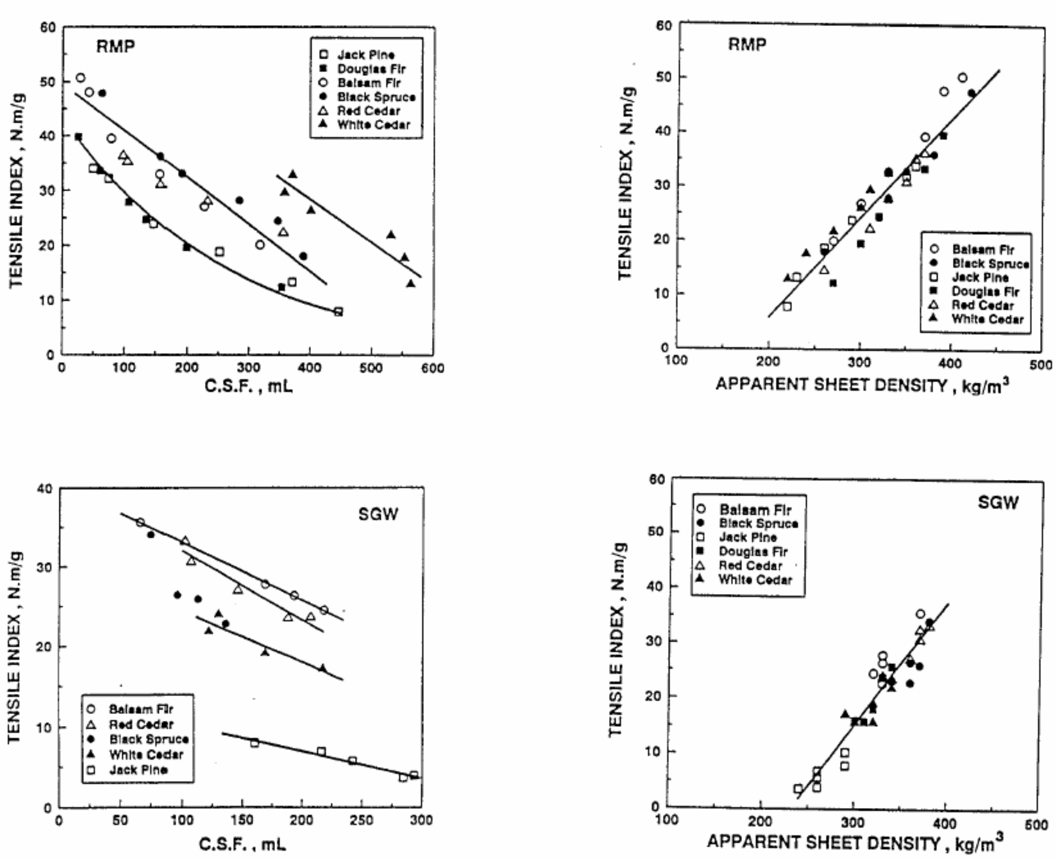
The effect of fines in mechanical pulps and papers is significant.

The amount of fines, as indicated by the % of material that passes through a 200 wire per inch mesh, has a direct impact on the scattering coefficient of paper. This is shown in the figure above.



Further increasing the fines content also increases the tensile strength and density of the paper (shown above).

Stationwala et al, 1995 IMPC, 165-170



The species of wood pulp makes a big difference on the morphology of fibres (as we saw in topic 2) and the how they are pulped. The figure above indicates the relation between some of the basic pulp quality variables for a range of important Canadian tree species.

New Process (RTS)

Retention: Short retention in pre-heater (10-20s). The short time at elevated temperature reduces the brightness losses (Net 1 pt brightness improvement). Also short residence time during refining helps.

Temperature: increase pressure to 5.5-6.0 bar

Speed: Increase speed to 2000-2500 RPM. Decreases specific energy to get same ‘quality of pulp’. The result is a 15% energy reduction.

Ref: Cannell, 1999; Fergusson, 1997; Patrick, 1999).

Process Control Strategies

1. Refiner load constant by controlling production rate (controlled by screw feed to refiner)
2. Decrease variation by adjusting dilution
3. Refiner load constant by adjusting the plate gap. This is accomplished by applying axial thrust hydraulically. A sensor detect clearance accurately. Note: that pad collapse can occur and the plate will clash.

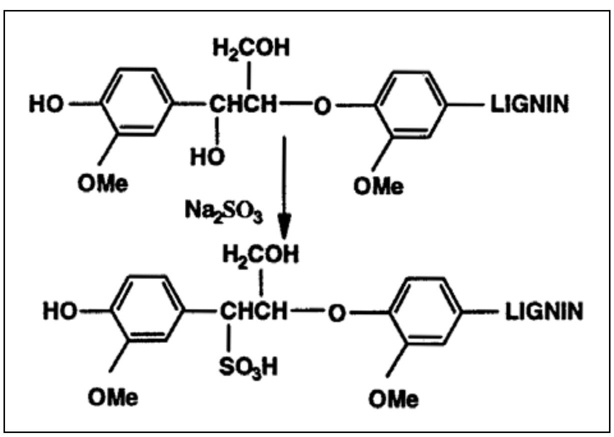
Chemically Modified Mechanical Pulps

In order to reduce energy consumption and improve pulp quality in mechanical pulping, chemical treatments of various types may be employed. These treatments are mild in comparison to those used in the chemical pulping and bleaching. They give “chemically modified” pulps. The aim is to retain the high yield range of 90-95%, which is a major advantage of mechanical pulping. More severe chemical treatments, which lower the yield to the 85-90% range, are called “chemi-mechanical” pulps.

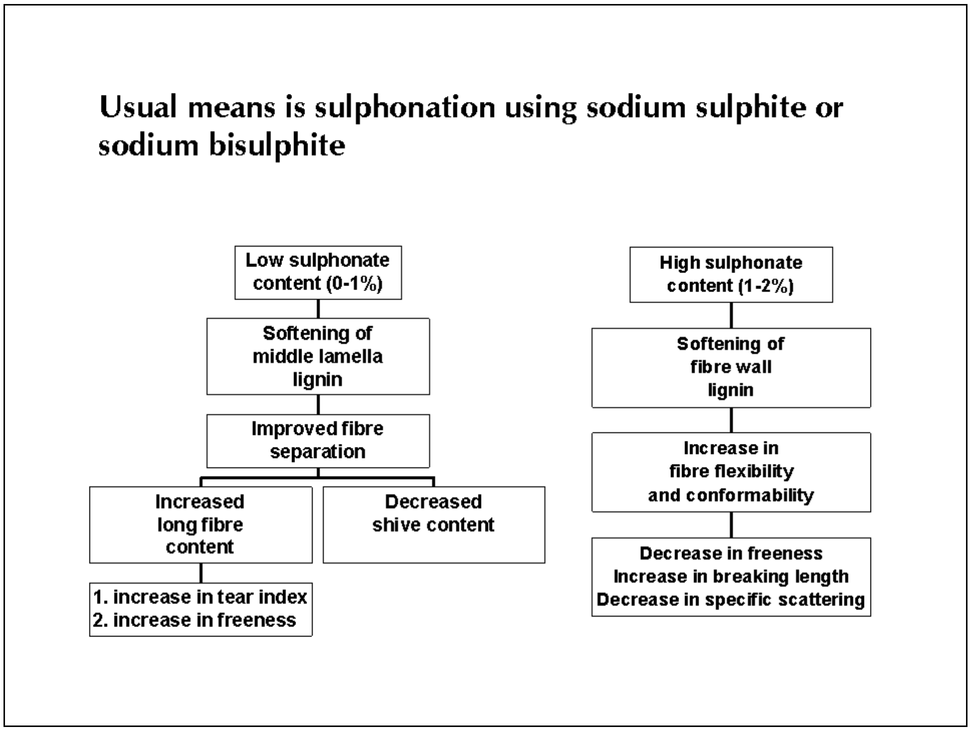
There are three approaches to treatment: pre-treatment, post-treatment, and inter-stage treatment.

Pre-treatments of wood chips aim primarily to lower energy consumption. Post-treatments aim to flexibilize fibres, to produce better bonding in paper. Inter-stage treatments aim at some combination of these two.

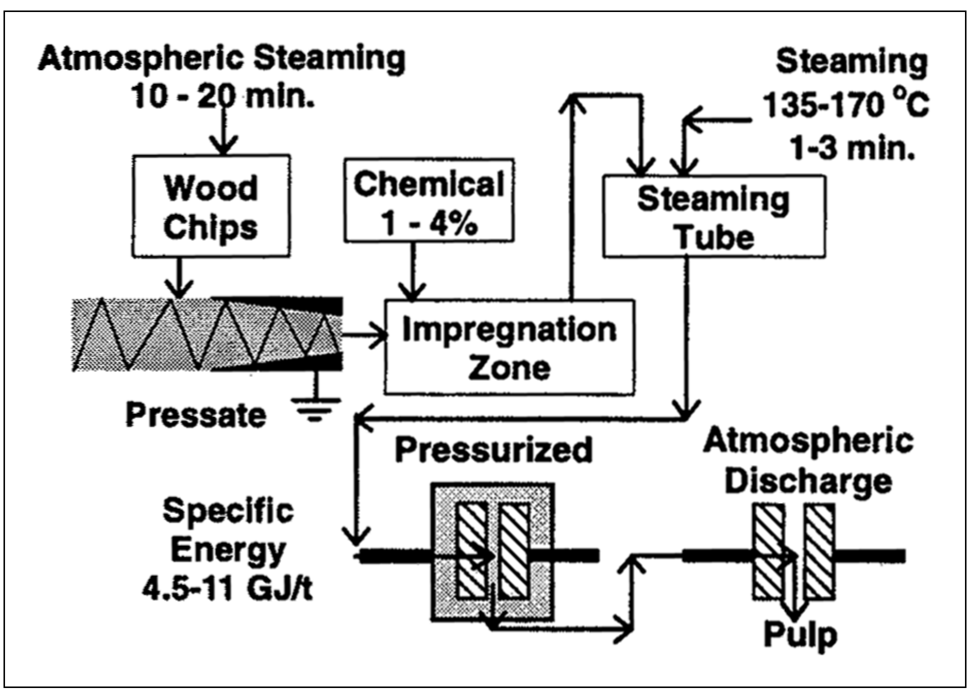
Sulphonation is one common form of chemical treatment. Here wood or fibres are reacted with sodium sulphite or sodium bisulphate to produce a reaction in which sulphonic acid breaks down the lignin in the wood structure. This replaces some lignin groups with sulphite ions. The nature of these sulphonated bonds in lignin is shown in Fig 1. This reaction causes a “softening” of the lignin.



The various approaches to sulphonation are described below.



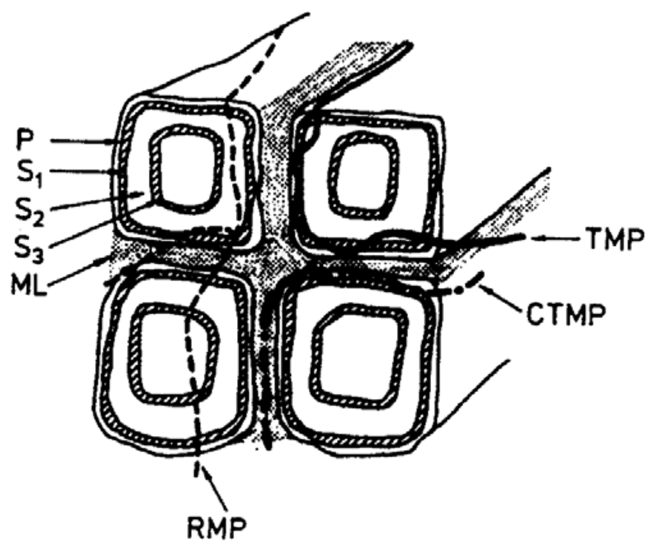
The flow sheet for one treatment, a chip pre-treatment for TMP called "Chemi-thermomechanical" (CTMP) pulping, is shown below



In RMP the heating beyond lignin softening temperature takes place in refining due to cyclic compressions. Lignin is relatively stiff. And fibres break uncontrollably. The fracture line will more often go through the secondary wall exposing more cellulose creating better bonding surface. However the fibres are stiffer and shorter which makes a weaker pulp.

TMP the fibres aer heated just below the glass transition temperature (140 C) by pre-heating under pressure. In refiner fibre detached more gently and break in the middle lamella which is rich in lignin. TMP takes more energy to get a higher quality because the fibres require more work to expose the secondary wall cellulose. CTMP fibre tend to be more flexible and longer and with more energy can have good surfaces available for bonding and can be quite strong.

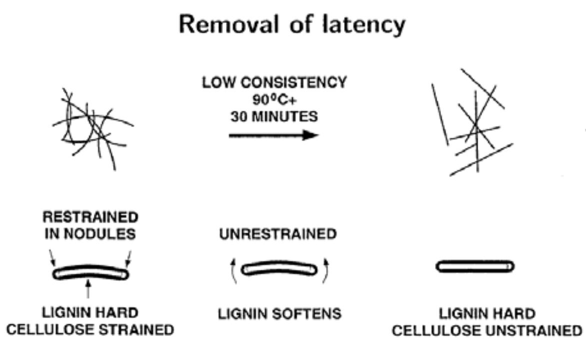
CTMP Lignin softened by temperature and the chemicals. Almost always break along Middle lamella resulting in long fibres with a low shive content. These fibres also require extre energy to expose the cellulose. CTMP fibres are even more flexible and longer than TMP and can result in very strong pulp.



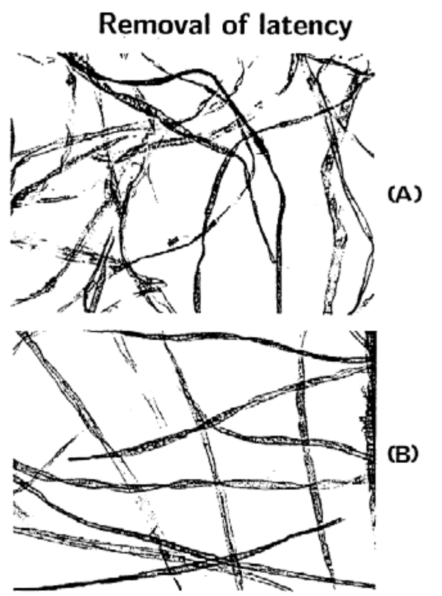
3. ***Latency Removal***

After pulping the fibres are curled and very stiff. This is because the lignin in the fibres cools quickly as the fibres escape from the refiner at high consistency locking the fibres together and kinked and curled.

The pulp as it exits from the refiner is not useful for making pulp. To release the properties of the fibre (the Latent properties) the fibres sit in a relatively low consistency tank at elevated temperatures to untangle and straighten the fibres. This is called latency removal.



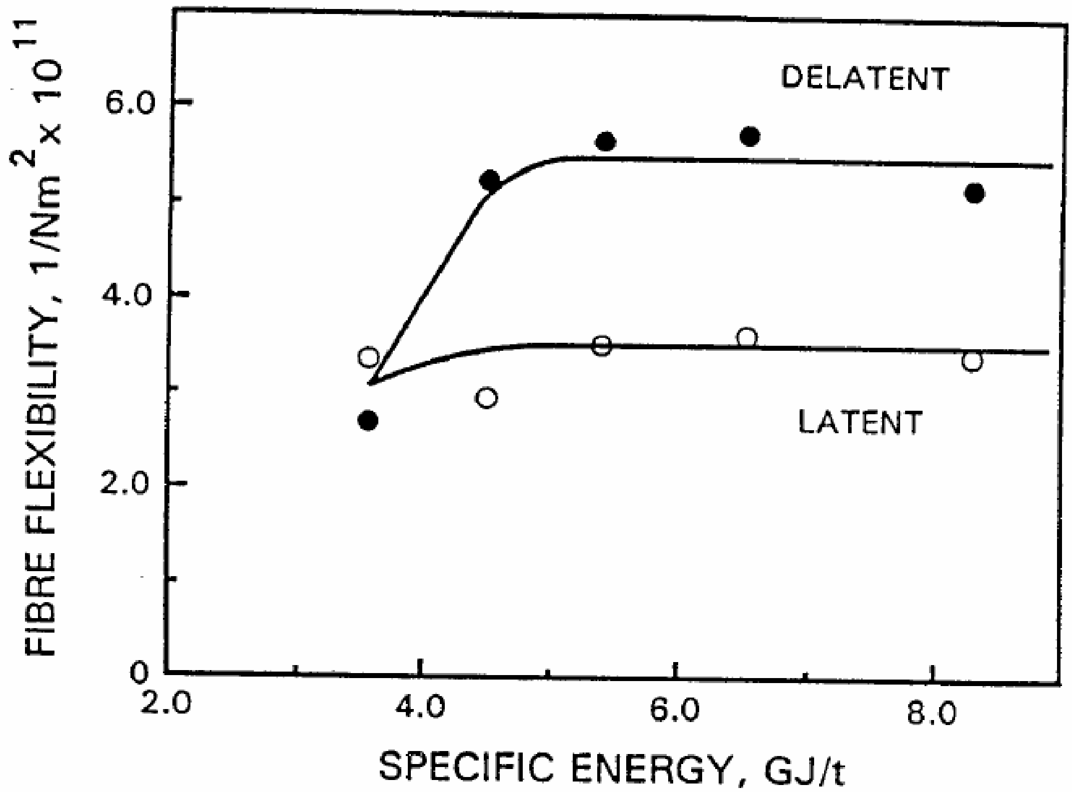
(a)



(b)

The figure above (a) illustrates that when pulp is held at low consistency, at 90 degrees C for 30 minutes that the fibres straighten out and disentangle, thus becoming useful for papermaking. Figure (b) shows how the fibres are much straighter after latency removal.

Effect of latency removal on fibre flexibility



This figure shows hwo the flexibility of the fibres is much greater after latency removal (delatent). In general we can say that latency removal has the following effect on the pulp:

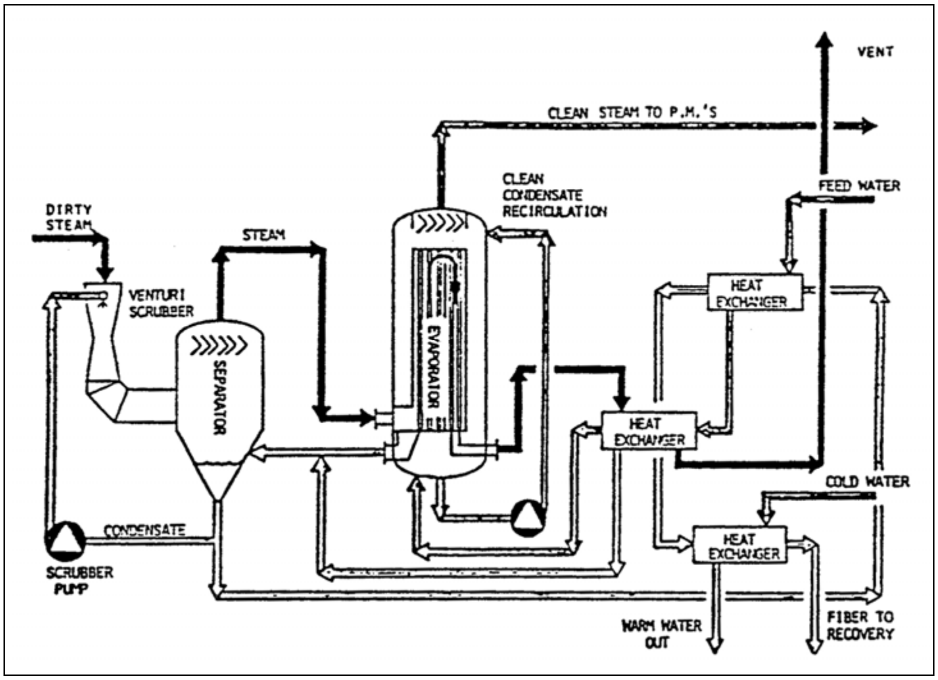
Drainage (Freeness):	decreases
Fines retention:	increases
Bulk:	decreases
Tensile:	increases
Wet web strength:	increases
Stretch:	decreases
Light scattering coefficient:	decreases
Light absorption coefficient:	increases

4 Heat Recovery

A large amount of steam is produced in mechanical pulping. For economy, it is necessary to recover as much of this heat as possible. It is used to heat buildings, warm hot water for paper machines, and dry paper on paper machines. Typically, no more than 20% of the waste heat from a TMP plant is needed for hot water or building heating. However, the dryer on a paper machine requires more heat than a TMP plant can supply.

Steam is separated from pulp in the TMP plant in pressurized hydrocyclones. After this, the steam still has impurities, such as fibres, resin acids, etc which must be removed before the steam distribution system. This takes place in a recovery process of the type shown in Fig 9. Here, steam from the pressurized cyclone is first passed through a venturi scrubber where water is sprayed into the steam in the throat of the venturi, rewetting solid particles. A separator follows, which has a large diameter that reduces steam velocity to a level which allows solid particles to settle by gravity. The steam then passes to an evaporator (shell and tube heat exchanger) where it is condensed. The heat is transferred to clean steam on the other side of the exchanger. The clean steam can be used on the paper machine. If it has fallen below 350-500 kPa (60psi), recompression is needed.

Good heat recovery systems may recover 55-65% of the energy supplied to TMP refiners in the form of clean steam. However, it should be noted that this recovered energy is in the form of low temperature heat whereas energy supplied to the refiners was in the form of electrical energy. Thus, the entropy of the recovered energy is far greater than the initial energy, meaning it is of less value. This second law of thermodynamics must be borne in mind along with the first law in assessing the energy efficiency the heat recovery process.


VENT
CLEAN STEAM TO P.M.'S
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HEAT
EXCHANGER
COLD WATER
CONDENSATE
SCRUBBER
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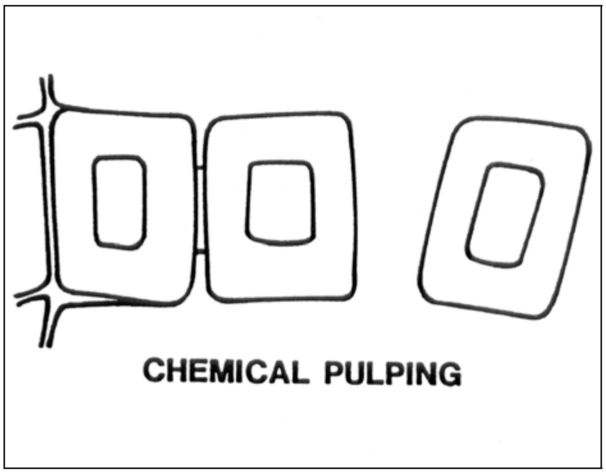
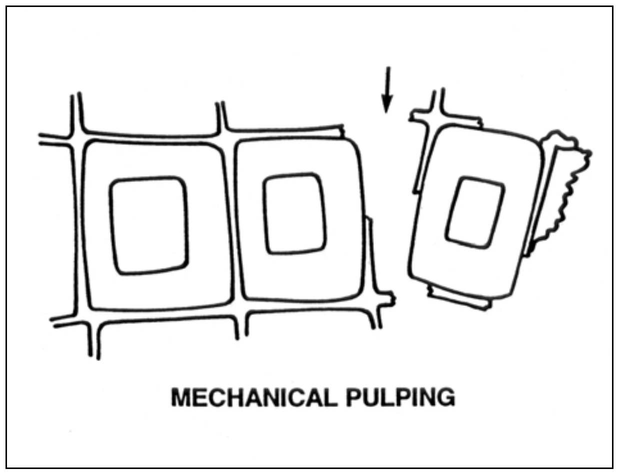
HEAT
EXCHANGER
WARM WATER
OUT
FIBER TO
RECOVERY

5 Chemical pulping versus mechanical pulping.

Mechanical pulping removes fibres from wood by breaking them loose from the wood matrix rather than by dissolving the lignin holding fibres in the wood matrix as is done in chemical pulping. As a result, mechanical pulps have shorter fibres and many more fines than chemical pulps.





However, as we have discussed, there are many differences both in quality and the cost of mechanical and chemical pulps and as a result they are used in different applications and products. In general, chemical pulps are not only longer but they are much more flexible and have a nearly pure cellulose surface that forms strong bonds and strong paper. They can also be much brighter and form smoother sheets but they are considerably more expensive to produce.

Mechanical pulps on the other hand are less expensive, weaker, have higher opacity and are not as bright. They are used in applications that are typically single use, for example, newspapers, towels, …

The pictures below illustrate the differences in the pulps.

Mechanical pulps also possess other advantages and disadvantages relative to chemical pulps

	Chemical	Mechanical
Yield Fibre/Wood	Low 40-70%	High 90-98%
Cellulose Purity	- High - lignin dissolved	Low - lignin remains
End Uses	High quality papers (eg., books). Dissolving pulp Reinforcement pkg.	Low quality High volume paper (e.g. newsprint) Molded products
Raw Material Sensitivity	Low	High

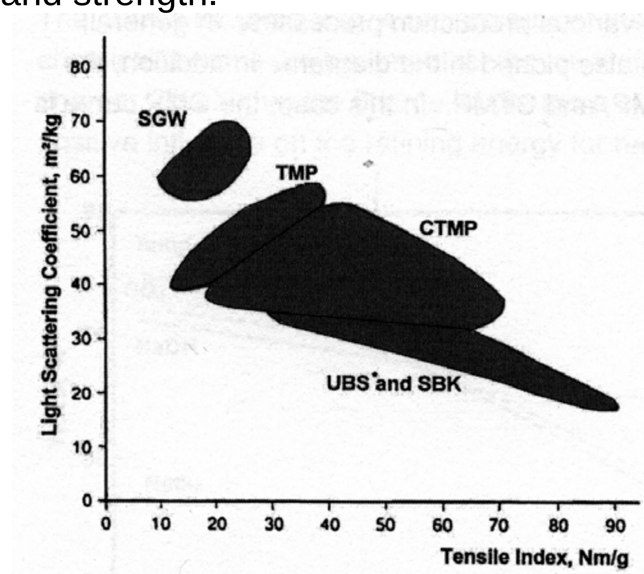
Basic quality differences between chemical and mechanical pulps.

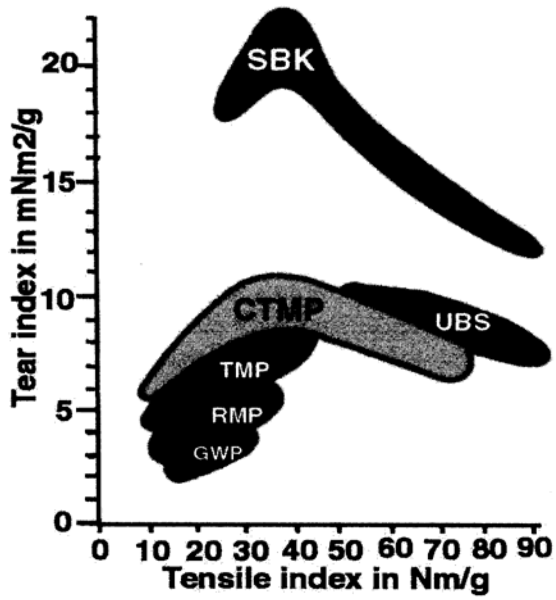
	Chemical	Mechanical
Strength	High - fibres intact	Low - fibres damaged
Bulk	Low - more flexible fibres	High - few and less flexible fibres
Optical	Dark but bleachable Poor light scattering	Bright but hard to bleach high Good light scattering
Drainability	Good - long fibres few fines	Poor - short fibres, many fines
Permanence (optical)	Good	Poor

The cost differences between chemical and mechanical pulps. You can see why mechanical pulps are used in applications where they can be … they are considerably cheaper to produce.

	Chemical	**Mechanical**
Raw material	High – because fo the low yield (50%)	Low – high yield
Capital	High	Low
Operating	High	Low
Auxillary (pollution, recovery, etc)	High	Low for slush pulps … few markets pulps

As mechanical pulp quality is improved, mostly through the use of more chemical applications it is beginning to merge with chemical pulps. The figure below shows how the major manufacturing methods compare in optical properties and strength.




SBK
CTMP
UBS
TMP
RMP
GWP
Tear index in mNm2/g
0
5
10
15
20
0 10 20 30 40 50 60 70 80 90
Tensile index in Nm/g

6 Mechanical Pulp Brightening

Low brightness in the range 55-60% ISO is one of the disadvantages of mechanical pulps. This is the range of typical newsprint. This level may be compared to the brightness of typical copy paper (the paper on which these notes are printed), which is in the range 80-85% ISO. A further shortcoming of mechanical pulps is their tendency to darken and yellow with time. To avoid reversion, lignin must be removed from the pulp, as is the case for the bleached chemical pulp from which this copy paper was made. However, the yield is far lower than would be the case for mechanical pulp.

It is sometimes necessary to increase brightness of mechanical pulps, even if temporarily, for a short-life product such as newsprint. This is particularly important for four-colour printing which is growing in use. The objective, however, is to accomplish this without yield loss. This is called “brightening” as opposed to “bleaching” in which lignin compounds are removed.

The dark colour in mechanical pulp comes from compounds in lignin called chromophores. The aim in brightening is to react these chromophores to change their light absorption without removing the lignin. This is accomplished by oxidative or reductive brightening reactions which modify the molecular structure of the chromophores so that they absorb a lower wavelength light and thereby are brighter.

6.1 Reductive Brightening

Reductive brightening is commonly accomplished with sodium dithionite (sodium hydrosulphite). This gives a modest increase in brightness (about 8 points). Some typical conditions for its use are shown in Fig 4, and a process flow sheet is given in Fig 5. This is a relatively simple form of brightening often used for a modest brightness gain in newsprint.

6.2 Oxidative Brightening

Oxidative brightening is typically achieved with hydrogen peroxide. This gives up to 25 points increase in brightness.

The peroxide must be used in alkaline solution, which can darken the pulp, and therefore efficient brightening requires an optimum ratio of caustic to peroxide. In addition, some residual peroxide must remain after brightening to prevent alkaline darkening.

Hydrosulphite

- **Process conditions**
  - **Addition rates 4 to 8 kg//t**
  - **Temperatures 20 to 60°C**
  - **Retention times 1 to 2 hours**
  - **pH 5 to 6**
  - **Consistency 3 to 5%**
  - **Chelant 0.2 to 0.5%**
- **Brightness**
  - **Gains 6 to 10 points**
  - **Final 60 to 65%**
- **Final brightness depends upon incoming pulp**
  - **SGW > RMP > TMP**

Figure 4

Hydrosulphite Bleaching

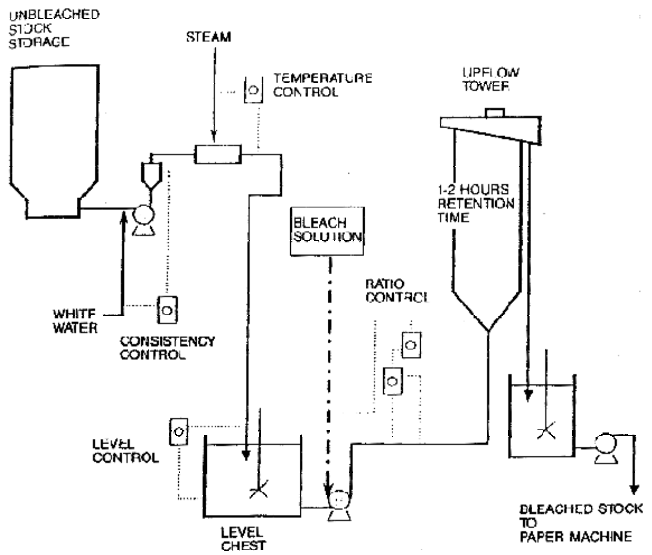


Figure 5

Other factors also complicate peroxide brightening. The peroxide breaks down in contact with transition metal ions, which are almost always present in pulp. To overcome this, a chelating agent (DTPA) must be added to sequester these ions, and these ions are then washed out. Also, sodium silicate must be added to stabilize the peroxide and to buffer the pH.

Typical peroxide brightening conditions are shown in Fig 6 and a flow sheet is shown in Fig 7.

Hydrogen Peroxide

- Application Conditions
  - Addition rate 10 to 50 kg/t
  - Temperature 40 to 70°C
  - Retention times 1 to 5 hours
  - pH Initial 10.5 to 11
Final 9 to 9.5
  - Sodium silicate 3 to 6% on pulp
  - $MgSO_4$ 0.25% on pulp
  - Chelant 0.25% on pulp
  - Consistency 15 to 30%
- Brightness gains up to 20 points

Figure 6

Two Stage Peroxide Bleaching

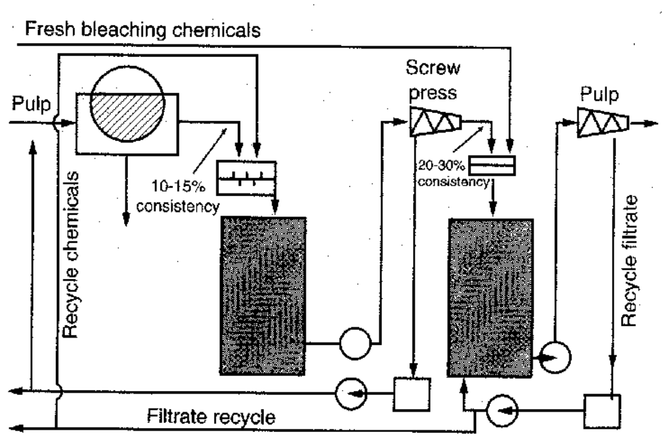


Figure 7

Figure 9

APPENDIX

4.3.2. Capacity and efficiency of heat recovery system

The rate of heat transfer from a heat exchanger is given by:

$$Q = UA\Delta T_{LM} \tag{13}$$

where U is the heat transfer coefficient, A is the surface area available for heat transfer and ΔT_{LM} is the log-mean temperature difference between the shell side and the tube side of the heat exchanger. If we assume that only changes of phase are occurring in the heat exchanger, i.e. that there is negligible temperature change in either the shell side or the tube side, then the above equation reduces to:

$$Q = UA(T_{tube} - T_{shell}) \tag{14}$$

where T_{tube} is the temperature of the process steam and T_{shell} is the temperature of the clean steam produced.

The pressure of the clean steam is normally controlled from the steam plant and is thus constant during normal operation. U and A are constants for a given system (although U can drop due to fouling of the heat exchanger) so the heat transfer rate Q can only be increased by increasing the temperature of the process steam. This is done by increasing the cyclone pressure, and thus the refining pressure. However, refining pressure affects pulp properties and there is a definite limit to the pressure (and temperature) at which a refiner should operate. As the refining temperature increases, lignin becomes progressively softer and fibres tend to separate by fracture through the lignin-rich middle lamella. The fibres are then coated with lignin and very little of the secondary wall is exposed, making it hard for water to penetrate them. The fibres are thus inherently stiffer (once lignin hardens upon cooling) and harder to flexibilize.

The heat transfer rate Q provides a measure of the capacity of the heat recovery system, but we are usually more concerned about its efficiency. Integrating Q over the time spent in the heat exchanger allows to calculate the total heat absorbed by the clean condensate fed to the heat exchanger. Mathematically, this is expressed by:

$$H_{so} - H_{ci} = \int_0^T Q dt \tag{15}$$

where H_{so} is the total heat of the clean steam coming out of the heat exchanger and H_{ci} is the total heat of the clean condensate fed to the heat exchanger. Dividing this by the energy spent in the refiners during the same time, we get the clean steam energy efficiency (η_{cs}) of the system:

$$\eta_{cs} = \frac{H_{so} - H_{ci}}{E_i} \tag{16}$$

where E_i is the electrical energy input to the refiners. Alternately, if the heat transfer rate Q and the refiners' power consumption P are constants, η_{cs} can simply be calculated as:

$$\eta_{cs} = \frac{Q}{P} \tag{17}$$

The clean steam energy efficiency can reach 55 to 65% for systems presenting favorable conditions. Finally, the net energy consumption of the system is given by:

$$E_{net} = E_i(1 - \eta_{cs}) \tag{18}$$

Fig.22 shows a graphical representation of an overall energy balance on a TMP system with heat recovery.

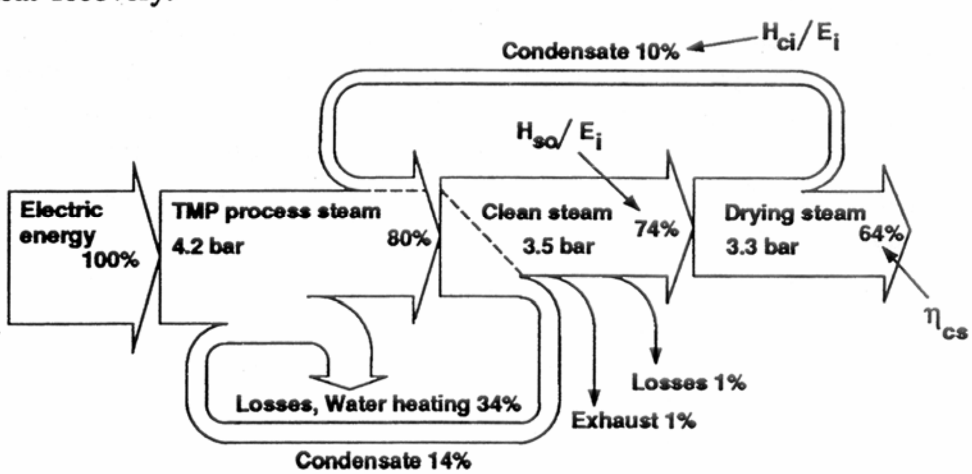


Fig. 22 Energy balance of TMP steam recovery for paper drying