Stock preparation & approach system

Process detail

2.1 Slushing / pulper station with auxiliaries
2.2 Screening and cleaning
2.3 Fractionation
2.4 Flotation
2.5 Dispersion
2.6 Refining
2.7 Stock mixing
2.8 Approach system
REFINING

1. Targets & principles of refining
2. Introduction to refining theories
3. Refining process
Targets & principles of refining
Targets of refining

• The target of the refining is to develop fibers to obtain desired properties for paper or board.

• Physical development of fibers so that they form strong and smooth paper sheet with good printing properties.

• Refining is based on mechanical treatment with metallic bars with the presence of water.
Morphological characterisation of fibers

Pine
*Pinus silvestris*

- Fiber length: 3.5 mm
- Coarseness: 0.16...0.23 mg/m
- Fibers: 2.5 million per gram

Eucalyptus

- Fiber length: 0.8 mm
- Coarseness: 0.08 mg/m
- Fibers: 15 million per gram
Effect of refining

Fiber floc gets the first hit

It is pressed between bars

It leaves tailing edge

Plates or fillings are grooved so that the bars treat fibers and grooves between the bars allow fiber flow through the refiner.
Fiber properties of softwood

• The role is to ensure strength of the paper.
• Excellent reinforcement fibers are flexible, strong and long.
• Thin-walled fibers are flexible and can get close together ensuring good bonding ability.
• Thick-walled fibers yield high tear strength.
Fiber properties of hardwood

• The role is to ensure the good printability of the paper.

• Short fibers and narrow fiber length distribution give good formation.

• Sufficient tensile strength and tear strength are also required for good runnability.

• The higher the number of fibers per gram, the better the optical properties.
Other paper making fibers

• **Non-wood plants** such as straw, bagasse, bamboo, kenaf, flax, hemp and cotton are used for special paper grades and need refining sometimes.

• **Recycled fibers** are increasingly used in papermaking. Refining is recommended for many paper grades. This is due to lost fiber properties in earlier papermaking processes.
REFINING

1. Targets & principles of refining
2. Introduction to Refining Theories
3. Refining process
The effect of refining

- Strength properties generally, like tensile, burst and internal bonding strength are increased
The effect of refining

- Tear strength is initially increased, but is then reduced after prolonged refining

![Graph showing the effect of refining on tear strength](image)
The effect of refining

- Drainage resistance and water removal resistance are increased
The effect of refining

- Air permeability, bulk, absorbency, opacity, brightness and light scattering are reduced
The effect of refining

• Fiber length are reduced
Introduction to refining theories

• Refining theory is a mathematical way to describe refining action.

• The first to introduce refining theory was Jagenberg in 1887. This consists term such as beating area and beating force, which are still used as a basis.

• The common feature of theories is that the total refining power is divided into two components, net and no-load power.
No-load power & maximum loaded power

- \( P_{\text{max}} = M_t \times 2\pi \times n \)
  - \( M_t \) max moment
  - \( n \) speed

- \( P_{\text{idling}} = k \times n^{2.3} \times d^{4.5} \)
  - \( k \) constant
  - \( n \) speed
  - \( d \) diameter
Refining
Power distribution

Refiner load $N_T$

No load power for stock circulation
No load power for water circulation
No load power for empty machine

$\text{Efficiency} = \frac{N_E}{N_T} = \frac{N_E}{N_E + N_H}$
No-load power & maximum loaded power
Amount of refining

\[ t/h = m^3/h \times C \, (\%) \]

\[ SRE \, (kWh/t) = \frac{N_E \, (kW)}{m \, (t/h)} \]

\[ N_E \, (kW) = N_T \, (kW) - N_H \, (kW) \]
Amount of refining

\[ SRE \ (\text{kWh/t}) = \text{IN} \ (\text{km/kg}) \times \text{IE} \ (\text{Ws/m}) \]

The amount of refining is the number of refining impacts multiplied by the energy content of the impacts. It can be calculated also in the conventional manner.
Specific edge load theory

\[ \text{SRE, kWh/t} = \frac{P_{\text{total}} - P_{\text{no-load}}}{\text{Production}} \]

- Introduced by Brecht and Siewert in 1966 through earlier work of Wultsch and Flucher in 1958.

- The amount of refining is described with the specific refining energy, SRE, in net kWh/t.
Specific edge load theory

\[
SEL, \quad J/m = \frac{P_{total} - P_{no\text{-}load}}{CEL \times n}
\]

• The nature of refining is evaluated by the specific edge load, SEL, which describes the intensity of the refining impacts in J/m or Ws/m.

• SEL is the energy applied to fibres from the rotor edge to the stator edge.
Refining intensity

**Specific Edge Load**

\[
SEL \ (J/m) = \frac{N_{E} \ (kW)}{L_{s} \ (km/s)} = \frac{N_{T} \ (kW) - N_{H} \ (kW)}{C_{l} \ (km) \times n \ (r/s)}
\]

SEL is the energy applied to fibers from the rotor edge to the stator edge.
**Amount of refining**

**Energy of refining impacts**

\[
IE \, (\text{Ws/m}) = \frac{N_E \, (\text{kW}) = N_T \, (\text{kW}) - N_H \, (\text{kW})}{L_s \, (\text{km/s}) = C_l \, (\text{km}) \times n \, (\text{r/s})}
\]

This describes the amount of energy the fibers receive in the refiner. This is the same value as the conventional specific edge load value \((Ws/m = J/m)\).
Specific surface load theory

\[
\text{SSL, J/m}^2 = \frac{\text{SEL}}{\text{IL}}
\]

- The nature of refining is evaluated by the specific surface load, SEL, which describes the intensity of the refining impacts in J/m² or Ws/m².

- SSL is the energy applied to fibers from the rotor surface to the stator surface.
Intensity of refining

Specific Surface Load

SSL (J/m²) = \frac{SEL (J/m)}{IL (m)}

SSL is the energy applied to fibers from the rotor surface to the stator surface
Refining intensity

**Specific Surface Load**

\[
IL \ (\text{mm}) = \frac{W_{\text{rotor}} \ (\text{mm}) + W_{\text{stator}} \ (\text{mm})}{2} \times \frac{1}{\cos \frac{\alpha}{2}}
\]
Specific edge load vs. Specific surface load

- The specific surface load theory is valid when the fiber floc cover the whole width of bar surface.
Refining system

- **Batch or Continuous** - the latter is more common. Batch operation is used typically for paper grades that require high refining degree.

- **Separate or Mixed** - both are used. Combination of these can offer benefits from both.

- **Number of stages** depends on requirements - refining degree and fiber properties.
Refining system
Combined system

Broke

SW

HW

To Machine Chest

Blending Chest
Refining system
Energy input / split per stage

- Max. specific surface load at achieved refining degree must be taken into account as shown earlier, e.g. for softwood:

15 SR

130 kWh/t → 120 kWh/t → 100 kWh/t

35 SR
Refiner fillings

Geometry

- Typically metallic stainless steel fillings / segments are used.
  The basic design parameters are width of bars and grooves, height of bars and angle of bars.

- The optimal fillings are selected based on fibers, so that long and strong fibers require wider bars and grooves than shorter fibers.
## Refiner fillings
### Geometry

<table>
<thead>
<tr>
<th>Application</th>
<th>Bar width, mm</th>
<th>Groove width, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardwood</td>
<td>2.0…3.0</td>
<td>3.0…4.0</td>
</tr>
<tr>
<td>Mixed pulp</td>
<td>3.5</td>
<td>4.5</td>
</tr>
<tr>
<td>Softwood</td>
<td>4.0…5.5</td>
<td>5.0…7.0</td>
</tr>
<tr>
<td>Fibrillating</td>
<td>4.0…8.0</td>
<td>3.0…5.0</td>
</tr>
<tr>
<td>Cutting</td>
<td>2.5…4.5</td>
<td>7.0…9.0</td>
</tr>
</tbody>
</table>

In general the bar width is about 2 ~ 3 times of fiber length
Refiner fillings
Intersecting angle

• The bar to bar crossing angle varies from 10° to 40° depending on fibers, long fibers having greater angle.
• Too small angle increases noise level.
• Too big angle increases energy consumption and decreases hydraulic capacity.
Cutting edge length calculation

- CEL = Z_r × Z_st × l

- 12 segments in both rotor and stator
  four 315mm long bar
  two 210mm long bar
  two 105mm long bar

- Cutting edge length
  \[ Z_1 \times 96 \times 96 \times 0.105 = 967.7 \text{m/rev} \]
  \[ Z_2 \times 72 \times 72 \times 0.105 = 544.3 \text{m/rev} \]
  \[ Z_3 \times 48 \times 48 \times 0.105 = 241.9 \text{m/rev} \]
  Total 1753.9m/rev
Amount of refining
Typical specific refining energy

- NBKP 10 ... 15 kWh/t/°SR
- LBKP 7 ... 10 kWh/t/°SR
- Recycled fiber DIP 5 ... 7 kWh/t/°SR
- Recycled fiber OCC 7 ... 10 kWh/t/°SR
- NUKP 15 ... 17 kWh/t/°SR
Refining intensity

Specific Edge Load, typical figures

- Softwood, weak 2.0…4.0 J/m
- Softwood, strong 4.0…6.0 J/m
- Hardwood, weak 0.4…0.8 J/m
- Hardwood, strong 0.8…1.5 J/m
- Recycled fiber, weak 0.4…2.0 J/m
- Recycled fiber, strong 2.0…4.0 J/m
- Post refining of mechanical pulps 0.7…1.5 J/m
- Reject refining in chemical pulp mill 0.5…2.0 J/m
Amount of refining

Typical inputs in one pass

- NBKP: 60 … 200 kWh/t
- LBKP: 40 … 80 kWh/t
- Recycled fiber: 20 … 100 kWh/t
- Post refining of mechanical pulps: 30 … 80 kWh/t
- Trim refining: 20 … 50 kWh/t
Refiners
Sizing – excises

- Production capacity: 100 BDMT/Day; 3.3 Ton/Hr
- Consistency: 4.5%
- Flow rate: 20.5 l/s
- Freeness drop or SR increase degrees: 650 – 350 CSF; 17 – 36 SR
- Raw material: Bleached Eucalyptus
- End products: Coated base paper
- Basis weight: 100 – 180 gsm
- pH: 5 ~ 8
- Temperature: 25 ~ 40 °C
Refiners
Sizing – excises

1) SRE: LBKP 7 … 10 kWh/t/oSR
   SR 36 – 17 = 19 x 8 = 152 kWh/Ton
   2 – 3 stages of refiner needed ( LBKP 40 – 80 kWh/Ton/Stage )
   NE: 152 x 3.3 = 501 kW; 250 kW or 168 kW per refiner

2) SEL: 0.8 - 1.2 J/M

3) Motor speed: 900 rpm = 15 rps, 720 rpm = 12 rps

4) Cutting length selection:
   Case 1: 3 stage refining: 0.8 – 1.2 = 168 / Cl x 15
       Cl = 14.0 – 9.33 kM
   Case 2: 2 stage refining: 0.8 – 1.2 = 250 / Cl x 12
       Cl = 26.04 – 17.36 kM
Refiners
Sizing – excises

5 ) Motor sizing :
   Case 1 : 3 stage refining
   \[ NE = 168 \text{ kW} \; ; \; \text{speed} \; 900 \text{ rpm} \]
   Supplier A : \( NH = 40 \text{ kW} \; ; \; NT = 168 + 40 = 208 \text{ kW} \)
     Motor : 225 kW \; ; \; 900 \text{ rpm} 
   Supplier B : \( NH = 52 \text{ kW} \; ; \; NT = 168 + 52 = 220 \text{ kW} \)
     Motor : 250 kW \; ; \; 900 \text{ rpm} 

   Compared A & B in terms of \( NH \) ;
   \[ 52 \text{ kW} - 40 \text{ kW} = 12 \text{ kW} \times 3 = 36 \text{ kW} \]
   \[ 36 \text{ kW} \times 24 \text{ Hrs/Day} \times 340 \text{ Day/Year} = 293,760 \text{ kW/Year} \]
   in 10 years operation at 2.0 NT$/kWH = \text{NT$ 5,870,000.-}
5 ) Motor sizing:
   Case 2 : 2 stage refining
   \( NE = 250 \text{ kW} ; \text{ speed } 720 \text{ rpm} \)
   Supplier A : \( NH = 90 \text{ kW} ; NT = 250 + 90 = 340 \text{ kW} \)
    Motor : \( 400 \text{ kW} ; 720 \text{ rpm} \)
   Supplier B : \( NH = 115 \text{ kW} ; NT = 250 +115 = 365 \text{ kW} \)
    Motor : \( 400 \text{ kW} ; 720 \text{ rpm} \)

Compared A & B in terms of \( NH \) :
115 kW – 90 kW = 25 kW x 2 = 50 kW
50 kW x 24 Hrs/Day x 340 Day/Year = 408,000 kW/Year
in 10 years operation at 2.0 NT$/kWH = \textbf{NT$ 8,160,000.-}
Refiners
Sizing – excises

6 ) 2 stage or 3 stage comparison :
   No load power :
   2 stage installation has higher no load power than 3 stage about 60 – 74 kW

   Selection of refiner segments :

   Flow rate changes :
The amount of refining
Beating degree / Net refining energy

Short fiber
The amount of refining
Tensile index / Refining energy input

Short fiber
The amount of refining
Tensile index / Beating degree

![Graphs showing the relationship between beating degree and tensile index for different kWh/bdmt values.]

Short fiber
The amount of refining
Tensile index / Tear index

Short fiber
The amount of refining
Tensile index / Fiber length

Short fiber
The amount of refining
Beating degree / Net refining energy

Long fiber
The amount of refining
Beating degree / Net refining energy

Long fiber
The amount of refining
Tensile index / Total refining energy input

![Graph showing the relationship between Tensile Index and Total Refining Energy for Long fiber.](image)
The amount of refining

Tensile index / Total refining energy input

Long fiber
The amount of refining
Tensile index / Fiber length

Long fiber
The amount of refining
Max. Specific Surface Load / Beating degree
No-load power & total power

![Graph showing the relationship between total power and specific edge load. The line graph indicates an increasing trend as the specific edge load increases.]

- **TOTAL POWER**
- **NO LOAD POWER**

**Axes:**
- **Y-axis:** Total Power, KW
- **X-axis:** Specific Edge Load, J/m
## Refining process

<table>
<thead>
<tr>
<th>Consistency</th>
<th>Low consistency refining</th>
<th>Medium consistency refining</th>
<th>High consistency refining</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotor linear speed</td>
<td>15m/s – 25m/s</td>
<td>40m/s – 50m/s</td>
<td>90m/s – 110m/s</td>
</tr>
<tr>
<td>Consistency</td>
<td>2% - 6%</td>
<td>10% - 20%</td>
<td>30% - 35%</td>
</tr>
</tbody>
</table>
Refining result
HC vs LC refining

- Fiber Length
- Elongation
- Tear
- Tensile

Specific Energy Demand [kWh/t]
Refining result
HC vs LC refining

Unrefined After HC-refining 220 kWh/bdmt After LC-refining 110 kWh/bdmt

- Freeness, mL°SR
  - Unrefined: 705/15.7
  - After HC: 700/15.8
  - After LC: 550/21.6

- Bulk, cm³/g
  - Unrefined: 2.23
  - After HC: 1.93
  - After LC: 1.68

- Fiber length, mm
  - Unrefined: 2.30
  - After HC: 2.11
  - After LC: 2.25

- Tensile index, Nm/g
  - Unrefined: 46.0
  - After HC: 44.0
  - After LC: 84.0

- Tear index, mNm²/g
  - Unrefined: 19.3
  - After HC: 18.8
  - After LC: 12.2

- TEA, J/g
  - Unrefined: 0.9
  - After HC: 1.0
  - After LC: 2.0

- Gurley, s
  - Unrefined: 0.3
  - After HC: 0.3
  - After LC: 3.0
HC+LC Refining system

Twin roll press

32 - 35 % pulp

HC-refining stage

To PM

4 % pulp

water

Mixing Chest
4 % pulp

LC-refining stages
Refiners
Sizing - comparison

• Installed power
• Hydraulic flow rate
• No load power
• Control system
Refiners
Gap clearance and stability

\[ \Delta GC = \sin \alpha \times AM \]
\[ ALF = \sin \alpha \times LF \]

\[ \Delta GC = 0.5 \times ALM \]
\[ AFM = 0.5 \times ALM \]
\[ \Delta GC = AFM \]
Refiner

Rotation direction

FLOW

PRESSURE DIFFERENCE OVER THE REFINER

not pumping

pumping
Pumping
Non Pumping
REFINING

1. Targets & principles of refining
2. Introduction to Refining Theories
3. Refining process
Refiners - batchwise operated
Hollander - Beater
Refiners
Geometry

Conical Refiners

- Low cone
- Shallow angle
- “Jordan”

- Short cone
- Shallow angle
- “Conflo”

- Short cone
- Wide angle
- “Claflin”

Disc Refiners

- Single Disc
- Double Disc
- Multidisc
Conical refiner
Disc refiners

- The disc refiner group comprises three types, namely single-disc, double-disc and Multi-disc type refiners
Refining system
Control Strategy
Control of refining

- **Manual control**
  - control with gap clearance

- **Power control**
  - gap clearance controlled according motor power

- **Specific refining energy control**
  - motor power controlled according production

- **Freeness control**
  - refining energy controlled according freeness
  - temperature and couch vacuum i.e. can be used in a same way
Refining control

Power Control vs SEC Control

Specific Energy, kWh/t

Fiber Flow, t/h

Motor Power, kW
Stock preparation & approach system

Process detail

2.1 Slushing / pulper station with auxiliaries
2.2 Screening and cleaning
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2.4 Flotation
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2.6 Refining
2.7 Stock mixing
2.8 Approach system
Stock preparation

- **Broke Handling**
- **Stock Preparation**
- **Approach System**
- **White Water Handling**
Approach flow system

purpose of the system

• Ensure targeted BW and filler profiles
• Dampening of pressure pulsations and consistency variations
• Dilute thick stock to the PM headbox consistency
• Ensure efficient mixing of water, pulp and chemicals
• Feed full production to PM
• Remove undesired impurities
• Remove disturbing air amounts
• To secure runnability i.e productivity
  - various cleaning techniques
• To create uniform feed into headbox both in time and in place
  - jet speed control is done here
Approach flow system

Requirement

• Stability

• Flexibility

• Simplicity

• Reduced costs
Approach flow system

Requirement

Stability

Agility

Both are needed by today’s papermaker
Process simplification

- Smaller process
- Accurate system
- Direct feed to the machine
- Smaller equipment can be utilized
- Lower energy consumption

Conventional approach flow

- Large volumes
- Plenty of recirculation
- Long stabilization time

Modern approach flow

- Smaller process
- Accurate system
- Direct feed to the machine
- Smaller equipment can be utilized
- Lower energy consumption
Approach flow system
Overview
Approach flow system

Typical approach system for modern paper machine
Approach flow system

Typical approach system for modern board machine
### Approach flow system

**Approach system effect on quality**

<table>
<thead>
<tr>
<th>Properties of pulp</th>
<th>Approach System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formation</td>
<td>+++</td>
</tr>
<tr>
<td>Bulk</td>
<td>+++</td>
</tr>
<tr>
<td>Roughness</td>
<td>+++</td>
</tr>
<tr>
<td>Porosity</td>
<td>+++</td>
</tr>
<tr>
<td>Pin holes</td>
<td>+++</td>
</tr>
<tr>
<td>Absorbency</td>
<td>++</td>
</tr>
<tr>
<td>Filler/Fines dist.</td>
<td>++</td>
</tr>
<tr>
<td>Tensile strength</td>
<td>++</td>
</tr>
<tr>
<td>Tear</td>
<td>++</td>
</tr>
<tr>
<td>Internal bond</td>
<td>+++</td>
</tr>
<tr>
<td>Fiber orientation</td>
<td>+</td>
</tr>
<tr>
<td>Curl</td>
<td>++</td>
</tr>
<tr>
<td>Stiffness</td>
<td>++</td>
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<tr>
<td>Brightness</td>
<td>++</td>
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<tr>
<td>Blackening</td>
<td>+</td>
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<tr>
<td>Opacity</td>
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<tr>
<td>Basis weight</td>
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<td>MD</td>
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<td>Moisture</td>
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<td>MD</td>
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<tr>
<td></td>
<td>RE</td>
</tr>
</tbody>
</table>

**Big Influence: +++**

**Moderate Influence: ++**

**Light Influence: +**

**No Influence:** ++
Approach flow system
Proportioning control
Approach flow system
Fast and accurate consistency control

Conventional
Approach flow system
Fast and accurate consistency control

Modern
Approach flow system

Fast and accurate consistency control

**Conventional**

- Difficult tuning
- Sensitive for production changes
- Needs more mixing volume in the chests after
- Control is slow

**Modern**

+ No need for re-tuning
+ Independent from production changes
+ Smaller mixing volumes can be used
+ Stable consistency
+ Fast control
- 1 flow meter more
White water system

• Dilution of stock to PM headbox consistency takes place in short circulation:

• Final cleaning of stock takes also place in short circulation, because:
  - white water might contain sand and other impurities
  - broke might contain tapes and other impurities
  - fiber flocks and slime can be formed in the system.
  - in wire section air is mixed with water.
White water system
Short circulation / Long circulation

• Pulp is fed to PM headbox at 1 % consistency. The consistency after wire section is about 20 %. Thus 95 % of water is removed already in the wire section. This water goes back through the chutes into the wire pit and it is used for thick stock dilution. => Short circulation.

• Excess water from the short circulation is led to the white water chest and is used for dilutions in the stock preparation and broke system. => Long circulation.
Short circulation
General requirements

1. The short circulation should feed the headbox with a flow that is:
   - Free from pressure / flow variations (pulsations)
   - Free from consistency variations
   **To avoid basis weight variations**

2. The approach flow should be as free from air as possible to increase the de-watering speed and reduce bio activity

3. The headbox, wires and product should be protected from debris, spinning and fiber bundles by appropriate machine screening
White water system
Open system

Pulp from stock prep

5 %

Cons. Control water

3 %

Dilution for headbox

1 %

Headbox

Fresh water
- PM showers
- chemicals
- sealing water

Evaporation

White water from wire section

White water from press section

Paper

Fresh water consumption 120...150 m3/t
Fiber loss 20 ... 40 %
White water system

Short circulation

Fresh water consumption 40 ... 80 m3/t
Fiber loss 4 ... 8 %
White water system
Short circulation – water handling
White water system
Short circulation – approach flow
White water system
Long circulation

Fresh water consumption 5 ...15 m3/t
Fiber loss < 1 %
White water system
Long circulation - save all
White water system
Long circulation – stock preparation system