The effect of rotor position on pulp properties in a two-zoned low consistency refiner

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KEYWORDS: Low consistency refining, Gap, Mechanical pulping, Control strategy, Rotor position.

SUMMARY: Earlier studies have shown that plate gaps are sometimes unequal in two-zoned low consistency refiners and that unequal gaps render unevenly refined pulp. It is also known that optimisation of plate gap in low consistency refining leads to improved energy efficiency. In this work, trials were made in mill scale in a modern TMP line equipped with a prototype 72 inch TwinFlo low consistency refiner in second stage. The study was designed to investigate the development of pulp properties from different rotor positions by means of altering the outlet flow rate ratio. The specific energy consumption was calculated for each refining zone and setting, based on flow rate and temperature increase. In order to produce homogenous pulp, it was found that uneven plate gaps need to be compensated in low consistency refiners with dual refining zones. Results from the different flow rate adjustments indicated that the control setting with similar plate gap gave the most homogenous pulp. However, further studies are needed to find an adequate rotor control strategy. The temperature increase in each refining zone seems to correlate well with the applied specific energy consumption in each refining zone.

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Low consistency (LC) refining demands less electrical energy per ton produced pulp than traditional high consistency (HC) refining compared at certain strength properties. Depending on how and where in the process LC refiners are utilized, studies have shown 20-50% lower specific energy consumption (SEC) compared at certain tensile strength (Engstrand et al. 1990; Hammar et al. 1997; Welch 1999; Eriksen, Hammar 2007; Sandberg et al. 2009; Andersson et al. 2012). LC refining of mechanical pulp is normally applied in three different positions; main line second or third stage, reject second stage or post refining stage. Pulp consistency is typically between 4 and 5%. Besides lowering the SEC, adding LC refining also enables higher production rates, increased tensile index and decreased shive content in the pulp (Musselman et al. 1996; Cannell 2002).

Optimising plate gap in LC refining contributes to improved energy efficiency. A too small gap will lead to fibre cutting and a too large gap will not impose enough force on the fibres to achieve desired fibre treatment (Martinez, Kerekes 1994; Mohlin 2006; Luukkonen et al. 2010).

There are two major categories of LC refiners; conical and disc refiners. The disc refiners are often constructed with two refining zones. It has been documented that the rotor in two-zoned LC refiners sometimes diverts from its assumed centred position and that an asymmetric rotor position leads to unequally refined pulp from each refining zone (Eriksen, Hammar 2007; Andersson, Sandberg 2011). An example of a two-zoned LC refiner is shown in *Fig 1*. The image illustrates a prototype 72 inch TwinFlo (TF72), constructed with a two-sided rotor in between two stators. The stator disc on the motor end (ME) is fixed while the adjustment end (AE) stator is moveable to allow regulation of the refining energy. The rotor shaft is rotating on floating bearings to enable the rotor to stay centred when the AE stator is adjusted in either direction. Conventional TwinFlo refiners have a single inlet where pulp is distributed between the refining zones through the rotor hub. The TF72 has dual inlets and dual outlets and the pulp is directly fed into each refining zone. The two refining zones are separated by a mechanical seal between rotor periphery and housing. The separation allows different pressure and minimal mixing of pulp between the refining zones.

An uneven rotor position can be compensated for by altering the flow rate ratio between the two refining zones (Musselman 1995). Reducing the valve opening in one outlet will lead to a pressure increase in the corresponding refining zone and a decrease in flow rate. The pressure increase will move the rotor towards the opposite side (Andersson, Sandberg 2011). It should be emphasised though, that this method only works for refiners equipped with controllable dual outlets.

It has been noticed that the rotor is moving in a non-ideal way during continuous operation as the load in the refiner is altered. *Fig 2* illustrates how plate gaps in AE

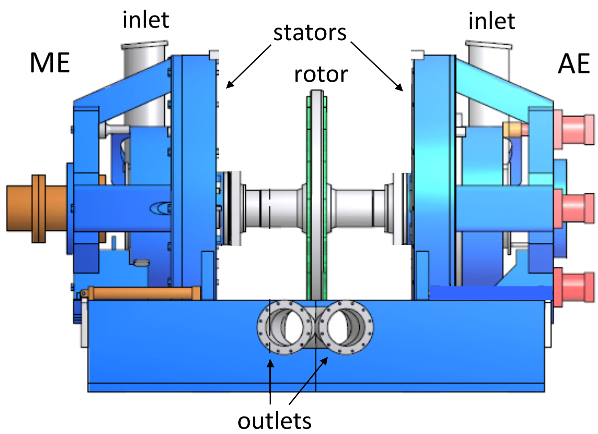

Fig 1. Image of the TF72 with dual inlets and outlets and with a two-sided rotor and two stators. ME denotes 'Motor End' and AE denotes 'Adjustment End'.

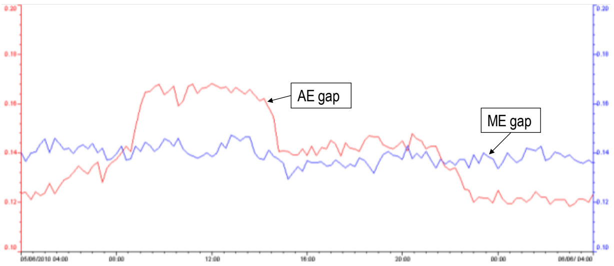

Fig 2. Plate gaps over a 24 hours period. The AE gap varied with load adjustments while ME gap stayed approximately at the same level.

and ME varied over a 24 hours period as an effect of load adjustments. In the given example, the AE gap changed over time with changing refiner load while the ME gap stayed rather constant. It is obvious by reading from the diagram that the rotor was not centred when the refiner load was adjusted. The rotor tended to stay at a constant distance from the ME stator. The reason for this is currently unknown.

Two strategies to compensate for uneven refining were recently investigated, where equal gaps and similar Canadian Standard Freeness (CSF) respectively were used as control parameters (Andersson, Sandberg 2011). Results showed that gap seemed to be a better control parameter than CSF to attain homogenous pulp (in this case regarding fibre length and shive content). CSF was not optimal as an indicator since values were only obtained online once every 15 min, whereas gap widths were displayed continuously in the refiner control system. Earlier not published mill trials have pointed towards equal outlet pulp temperature being a good indicator of similar CSF in the two refining zones. Since gap and temperature are monitored continually, they are therefore interesting to compare as control parameters. In this work, the aims were firstly to study the effect of different flow rate ratios on rotor position and pulp properties in a TwinFlo refiner, and secondly to determine if the temperature increase in each refining zone can be used to predict the refining action.

Materials and Methods

Trials were performed in mill scale at Holmen Paper Braviken paper mill outside Norrköping, Sweden. The TMP line used for the study operates with two parallel first stage refiners (RGP68DD) and a second stage 72 inch TwinFlo (TF72) prototype LC refiner. The TF72 is powered with a 5 MW motor. Refining power was constant 2.9 MW and total flow rate through the refiner was continuously 220 l/s. Recirculation was controlled by required production rate and kept relatively stable at around 95 l/s all through the trial. Inlet CSF was 120 ± 10 ml and pulp consistency 4.2%. Rotating speed was 320 rpm and LemaxX Spiral segments were fitted with bar edge length (BEL) 414.3 km/rev, giving no-load 0.8 MW (no-load was measured with stock in the refiner). The LemaxX Spiral segments are designed as a logarithmic spiral that gives constant bar crossing angle along the entire plate radius, *Fig 3*.

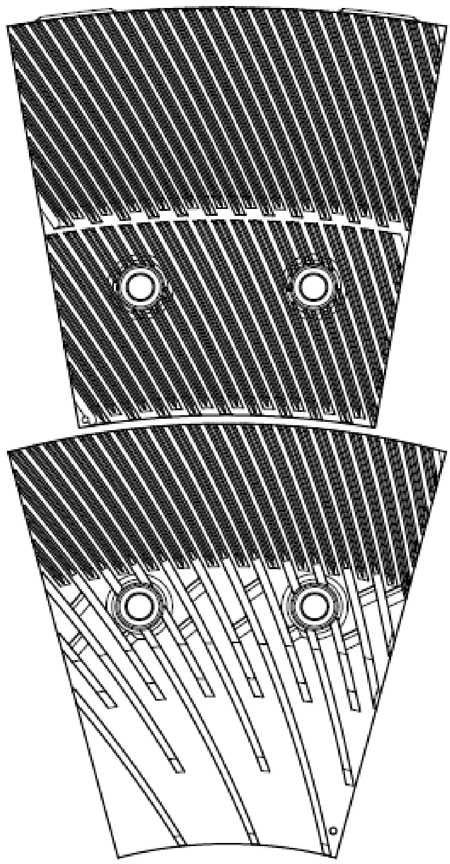

Fig 3. LemaxX segments.

The TF72 is designed with dual inlets and outlets, with the inlet piping splitting closely before the refiner, *Fig 4*. Inlet pipe (before splitting) and both outlet pipes are equipped with an online pulp analyser (KajaaniMAP) as well as flow meters, pressure and temperature gauges (Pt100). Gap sensors (AGS), providing individual gap measurements online, are installed on each stator side. Flow rates, temperatures, pressures and gaps were monitored continually while the online pulp analyser provided measurements every 15 min.

Fig 4 shows a schematic drawing of sample points and outlet valves positions on the TF72. The inlet manual pulp sample point is located on the pipe between feeding chest and recirculation while the online inlet sample point is placed on inlet pipe after recirculation. Manual and online sample points are located adjacent to each other on each refiner outlet pipe. Manual pulp sample points are marked with **M** and online pulp analyser sample points are marked with **O**.

The study was designed to investigate differences in pulp properties by running the TF72 with four different rotor positions by means of altering the outlet flow rate settings. The rotor position was shifted by varying the pulp outlet valve openings and thereby changing the pressure difference between refining zones. The pulp flow rate ratios were set at (AE/ME percentage) 50/50, 45/55, 35/65 and 65/35, each setting pushing the rotor to a different position. The first three ratios were aimed at controlling the refiner according to equal flow rates, equal gaps and equal outlet pulp temperatures.

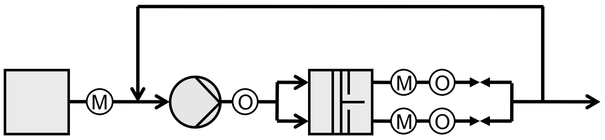

Fig 4. Schematic drawing of sample points and outlet valves positions on the TF72. Manual sample points are marked with 'M' and positions for online pulp sampling and temperature measurements are marked with 'O'.

Table 1. The four flow rate settings used in the study.

Setting	Ratio (AE/ME)	Flow rate AE (l/s)	Flow rate ME (l/s)
Flow	50/50	110	110
Gap	45/55	100	120
Temp	35/65	77	143
Extreme	65/35	143	77

The goal with the 65/35 ratio was to produce the least homogenous pulp of the four settings, as an extreme condition for the study. Pulp flow rates for each setting are shown in *Table 1*.

Pulp testing

Manual and online pulp samples were collected from refiner inlet and outlets. One compound manual sample and four to five online samples were collected from each position at every setting. Each manual sample was tested with triple analysis at the mill laboratory. The samples were prepared using hot disintegration (ISO 5263-3) and tested for consistency (ISO 4119) and CSF (ISO 5267-2). The online pulp analyser gave continuous measurements of fibre length and shive content.

Calculations

CSF values were calculated with averages from manual pulp sample analyses while changes in fibre length and shive content were calculated from online measurements.

A simplified energy balance over the refiner is shown in *Eq 1*.

$$E_{Ki} + E_{Hi} + E_{Pi} + E_{Ti} + P = E_{Ko} + E_{Ho} + E_{Po} + E_{To} + L \quad [1]$$

where

E = the energy per unit time (power),

P = the applied mechanical energy per unit time,

L = the sum of energy losses to the surrounding.

Indices *K, H, P* and *T* denote forms of energy; kinetic, potential, pressure, and thermal. Suffixes *i* and *o* indicate in and out of the refiner respectively.

If we assume that all applied electrical energy is transformed to heat, and that changes in kinetic, potential and pressure energy is negligible, as well as heat losses to the surrounding, the energy balance reduces to, *Eq 2*:

$$E_{Ti} + P = E_{To} \quad [2]$$

The thermal energy is calculated as *Eq 3*.

$$E_T = F \cdot C_p \cdot T \quad [3]$$

where

F = pulp mass flow rate (kg/s),

C_p = specific heat capacity of the pulp (J/gK),

T = pulp temperature (K).

Specific heat capacity of the pulp is assumed equal to that of water *i.e.* 4.19 J/gK. The influence of the lower heat capacity of wood fibres is negligible in this context.

The refining power (kW) can thus be expressed as *Eq 4*.

$$P = F \cdot C_p \cdot \Delta T \quad [4]$$

where

ΔT = temperature increase over the refiner (K).

In an analogous way, the refining power on each side of the rotor can be calculated as *Eq 5*.

$$P_x = F_x \cdot C_p \cdot \Delta T_x \quad [5]$$

where

x denotes AE or ME.

Net production $\dot{m}$ (adt/h) is calculated as, *Eq 6*.

$$\dot{m} = \frac{C_f \cdot F_{net} \cdot 3.6}{1000 \cdot 0.9} \quad [6]$$

where

C_f = pulp consistency (g/kg),

F_{net} = net pulp flow rate (kg/s), which is recirculation subtracted from gross flow rate through the refiner.

Production rate (adt/h) locally for each refining zone, $\dot{m}_x$ is given by *Eq 7*.

$$\dot{m}_x = \frac{C_f \cdot F_x \cdot 3.6}{1000 \cdot 0.9} \quad [7]$$

Total SEC (kWh/adt) is defined as *Eq 8*.

$$SEC_{total} = \frac{P_{gross}}{\dot{m}} \quad [8]$$

where

P_{gross} = total refiner (motor) power including no-load (kW).

The SEC for each refining zone is given by *Eq 9*.

$$SEC_x = \frac{P_x}{\dot{m}_x} \quad [9]$$

Replacing P_x and $\dot{m}_x$ in *Eq 10* gives

$$SEC_x = \frac{F_x \cdot C_p \cdot \Delta T_x \cdot 1000 \cdot 0.9}{C_f \cdot F_x \cdot 3.6} \quad [10]$$

which when simplified becomes *Eq 11*.

$$SEC_x = \frac{C_p \cdot \Delta T_x \cdot 250}{C_f} \quad [11]$$

Eq 11 gives that, at constant pulp consistency, SEC in each refining zone becomes a function of temperature increase only.

Table 2. Average numbers of gap, temperature increase, SEC, SEL and outlet pressure.

Setting	Gap (mm)		Δ Temp. (˚C)		SEC (kWh/adt)		SEL (J/m)		Pressure (bar)	
	AE	ME	AE	ME	AE	ME	AE	ME	AE	ME
Flow	0.12	0.27	3.5	2.8	87	70	1.06	0.84	3.22	3.07
Gap	0.19	0.19	3.3	3.1	82	77	0.89	1.01	3.70	3.53
Temp	0.30	0.08	3.0	3.1	75	77	0.65	1.25	3.53	3.19
Extreme	0.07	0.29	3.5	2.6	87	65	1.36	0.54	3.18	3.28

Specific edge load (SEL) is a common way of quantifying refining intensity and takes into account net power, BEL and rotational speed (Sundholm 1999). SEL tells the net energy applied to each meter of bar crossing (J/m) and is calculated by *Eq 12*.

$$SEL = \frac{(P_{gross} - P_{idle})}{n \cdot BEL} \quad [12]$$

where

P_{idle} = no-load power (kW),

n = rotation speed (rpm),

BEL = bar edge length (km/rev).

Specific edge load per refining zone is given by *Eq 13*.

$$SEL_x = \frac{(P_x - P_{idle}/2)}{n \cdot BEL/2} \quad [13]$$

Results and Discussion

With similar flow rates from both outlets (ratio 50/50), the rotor position was diverted towards AE and rather large differences in gap and outlet pulp temperature were obtained. At 45/55 flow rate ratio, the rotor was pushed towards ME into a centred position (equal gaps). At ratio 35/65, the rotor moved further in the ME direction, giving a large difference in gap but similar temperature. When the setting was altered to the extreme condition (ratio 65/35), the rotor moved back against AE and a larger difference in temperature was attained compared with earlier settings.

Since the rotor was diverting towards AE, the temperature increase was higher in AE for all flow rate ratios, except in the temperature setting where temperature increase became rather similar on both sides. Average temperature increases and calculated averages in SEC, SEL and pressure for each flow rate ratio are shown in *Table 2*. Calculated total average SEC and SEL were 138 kWh/adt and 0.95 J/m respectively throughout the trial.

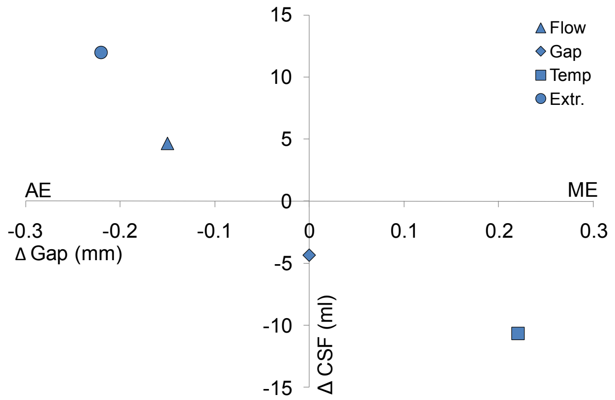

Fig 5. Differences in average outlet pulp CSF for each setting plotted against differences in average gap.

For each setting, changes in CSF, fibre length and shive content are presented in *Table 3*. It should be noted that statistical calculations showed a non significant difference in outlet CSF between AE and ME in the 'Flow' setting. With equal plate gaps, the lowest CSF reduction was obtained, fibre length was well preserved and shive reduction reached high and equal values. Similar results were obtained in an earlier study (Engstrand et al. 1995) when equal split was compared with unequal split in a Sprout-Waldron Twin 60 HC refiner, built on the same principle as the TF72. Apparently, equal gaps are beneficial in both HC and LC refining.

Differences in outlet CSF (AE – ME) in relation to differences in gap (AE – ME) for each setting are illustrated in *Fig 5*. Equal flow rates gave fairly similar CSF but a rather large difference in gap. With equal gaps, the difference in CSF reduction between AE and ME was similar to the 'Flow' setting. It was obvious that the 'Temp' and 'Extreme' settings rendered the most uneven gaps and CSF. The differences between AE and ME were 0.22 mm in gap and above 10 ml in CSF reduction.

Table 3. Average numbers of pulp properties for Feed, AE and ME respectively. Values of CSF are from manual testing while fibre length and shive content are from online pulp analyser.

Setting	CSF (ml)			Fibre length (mm)			Shive content (#/g)		
	Feed	AE	ME	Feed	AE	ME	Feed	AE	ME
Flow	182	126	131	1.21	1.17	1.21	231	115	144
Gap	171	125	120	1.22	1.18	1.20	207	111	112
Temp	178	123	112	1.20	1.18	1.17	208	123	114
Extreme	186	117	129	1.21	1.13	1.18	199	107	137

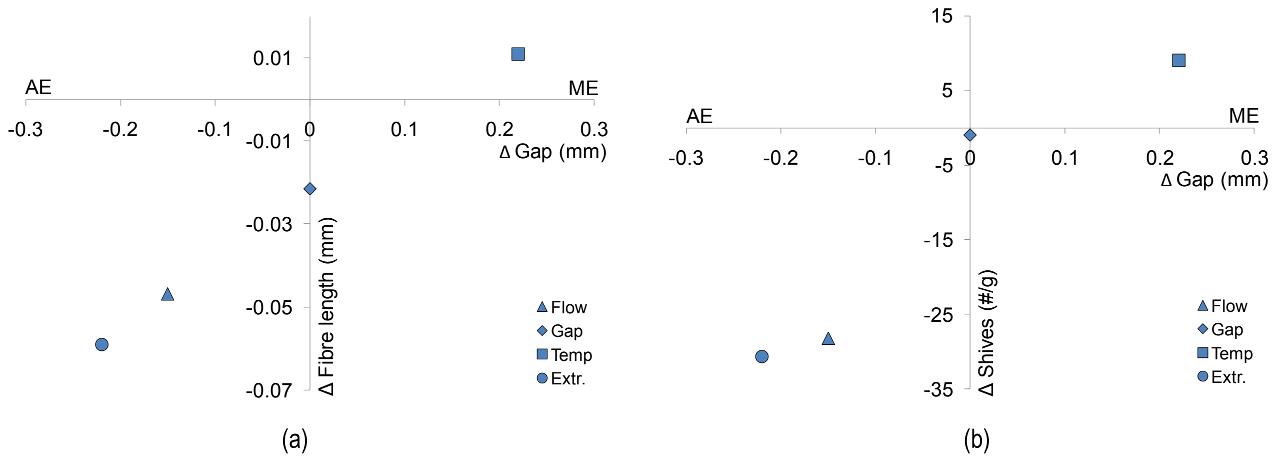

Fig 6. Differences in fibre length (a) and shive content (b) plotted with average differences in gap for each setting.

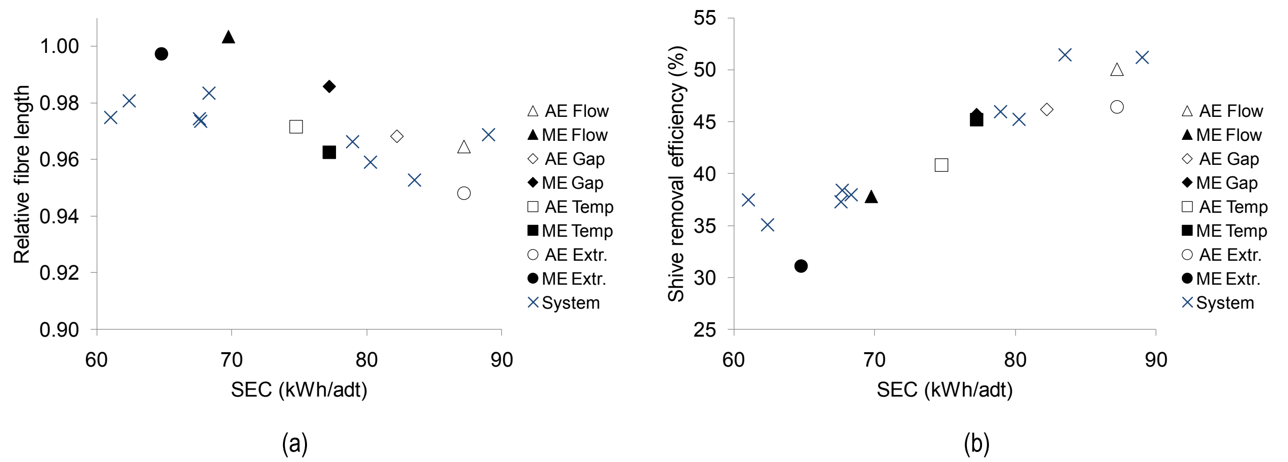

Fig 7. Relative fibre length (a) and shive removal efficiency (b) versus SEC. White symbols denote pulp samples from the adjustment end while black symbols denote pulp samples from the motor end. Crosses indicate data calculated from inlet and mixed outlet system pulps.

Fig 6a shows differences in fibre length (AE – ME) versus gap for the four settings. *Fig 6b* presents differences in shive content (AE – ME) with gap. The 'Temp' and 'Gap' settings reached even levels of fibre shortening and shive removal while the 'Flow' and 'Extreme' settings produced large differences between AE and ME.

The relation between gap and SEC is well known. With a constant mass flow of fibres, decreasing the gap will increase the refining power and thereby also increase SEC (Levlin 1988; Mohlin 2006; Eriksen, Hammar 2007; Lundin et al. 2008; Luukkonen et al. 2010). In this study, the overall SEC was held constant while the mass flow of fibres in each refining zone was altered with each setting. It is also well documented that fibre length (Koskenhely et al. 2005; Andersson, Sandberg 2011) and shive content (Welch 1999; Muenster et al. 2006) decrease with increasing SEC.

Fig 7a shows relative fibre length (calculated as outlet pulp fibre length divided by inlet pulp fibre length) plotted against SEC for each refining zone. The lower relative fibre length for AE pulp in three of the settings is probably related to the fact that the rotor was striving towards AE throughout the trial. In *Fig 7b*, shive removal efficiency is plotted with SEC, showing a clear but slightly curved relationship. In *Fig 7a* and *7b*, data is also shown calculated from system feed and mixed outlet pulps. The system data trends agree rather well with the trends from each refining zone, which indicates that the temperature increase correlates with the applied SEC in each refining zone. This is well in accordance with *Eq 11* above.

Since the AE stator constantly adjusts the load during operation, it is necessary to continuously compensate for uneven gaps to get uniform treatment in both refining zones. The adjustment strategy described in this paper is only possible if the refiner has separate pulp outlets and the flow rate ratio can be controlled. Other designs require a different solution for rotor position control. However, to develop a control strategy, smaller steps in rotor adjustments and more accurate measurements of temperature in particular, are needed in future studies.

The results from this study indicate that it is possible to adjust the rotor position by using outlet valves and that equal gaps are important to produce homogenous pulp. Gap measurement is however rather costly and a parameter such as outlet temperature would be easier to measure and control. It is however clear that the temperature measurement has to be very accurate since small changes in temperature indicate large changes in SEC.

Conclusions

It was observed that the rotor disc in a TwinFlo low consistency refiner did not centre itself properly between the stator discs during continuous operation. This rendered an asymmetrical rotor position and hence unequal plate gaps.

A non-centred rotor position gave uneven pulp quality because of unequal refining action in the two refining zones.

By altering pulp flow rate ratio between the two outlets it was possible to compensate for uneven refining caused by an un-centred rotor position.

The temperature increase in each refining zone seems to be a good indicator of the applied SEC in each refining zone.

From the four tested settings, equal gaps seemed to give the most homogenous pulp development from the TwinFlo.

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