Power consumption distribution in a TMP refiner: comparison of the first and second stages

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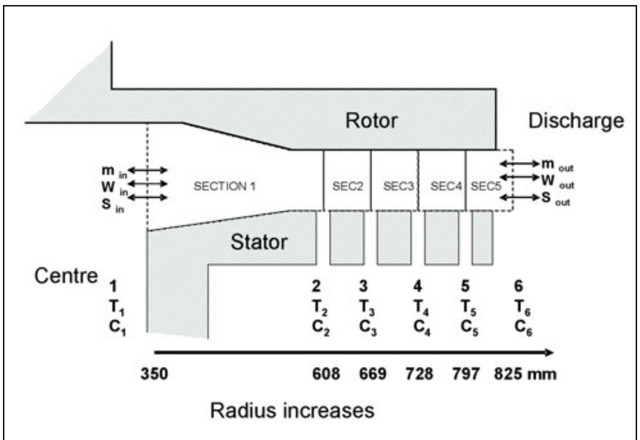
ABSTRACT: Wood chips are broken rapidly into coarse pulp in the breaking zone in the feed of a first stage TMP refiner. In a second stage refiner the breaking zone is removed, because the feed is coarse pulp discharged from the first stage refiner. We studied the power consumption in a second stage refiner and calculated the power consumption distribution for the first and second stages. The results show that the power consumption in a second stage refiner increases along the radius, while in a first-stage refiner, the distribution is more even. The innermost part of the second stage refiner seemed to work with a very low energy consumption, compared with the outer parts.

Application: Results of the study can be used to develop new energy-saving refiner segments for the first and second stage refiners.

A thermomechanical pulp (TMP) main line consists, in general, of two disc refiners in series. The first stage refiner has a chip breaking zone in its innermost part, where the wood chips are immediately broken into coarse pulp [1]. After the breaking bar zone pulp properties start to develop in the inner area of the narrower disc gap, this continues in the second stage refiner. The shive content and the proportion of the long fiber fraction decrease in the disc gap of the first stage refiner, while the fines content increases rapidly [2]. In the second stage refiner these pulp properties develop more gradually [2]. The coarse pulp discharged from the first stage refiner is fed to the second stage refiner, the purpose of which is to produce pulp with the desired properties using as small an amount of energy as possible. The innermost part of the second stage refiner differs significantly from that of the first stage refiner, because there is no chip breaking zone.



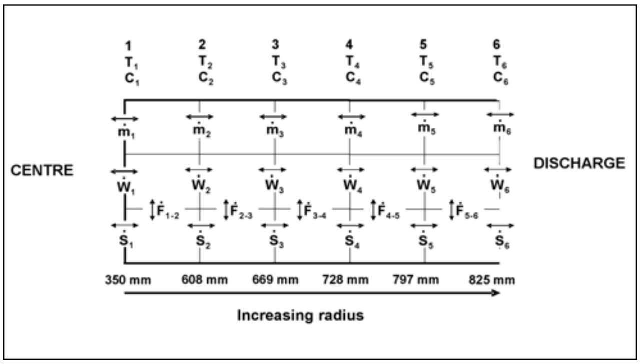
1. Division of the refiner disc gap into sections.

In earlier studies we presented a method for calculating the power consumption distribution in a refiner disc gap and in a first stage SD-65 TMP refiner [3]. We now use this method to calculate the power consumption distribution in a first and second stage TMP refiner, to compare the two and obtain new information on the refining phenomena and energy consumption in the refiner. Mill trials were performed to ascertain the consistency profiles in the refiner disc gaps.

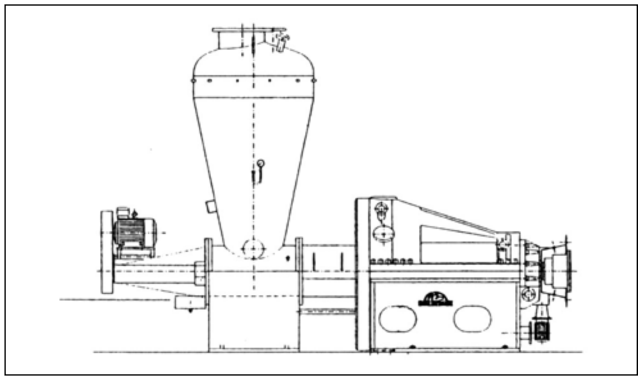
CALCULATIONS

The refiner disc gap was divided into sections according to the sampling points (**Fig. 1**). Point 1 is the feed (350 mm), point 6 is the outlet (825 mm), and points 2 to 5 are sampling points at distances of 608 mm, 669 mm, 728 mm, and 797 mm respectively. The temperatures and consistencies at all the sampling points are also presented. **Figure 2** shows the inflows, outflows, and flows between the phases through the sections.

The starting point for our earlier calculations was the feed into the refiner. As the blow back steam in the second stage refiner is not known, this calculation was based on the assumption that there is no steam flow over the stagnation point, the point of maximum temperature. Steady state conditions and the consistencies of the feed into the refiners were assumed, and it was also assumed that the consistencies and temperatures at each sampling point were known. The steam, water and fibers are assumed to be at equal tem-



2. Pulp, water, and steam flows through the sections.



3. Refiner.

peratures. The mass balance is given in Equations 1, 2, and 3, and the energy balance in Eq. 4.

$$\dot{m}_i = \dot{m}_{i-1} \tag{1}$$

$$\dot{W}_i = \frac{(100 - C_i)}{C_i} \cdot \dot{m}_i \tag{2}$$

$$\dot{S}_{i+1} = \dot{S}_i + \dot{F}_{i-i+1} \tag{3}$$

where $\dot{m}_i$ is pulp flow at the point i

$\dot{W}_i$ is water flow

c_i is consistency

$\dot{S}_i$ is steam flow

$\dot{F}_{i-i+1}$ is the flow between the steam and water phases

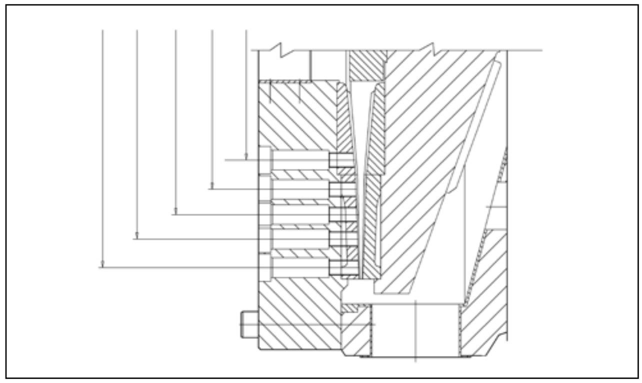
$$\begin{aligned} P_{i-i+1} = {} & H_{\dot{m}(i+1)} \cdot \dot{m}_{(i+1)} - H_{\dot{m}i} \cdot \dot{m}_i \\ & + H_{\dot{W}(i+1)} \cdot \dot{W}_{(i+1)} - H_{\dot{W}i} \cdot \dot{W}_i \\ & + H_{\dot{S}(i+1)} \cdot \dot{S}_{(i+1)} - H_{\dot{S}i} \cdot \dot{S}_i \end{aligned} \tag{4}$$

where P_{i-i+1} is power consumption between points I and i+1

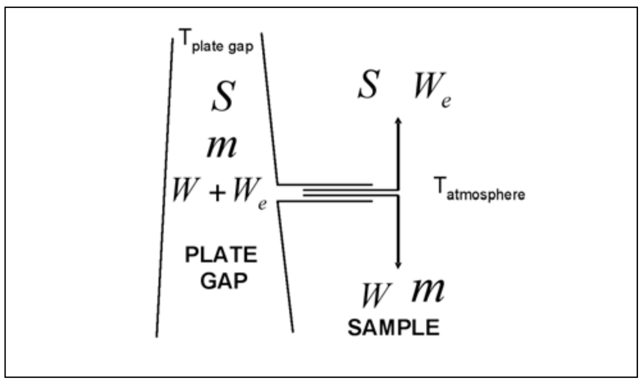
$H_{\dot{m}i}$ is the enthalpy of the pulp at point i

$H_{\dot{W}i}$ is the enthalpy of the water at point i

$H_{\dot{S}i}$ is the enthalpy of the steam at point i



4. Sampling perforations.



5. Sampling.

EXPERIMENTAL

Test runs were carried out at the Kajaani mill of UPM-Kymmene. The SD-65 type single disc refiners in the first and second stage positions were used in these test runs, and samples were taken during normal production under the standard operational conditions. The wood species was Norway spruce (*Picea abies*), and the refiner was equipped with perforated front plates and a perforated stator segment for sampling. There were five radially positioned sampling perforations, at radii of 525, 608, 669, 728, and 797 mm. The refiner is illustrated in **Fig. 3** and the sampling perforations in **Fig. 4**. To determine the consistencies in the disc gap, five corresponding samples were taken under normal operating conditions through perforations at radial positions of 608, 669, 728, and 797 mm and from the blow pipe.

The samples from the disc gap were taken with a special sampler in which the pulp was carried through a steam separator cyclone to an air-sealed bucket in which its consistency was determined.

When the pulp sample flowed from the high temperature conditions of the disc gap to the outside atmospheric temperature, the pulp and the water were cooled. Since this cooling off occurred through the evaporation of water, the consistency of the sample changed. The consistencies determined for the samples were therefore rectified to correspond to disc gap consistencies using a heat balance (Eq. 5).

Figure 5 illustrates the circumstances prevailing during sampling. The disc gap contained steam, fibers, and water. Whenever a pulp sample was taken from the disc gap temperature to the atmospheric temperature, steam was released. The temperature of the fibers and the water inside the fibers decreased as some of the water evaporated. When the temperature of the disc gap and the outside atmosphere are known, the heat balance can be used to estimate the change in consistency during sampling (steam is assumed to be saturated in the disc gap):

$$(W_e + W)h_{wl} + m\,h_{m1} = W_e h_{S2} + Wh_{W2} + mh_{m2} \quad (5)$$

where

h_s is the enthalpy of the saturated steam

h_m is the enthalpy of the pulp

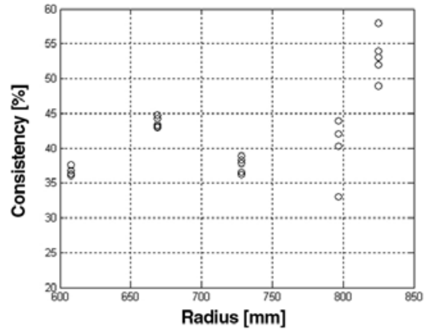
h_w is the enthalpy of the water

W_e is the mass of the water evaporated

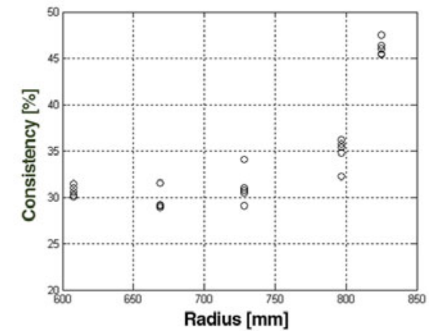
W is the mass of the water in the sample

m is the mass of the pulp

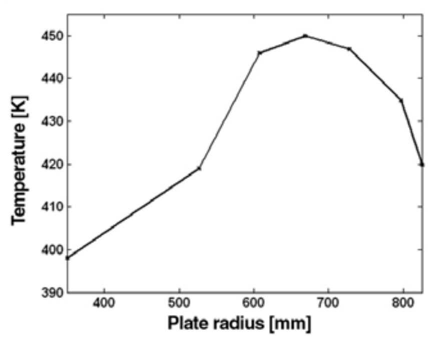
The change in consistency is approximately 6%, depending on the temperature at the sampling point and the measured consistency. Consistencies in the disc gap and after the refiner are presented in **Figs. 6** and **7**. Samples were taken from different radial positions one by one. The sampling procedure for the refiner was repeated five times to obtain a full understanding of refiner consistencies and to eliminate the effect of process variations.



6. Consistencies in the disc gap. First stage refiner.



7. Consistencies in the disc gap and after the refiner. Second stage refiner.

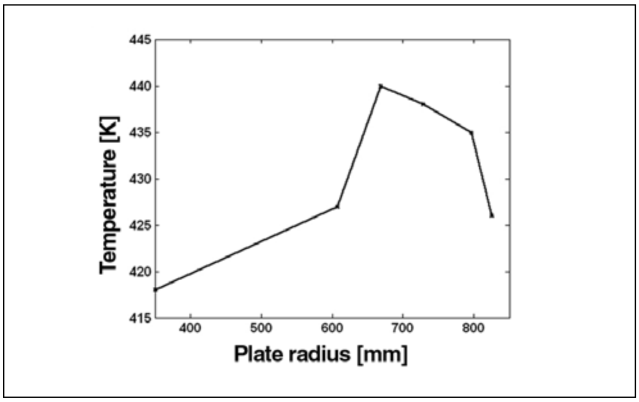


8. Temperature profile of the SD-65 first stage refiner [4].

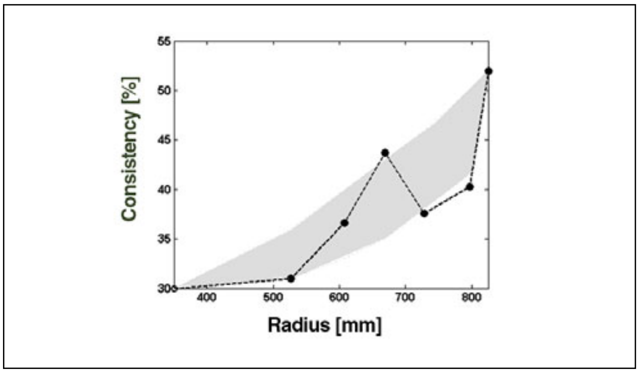
RESULTS

The calculation is based on the assumption that there is no steam flow over the stagnation point (S3 = 0 in Fig. 2). The temperature profiles used in the calculations were the common ones mentioned in the literature [4] and are presented in **Figs. 8** and **9**. The temperature profile has no significant effect on the power consumption distribution curve, so that a 10% change in the maximum temperature, for example, causes the total power consumption to change by less than 1% [3]. A production rate of 3.01 kg/s was used and motor powers of 10.5 and 6.3 MW for the first and second stage refiners, respectively.

Figure 10 (first refiner) and **Fig. 11** (second refiner) present consistencies used in the calculation; the circles represent measured values. The feed consistencies are not known, and the calculation was performed using feed consistencies that give total power consumptions of roughly the magnitude of the actual motor powers. The total power consumption calculation is closely dependent on the amount of water in the feed and in the outlet from the refiner, because, by far, the majority of the energy in the refiner disc gap is consumed in vaporization. The consistencies after the refin-



9. Temperature profile of the SD-65 second stage refiner [4].



10. Consistencies in the first stage refiner disc gap. Circles represent measured values.

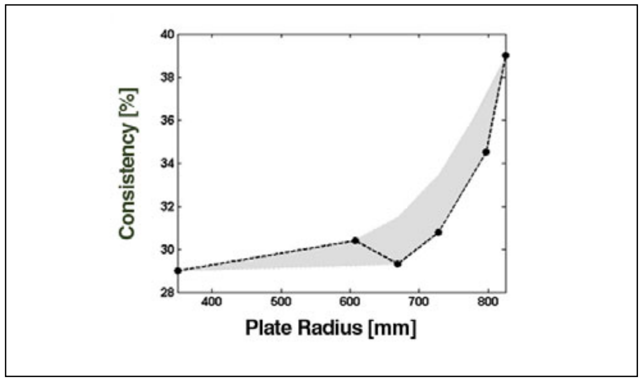
ers were measured, and thus the calculation was performed by assuming feed consistencies (30% for the first stage refiner and 29% for the second stage refiner). The power consumption distribution was calculated using different monotonously increasing consistency curves to cover all the measured values, using grey areas in Figs. 10 and 11. The measured consistency profiles were also used in the calculations (dashed lines).

The enthalpy of the fibers is calculated using an enthalpy equation determined for wood [4] (Eq. 6) and those of water and saturated steam are handbook values [5].

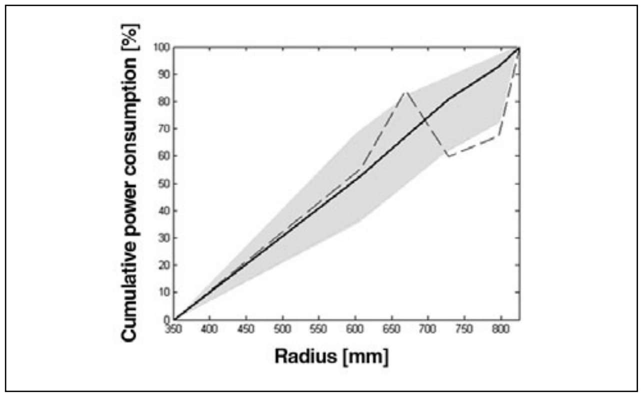
$$H_m = (0.04828 + 0.003976 \cdot T) \cdot T \qquad (6)$$

where T is temperature.

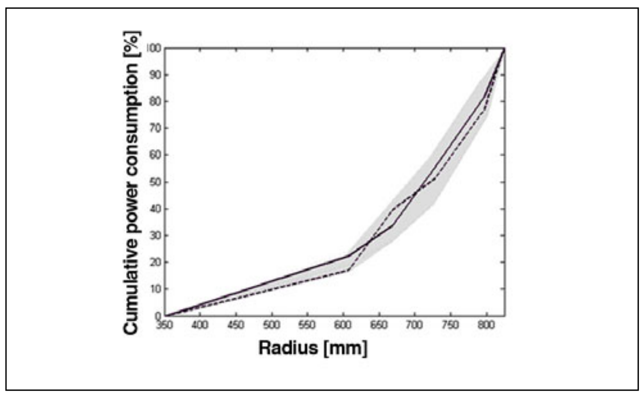
The power consumption distributions are calculated using Eqs. 1, 2, 3, and 4, together with the consistency curves presented in Fig. 10 for the first stage refiner and in Fig. 11 for the second stage refiner. The result is the cumulative power consumptions as functions of plate radius presented in **Figs. 12** and **13**, where the dashed lines were then cal-



11. Consistencies in the second stage refiner disc gap. Circles represent measured values.

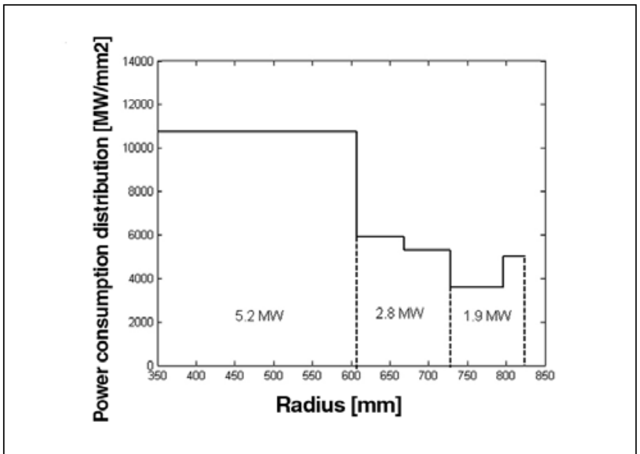


12. Cumulative power consumption in the disc gap of the first stage refiner.

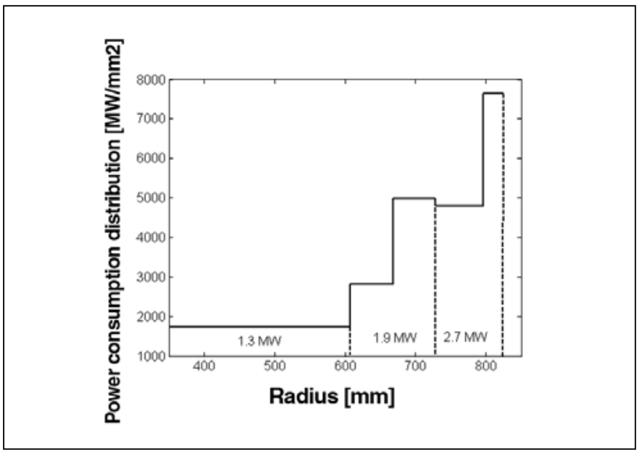


13. Cumulative power consumption in the disc gap of the second stage refiner.

culated using the measured consistency profile. The power consumption distributions, which were calculated using the average cumulative power consumptions (solid curves in Figs. 12 and 13), are presented in **Figs. 14** and **15**. The total power consumptions, $\sum P_i$= 9.9 MW for the first stage refiner and 5.9 MW for the second stage refiner, were obtained.



14. Power consumption distribution in the first stage refiner as a function of the plate radius.



15. Power consumption distribution in the second stage refiner as a function of the plate radius.

DISCUSSION

The calculations were based on the consistency profiles determined from the disc gap samples. As can be seen in Figs. 10 and 11, the consistency seems to decrease after a radius of 600 mm for the second stage refiner and 660 mm for the first stage refiner. It is proposed that the strange shape of the measured consistency profile may be due to some form of systematic error in sampling [1], but it could also be that the dilution water was not totally mixed with the pulp in the inner parts of the refiner and the samples taken from the stator side thus gave a higher consistency for the pulp than was the case in reality. The decrease in consistency was certainly much higher in the first stage refiner than in the second stage, and the dilution water could probably mix with the coarse pulp in the feed of the second stage refiner more easily than with the chips in the feed of the first stage refiner. As there are still some uncertainties regarding the real consistency profile of refiner disc gap, and as the calculation is very sensitive to the shape of the consistency profile, this study was carried out using measured values for the disc gap consistencies (dashed lines) and also using different monotonously increasing consistency profiles.

The feed consistencies were chosen so that the calculation gave roughly the magnitude of the total motor power, based on the assumption that the dry content of chips in the feed of the first stage refiner was 30% and the pulp consistency in the feed of the second stage refiner was 29%. We can justify this method for estimating the feed consistency when we calculate the power consumption distribution. The accurate values of the water flows in the feed of the refiners were not known, because they depended on so many factors that are difficult to measure. The feed consistency in the first stage refiner depends on the moisture content of the chips, conditions in the pre-heater, the dilution water flows and the amount of flow-back steam, while that in the second stage refiner is determined by the consistency of the pulp after the first stage refiner, the dilution water flows to the steam separator system and to the feed of the refiner, and the conditions in the steam separator cyclone. The amount of water in the feed of the refiner strongly affects power consumption distribution curve and especially total power consumption. However, it is not necessary to know the exact amount of water in the refiner feed to obtain new information on the power consumption distribution in the refiner, because the feed consistency can be assumed to a level where calculation gives roughly the magnitude of the actual motor power. Of course, it has to be assumed that refining power is mainly consumed by vaporization and heating of fibers and water, while power needed to produce new fiber surfaces as well as the idling power of the refiner is very small.

The calculations were also based on the assumptions that the steam flow over the maximum temperature is zero, the steam is saturated and that water, fibers, and steam are at equal temperatures. There are no publications dealing with the temperatures of pulp and water in refining as compared with steam, but as most of the refining power is used for the evaporation of water, the slight differences in pulp and water temperatures are not very significant for the end result.

The results showed that the power consumption distribution curve is of different shapes in the disc gap of the first and second stage refiners in the case of the measured consistency profile and all the theoretical ones. The power consumption distribution seems to be almost even in the disc gap of the first stage refiner, while that in the second stage refiner seems to increase exponentially along the radius. The power consumption is minor in the innermost part of the second stage refiner compared with the outer parts of the refiner disc gap and compared with the inner parts of the first stage refiner.

CONCLUSIONS

The power consumption distribution differs between the first and second stage refiners. The power is consumed quite evenly in the first stage refiner compared with the second stage, where it increases along the radius, being minor in the innermost part compared with the outer parts.

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INSIGHTS FROM THE AUTHORS

High electrical energy consumption of TMP process has turned out to be a serious problem. Continuously rising electricity costs impair the profitability of papermaking. To decrease energy consumption in TMP process, mechanisms in refiner gap should be understood. This work is part of our study on mechanisms of TMP refining.

We have calculated power consumption distribution of a first stage refiner (Paper and Timber 2006) and also compared segment types in the first stage (IMPC 2007). The work presented here is the natural continuum of our work.

Phenomena inside the plate gap are very challenging to study due to harsh conditions inside the refiner. Our approach was to measure consistency profile by the disc gap samples. Stator segments and the front plate of a single disc refiner were perforated, and sampling was carried out during normal operational conditions of the mill. Consistency profile in the disc gap was then measured and power consumption calculation was carried out based on the measured profile.

The interesting finding was that power consumption in the second stage refiner was unevenly distributed. The inner parts of the refiner do not work very effectively.

The information in this study reveals that new types of energy saving refiner segments should be developed for second stage refiners.

To fully understand the TMP process, we need to precisely understand which mechanisms dominate in different parts of a refiner. It is important that energy is used to develop fibers, not only to heat pulp, which is likely the case in standard TMP refiners.

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