Power Consumption and Fibre Development in a TMP Refiner Plate Gap: Comparison of LE- and Standard Refiner Segments

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Abstract

The aim of this study was to get new information about the power consumption of thermomechanical pulp refining and about the mechanisms of the refining. Power consumption distribution and fibre development in a TMP refiner plate gap was studied using data from mill test trials conducted using the LE segments and the standard segments in a refiner. The effects of these different types of segments on refining were compared.

The power consumption distribution curve was calculated based on mass and energy balances and by using the temperature and consistency profiles of the refiner. Temperature and consistency profiles were determined in connection with the test trials. The calculation was based on the assumption that there is no steam flow over the point of the maximum temperature. The feed consistencies were not known and the calculation was done using the feed consistencies that gave total power consumptions roughly the magnitude of the actual motor powers.

The consistency profile in a refiner plate gap depended on the refiner segments used. When LE segments were used, the consistency steadily increased. With standard segments there was an increase in the consistency curve in the middle part of the plate radius. Because the calculation is sensitive to changes in the consistency profile, the power consumption was calculated by using different monotonously increasing consistency profiles.

The results of the calculations showed that the power consumption distribution in a TMP refiner plate gap depends on the segment geometry used in the refiner. When standard segments were used the power consumption distribution was more or less even. When unidirectional LE segments were used, most of the power was consumed in the outer parts of the refiner. The development of fibre properties occurred mainly in the outer parts of the refiner plate gap. When using LE segments the freeness decreased more rapidly in the outer parts of the refiner plate gap than with standard segments. With the same specific energy consumption LE segments produced pulp with lower freeness.

Introduction

Thermomechanical pulping process is very energy-intensive. In recent decades the process has been empirically developed towards better energy efficiency. There have been several attempts to reduce the energy consumption of TMP refining: pre-treatment of chips or coarse pulp and refiner treatment, high processing pressure and temperature, new segment geometries and optimization of process conditions /1/.

Many of the energy saving refining concepts presented in recent years are based on the reduced residence time of pulp in the disc gap. In the inner part of the refiner there is generally assumed to be an energy intensive area. The fibre residence time has been observed to be highest in the inlet zone of the refiner, but when pulp enters the middle zone it is transported very rapidly through the outer refining zone into the housing /2/. Power consumption has also been shown to be highest in the area in which the residence time of pulp is the highest /3/.

A lower residence time of pulp in the area of high energy consumption can be achieved e.g using low energy segments. Low energy segments are presented in Fig 1. In these types of segments the segment bars form a pumping angle at the inner area in the disc gap /4/. This type of geometry feeds pulp faster into the refining zone, reducing the residence time of pulp at the inlet section of the refiner and thus reducing energy consumption. The effect of the segment geometry on the residence time in the disc gap has been measured with both standard and low energy segments /2/. These measurements showed that LE segments had shorter residence time in the inner zone of the disc gap. That indicates that refining power is mainly consumed in the outer parts of the refiner when LE segments are used. There are not, however, any publications about power consumption distribution in the disc gap of LE segments.

In this study, LE and standard refiner segments were compared. The power consumption distribution and the development of fibre properties in a refiner plate gap were studied in order to get new information about the refining phenomenon.
Calculations

The refiner plate gap was divided into sections according to the sampling points (Fig. 2.). Point 1 is the refiner feed (350 mm), point 6 is the refiner outlet (825 m), and points 2 to 5 are sampling points of 608 mm, 669 mm, 728 mm and 797 mm respectively. The temperatures and consistencies at each sampling points are also presented. Fig. 3. shows the inflows, outflows and flows between phases through the sections.
The calculation is based on the assumption that there is no steam flow over the stagnation point, the point of the maximum temperature. The consistencies in the feed of the refiners are assumed. Steady state conditions are assumed. It is also assumed that the consistencies and temperatures are known at each sampling point. Steam, water and fibres are assumed to have equal temperatures. Mass balance is given as Equations 1, 2 and 3, and energy balance as Equation 4.

\[
\dot{m}_i = \dot{m}_{i+1}
\]

\[
\dot{W}_i = \frac{(100 - c_i)}{c_i} \cdot \dot{m}_i
\]

\[
S_{i+1} = S_i + \dot{F}_{i,i+1}
\]

where

\( \dot{m}_i \) is pulp flow at the point \( i \)

\( \dot{W}_i \) is water flow

\( c_i \) is consistency

\( S_i \) is steam flow

\( \dot{F}_{i,i+1} \) is flow between steam and water phases

\[
P_{i,i+1} = H_{ni(i+1)} \cdot \dot{m}_{i(i+1)} - H_{ni} \cdot \dot{m}_i \\
+ H_{Wi(i+1)} \cdot \dot{W}_{i(i+1)} - H_{Wi} \cdot \dot{W}_i \\
+ H_{Si(i+1)} \cdot \dot{S}_{i(i+1)} - H_{Si} \cdot \dot{S}_i
\]

where

\( P_{i,i+1} \) is power consumption between points \( i \) and \( i+1 \)

\( H_{ni} \) is enthalpy of pulp at the point \( i \)

\( H_{Wi} \) is enthalpy of water at the point \( i \)

\( H_{Si} \) is enthalpy of steam at the point \( i \)

**Experimental**

The data used in this calculation were collected in a test series conducted in 1994 – 1995 at UPM-Kymmene Kaipola mill in Finland. Test runs were initially done in order to improve the controllability of the TMP process, to save energy in the refining process and to improve the quality of pulp and printing papers. The SD-65 type single disc refiner, at the first stage position, was used in the trials: in one test trial standard refiner segments were used whereas in the other trials the LE segments were used. The specific energy consumption in both of these trials was the same: 1.1 MWh/t.

For sampling, the refiner was equipped with perforated front plates and a perforated stator segment. There were five radially-positioned sampling perforations; at radii of 525, 608, 669, 728 and 797 mm. Samples were taken with a special sampler. The refiner is presented in Fig. 4 and the sampling perforations in Fig. 5. Pulp samples were taken from the plate gap at different radii and from the blow line after the first stage refiner. The consistency, freeness, and mass proportion of Bauer McNett fractions were analyzed. There were temperature measurements at the same radii as the sampling perforations. Process data during the test trials were also collected. The wood species was Norway spruce (Picea abies).
When the pulp sample flowed from the high temperature conditions of the plate gap to the outside atmosphere temperature, both pulp and water cooled. The cooling off occurs by the evaporation of water, and the consistency of the sample changes. The determined consistencies of the samples were rectified to correspond with plate gap consistencies using a heat balance (Equation 5).

The circumstances prevailing during sampling are illustrated in Fig. 6. The plate gap contains steam, fibres and water. When a pulp sample is taken from the plate gap temperature to the atmospheric temperature, steam is released, the temperature of the fibres and of the water inside the fibres decreases, and simultaneously some of the water is evaporated. When the temperature of the plate gap and the outside atmosphere are known, a heat balance can be used to estimate the change in consistency during sampling (steam is assumed to be saturated in the plate gap):

\[
(W_e + W)h_{w1} + m h_{m1} = W_e h_{s2} + W h_{w2} + mh_{m2}
\]  

(5)

where
- \(h_s\) is enthalpy of saturated steam
- \(h_m\) is enthalpy of pulp
- \(h_w\) is enthalpy of water
- \(W_e\) is mass of evaporated water
- \(W\) is mass of water in sample
- \(m\) is mass of pulp

The change in consistency is about 6%, depending on the temperature in the sampling point and the measured consistency.

**Results**

The process data collected during test trials is presented in the Table 1. The temperature profile in the plate gap of the LE segments (circle points) and the standard segments (square points) are presented in Fig 7.
<table>
<thead>
<tr>
<th></th>
<th>Standard segments</th>
<th>LE-segments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power [MW]</td>
<td>9.21</td>
<td>9.66</td>
</tr>
<tr>
<td>Production rate [kg/s]</td>
<td>2.31</td>
<td>2.43</td>
</tr>
<tr>
<td>SEC [MWh/t]</td>
<td>1.11</td>
<td>1.11</td>
</tr>
</tbody>
</table>

Fig 7. Temperature profile for SD-65 primary refiner. Standard refiner segments and LE-segments were used.

The measured consistencies in the plate gap and after the refiner are presented in Fig. 8 (standard segments) and Fig. 9 (LE segments). The power consumption distribution was calculated using the measured consistency profile, as well as different monotonously increasing consistency curves (grey areas in Fig 8 and 9) representing maximum and minimum values.

Fig. 8. Consistency profile with standard segments.
The calculation was based on the assumption that there is no steam flow over the stagnation point ($S3 = 0$ in Fig 2). The power consumption in the refiner plate gap was calculated using Equations 1, 2, 3 and 4, the temperature profiles of Fig 7 and the consistency profiles of Fig 8 and 9.

The result was the cumulative power consumption curves presented in Fig 10 and Fig 11 for standard and LE segments respectively. The solid curves correspond to measured consistency curves and gray areas to the gray consistency areas of Fig 8 and 9. The average power consumption curves (dashed lines in Fig. 10 and 11) gave the power consumption distributions presented in Fig 12 and Fig 13 for standard and LE segments respectively. In the case of standard segments the power is mainly consumed in the inner parts of the refiner while in the case of LE segments the power is mainly consumed in the outer parts of the refiner. The total power consumption in these calculations was $\sum P = 8.9$ MW for standard segments and 9.3 MW for LE segments.
Fig. 11. Cumulative power consumption with LE-segments.

Fig. 12. Power consumption distribution with standard segments.

Fig. 13. Power consumption distribution with LE-segments.
Fibre properties

The development of freeness in a plate gap is presented in the Fig. 14. Fibre properties after the first stage refiner are presented in the Table 2.

![Graph showing freeness as a function of the plate radius in a refiner disc gap – standard and LE-segments were used.](image)

Table 2. Some pulp properties after the first stage refiner.

<table>
<thead>
<tr>
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<th>LE-segments</th>
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<tbody>
<tr>
<td>CSF (ml)</td>
<td>505</td>
<td>370</td>
</tr>
<tr>
<td>Fibre length (mm)</td>
<td>1.95</td>
<td>1.65</td>
</tr>
<tr>
<td>BMN +14-fraction (%)</td>
<td>43.0</td>
<td>34.1</td>
</tr>
<tr>
<td>BMN +28-fraction (%)</td>
<td>10.5</td>
<td>11.4</td>
</tr>
<tr>
<td>BMN +100-fraction (%)</td>
<td>23.6</td>
<td>31.1</td>
</tr>
<tr>
<td>BMN +200-fraction (%)</td>
<td>3.0</td>
<td>4.8</td>
</tr>
<tr>
<td>BMN -200-fraction (%)</td>
<td>19.9</td>
<td>18.6</td>
</tr>
</tbody>
</table>

Discussion

The calculation was based on the assumption that there is no steam flow over the stagnation point and the consistency in the feed of the refiner was chosen so that the calculation gives total power consumptions roughly equal to the magnitude of the actual motor powers. The power consumption calculation is strongly dependent on the amount of water in the feed and in the outlet of the refiner because nearly all of the energy in the refiner is consumed in vaporization. The consistencies after the refiners were measured and thus the calculation was done by assuming the consistencies in the feed of the refiners.

The calculation was based on the consistency profiles determined from plate gap samples. As can be seen in Fig 8, the consistency seems to decrease after a radius of 660 for the first stage refiner when standard segments were used. Similar shapes of consistency curves were not observed when LE segments were used in the refiner (Fig 9). This strange shape of the measured consistency profile has been proposed to be due to some systematic error in sampling /1/. The exact
reason for the strange consistency curve is, however, not known. Because of that and because the calculation is very sensitive to the shape of the consistency profile this study was conducted using the measured values of plate gap consistencies and also using the different monotonously increasing consistency profiles.

The results of the calculations showed that power consumption distribution in the refiner plate gap depends on the segment geometry used in the refiner. When using standard segments in a refiner, a greater amount of power is consumed in the inner parts of the refiner compared to LE segments. When LE segments were used, a greater amount of power was consumed in the outer parts of the refiner plate gap while in the most inner parts of the refiner power consumption was minor. Based on the results of fibre development in the refiner plate gap and residence time measurements Härkönen et al. /5/ have concluded that there is a gentle refining zone before the temperature maximum in the refiner plate gap, where inter-fibre refining is the main mechanism. The outer parts of the refining zone are proposed to be an area of harsh refining. With LE segments the power was mainly consumed in the outer parts of the refiner. When comparing the development of freeness in the disc gap (Fig 14) pulp is more evenly developed when standard segments were used compared to the LE segments. In the area of harsh refining there occurs more harsh refining and cutting of fibres. The specific energy consumption was the same in both of the test trials. Fibre properties after the refiner, however, differed a lot (Table 2). Compared to the standard refiner segments, LE segments produce pulp with lower freeness and shorter fibres. The coarse fibre fraction (R14) was smaller, and middle fractions (+28, +100, +200) were higher when LE segments were used in the refiner.

Conclusions

This study shows that the power consumption distribution in a TMP refiner plate gap depends on the segment geometry used in the refiner. When standard segments were used, most of the refining power was consumed in the inner parts of the refiner. When unidirectional LE segments were used, most of the power was consumed in the outer parts of the refiner. With LE segments, refining occurs in the area of harsh refining and LE segments produce pulp with shorter fibres and lower freeness.

Acknowledgement

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References

Power consumption distribution and fibre development in a refiner disc gap: LE- and standard refiner segments

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Content

- The method to calculate power consumption distribution inside a TMP refiner

- Power consumption distribution and fibre development in a refiner disc gap
  - Standard segments
  - LE-segments
The Method

• Power consumption calculation is based on:
  – Mass- and energy balances
  – Consistency and temperature profiles
  – Production rate, motor power

• Assumptions:
  – steam is assumed to be saturated
  – steam, fibres and water is assumed to have equal temperatures
  – Feed consistency
  – no steam flow over the point of maximum temperature
The Method

Rotor Centre Discharge

SECTION 1: C2 C3 C4 C5 C6

T1 T2 T3 T4 T5 T6

Increasing radius

350 608 669 728 797 825 mm
The Method

Fibre mass flow is known

Water mass flow is calculated:

\[ \dot{W}_i = \frac{(100 - C_i)}{C_i} \cdot f_i \]

Steam mass flow from mass balance, no steam flow over the point of maximum Temperature.
Water and steam enthalpies are handbook values, enthalpy of fibres is calculated by the equation (McMillin, C. W. 1969):

\[
H_f = (0.04828 + 0.003976 \cdot T) \cdot T
\]

Motor power = \( \Sigma P_i \) + losses

\[
P_{i - i + 1} = H_{f(i+1)} \cdot f_{i+1} - H_{f_i} \cdot f_i \\
+ H_{W(i+1)} \cdot W_{i+1} - H_{W_i} \cdot W_i \\
+ H_{S(i+1)} \cdot S_{i+1} - H_{S_i} \cdot S_i
\]
The Method

- 96% of actual motor power is assumed to be consumed by heating and vaporization
  - Power consumption is calculated assuming the feed consistencies to the level that give 96% of actual motor power
The Method - summary

- Production rate, consistency profile
- Mass balance
- Temperature profile
- Energy balance
  - Enthalpy of pulp, water and steam

Mass flows

Power consumption distribution
Power consumption distribution and fibre development in a refiner disc gap

Standard and LE-segments

Standard segments

LE-segments
Power consumption distribution

Process data

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Power consumption distribution
Temperature profiles

![Graph showing temperature profiles against radius in millimeters.](image)
Power consumption distribution consistency profiles
Power consumption distribution

**Results**

\[ \sum P_i = 8.9 \text{ MW} \]

\[ \sum P_i = 9.3 \text{ MW} \]
Power consumption distribution

Results

**Standard**

- Power consumption distribution [W/mm²]
- Radius [mm]
- 5.1 MW
- 3.1 MW
- 0.7 MW

**LE**

- Power consumption distribution [W/mm²]
- Radius [mm]
- 2.1 MW
- 2.8 MW
- 4.4 MW
Fibre development in a disc gap
## Fibre development in a disc gap

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Conclusion

• Power consumption distribution depends on the segment geometry used in a refiner
  – With standard refiner segments power was consumed more inner parts of the refiner while with LE-segments power was mainly consumed in the outer parts of the refiner

• Development of fibres depends segment geometry used
  – LE-segments produced pulp with shorter fibres and lower freeness compared to the standard refiner segments
Conclusion

- Standard segments
  Power is consumed in the inner parts of the refiner and pulp developed more evenly compared to LE-segments.
  ⇒ gentle refining

- LE -segments
  Power is mainly consumed in the outer parts of the refiner and freeness decrease rapidly there
  ⇒ harsh refining

- Method to calculate power consumption distribution inside the TMP refiner give a new systematic tool to develop new energy saving refiner segments

Acknowledgement