Optimization of a brownstock washing line

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ABSTRACT: The objective of this study was to improve the efficiency of a certain Scandinavian chemical pulp mill's brownstock washing line. The information was collected by using online devices (a refractometer and a conductivity meter), and the whole line was controlled by an upper level control system. The results indicate that it is possible to reduce the amount of brownstock washing loss by controlling the dilution factor (DF) of the entire brownstock washing line, via the use of torque control of washers and real time wash loss measurements. Simultaneously, the amount of used wash water is decreased, thus significantly improving the economic efficiency of the fiber line, especially in the evaporation and bleaching plant. Real time dissolved dry solids (DDS) measurements proved useful for controlling and monitoring the wash loss and water consumption.

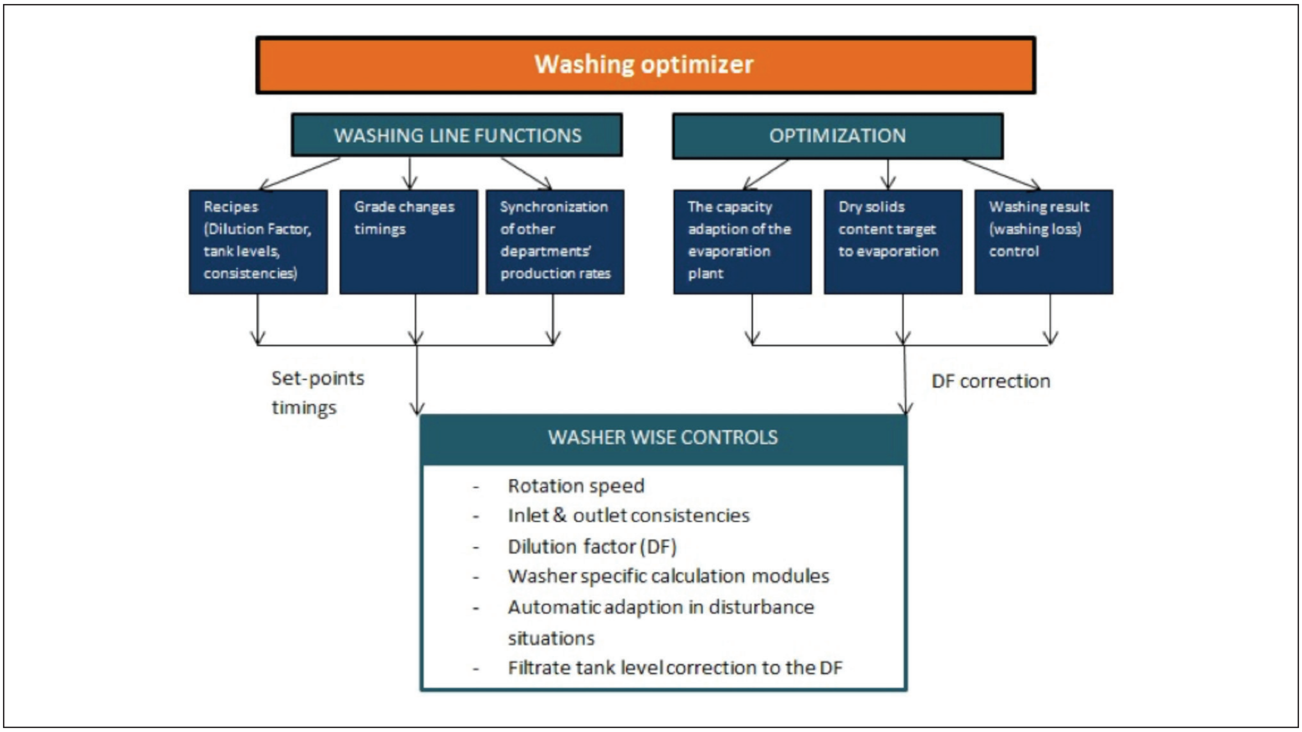
Application: We discovered the importance of accurate measurement technology for an effective control of the line. If the measurements are not giving accurate results, the capacity to control the line is diminished and, consequently, money and environmental performance are lost. It is possible for mills to learn the importance of control and monitoring of washing and the importance of accurate inline measurements from this research. They can also learn new information for the reaction of different adjustments. This information could be beneficial for Research and Development engineers, as well as production personnel.

In chemical pulping, the purpose of brownstock washing is to remove soluble matter — both organics and inorganics — from the pulp suspension while using the lowest possible amount of wash liquor. This is typically performed using the direct counter current washing principle that minimizes the amount of used wash water [1]. Efficient washing improves the recovery of cooking chemicals (sodium [Na] and sulfur [S]) and wood based dissolved organics for use in energy recovery. It also reduces the additional consumption of reagents in the subsequent bleaching stages [2]. Sufficient washing also has a positive effect on pulp quality, and it efficiently prevents deposition problems [3]. The performance of washing could be controlled in two main ways: using wash loss or the dilution factor (DF). The wash loss indicates the amount of washable compounds in the pulp suspension that could have been removed by washing, and the DF indicates the net amount of water that is added during the washing of diluted black liquor and can be negative, zero, or a positive number.

The optimization of washing equipment and stage washing performance is highly important for economic reasons. Process measurements and control are also important for efficient filter operation, and the data collected is valuable for process modelling [4]. Traditionally, washers have been controlled individually and the methods to evaluate wash loss inline have been rather imprecise. To achieve an effective trade-off between the previously mentioned objectives of brownstock washing, comprehensive and precise control of the washing line is needed. Effective control requires both proper inline monitoring of wash loss and an upper level control system to adjust water usage and other key parameters of the whole washing line.

Many advanced control systems to optimize brownstock washing have been introduced by different suppliers. These approaches are all more or less based on the criteria of production rate feed forward, washing loss feedback, and tank level control [5-8]. **Figure 1** represents a strategy for a washing optimizer. The structure of the different washing optimizers tend to be somewhat similar, having washer specific controls and also an upper level control system to manage the DF and washing loss of the whole washing line. Furthermore, some washing line control systems have the option to adapt the line according to requirements from other departments, e.g., the evaporation plant.

In this study, all the investigated washers were drum displacer (DD) washers. The pressure diffuser description has been illustrated by Qvintus [10] and also in our earlier study [4]. In conventional DD washer control, operators adjust the amount of wash liquid, the pulp inlet pressure, and wash liquid pressure so that these three parameters maintain a certain balanced state with a desired production rate. This makes control of the DF rather difficult. The operator has to optimize many interacting variables affecting the washing process, making the control of one individual parameter rather problematic.



1. The strategy of a washing optimizer [9].

MATERIALS AND METHODS

The experimental part of this study dealt with the introduction and development of an upper level control system and new measuring devices, as well as the trials carried out to measure their performance. Furthermore, trials were carried out to determine the optimum values for the operational parameters so that the washing line could be operated in an economically and environmentally sustainable manner. The parameters included were the DF, production rate, drum torque and feed consistency. All trials were performed at a chemical pulp mill producing bleached hardwood kraft pulp at about 300,000 a.d. metric tons/year. The sawdust digester also produced softwood pulp for the line. The mill is located in Scandinavia.

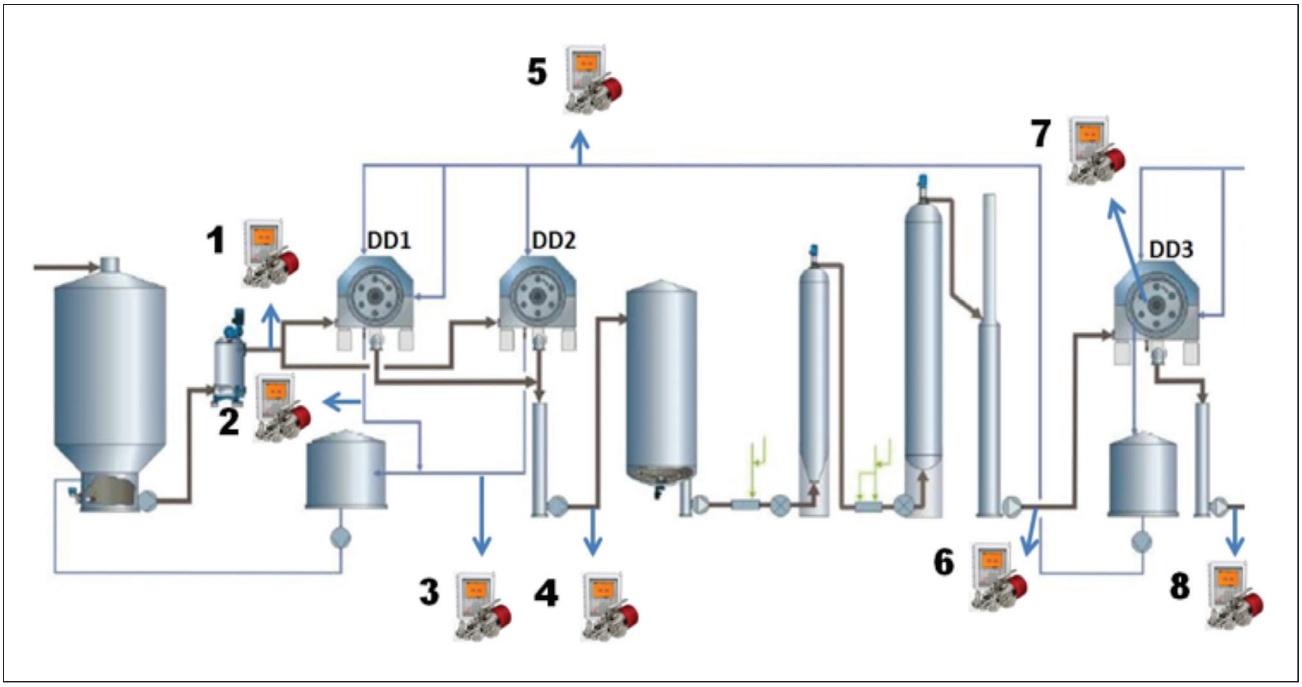
Brownstock washing line

The brownstock washing line consisted of three DD washers (DD1, DD2, and DD3) and two stage oxygen delignification. A total of eight inline refractometers were installed in the washing line to measure real time dissolved solids. Four of the refractometers were in pulp and four in filtrate lines, as in **Fig. 2**. Due to the measurement principle, it was possible to measure dissolved dry solids (DDS) from the liquid in pulp slurry without any effect of fibers on the measurement. Concentrations of the DDS varied from 0.1-1% (DD3 pulp out) to 11-14% (DD1 and DD2 pulp in). Component manufacturers can prove that accuracy of the refractive index measurement is ±0.0002 nD, which typically corresponds to ± 0.1% by weight and repeatability nD ±0.0001, which typically corresponds to ± 0.05% by weight in all situations. However, depending on the operating conditions, the measurement accuracy and precision can be significantly higher than generally stated by the manufacturer. In this case, conditions were favorable for accurate measurement, because temperature did not vary rapidly and the measurement range was narrow. Precision of the refractive index measurement therefore effectively reached +/-0.015%. This precision of measuring was sufficient to control total dissolved solids (TDS) in installations 1-6 and was acceptable in installations 7-8. Furthermore, other existing instrumentation in the washing line was also used to evaluate the performance and efficiency of washing. Instrumentation measurements used included those from flow meters (in wash liquor lines for each of the three washers), consistency transmitters (pulp in for the washers), and from three conductivity meters. Conductivity instruments were located in the liquor line leaving the vacuum tank for each of the three washers. Figure 2 illustrates the layout of the fiber line and installation sites of the refractometers.

Upper level control system

An upper level control system was put into service in co-operation with the system provider. The control system had two principal functions: DF control and the DD washer drum rotation speed control.

The control of DF by the upper level control system was constructed so that the DF of DD3 controlled the DF of the whole washing line. This meant that, during normal operation, the wash liquor circulation of the line would be closed and the DD3 bypass valve and the wash liquor storage empty-



2. Refractometer installation sites in the brownstock washing line. (1. DD1 & DD2 pulp in; 2. DD1 wash filtrate; 3. DD2 wash filtrate; 4. DD1 & DD2 pulp out; 5. DD3 wash filtrate; 6. DD3 pulp in; 7. DD3 wash liquor from vacuum tank; 8. DD3 pulp out).

ing valve would remain closed. Hence, all the wash water entering the washing line would be utilized in DD3, enabling a higher dilution ratio for the washer and enhancing the efficiency of the line.

A feed forward control signal from the production rate to the wash water feed amount in DD3 was used to maintain the DF, while the DFs of the pre O_2 washers, i.e., DD1 and DD2, were determined by the wash liquor balance of the DD3 wash liquor tank. A feedback was used to tune the DF of the line according to the stage and condition of the line. The feedback for the DF consisted of the liquor balance, dissolved solids, and conductivity. Refractometers measuring dissolved solids gave feedback to the DF control in real time, while conductivity measurements were averaged.

Different parameters involved in the control had different weights when calculating the DF. Parameters to control the dilution factor were also selected so they would not conflict with each other. In case of conflicting parameters, the effect was adjusted to produce the final control. For example, if the DF objective requested more feed water while at the same time the DS objective requested less water, the final feed water adjustment was determined by the weight and value of the parameters. Numerically, if DF asks for +2 L/s of shower water and DS asks for -1 L/s and both parameters have the same weight, the real change is +0.5 L/s.

The DD washers' drum rotation speed was based on torque control instead of conventional feed pressure control. The torque control was constructed so that the operators set the setpoint for the torque, and the drum rotation speed was adjusted to keep the torque constant. Feed pressure was configured by an upper limit. If this limit was exceeded, the control would automatically change the controlling parameter from torque to feed pressure to lower the feed pressure to the desired level. After the feed pressure was below the desired limit, the controller started to control the torque anew.

The drum torque approach appeared to work well; however, a problem occurred calling for enhancement of the control system. The drainability properties of pulp may change greatly due to a change in raw material quality or cooking conditions. If the drum torque is kept constant and the drainability of the pulp changes, the feed pressure could change dramatically. During the testing period, it was quite common for the feed pressure to drop to an inadequate level, causing rapid deterioration in the wash result. If the pulp had good drainability, the torque could have been significantly higher than it was set by the setpoint. This problem was addressed by creating a floating setpoint for the drum torque.

The idea of the floating setpoint was that it was automatically adjusted to the optimum level, depending on the pulp properties. The floating setpoint was created by first creating a calculator to keep count of the times per hour the feed pressure exceeded the set upper limit. Then, a lower limit and an upper limit were set for the times the feed pressure exceeds the limit per hour. If the times of exceedance per hour exceed the upper limit, the torque setpoint was automatically decreased a certain amount. On the other hand, if the times of feed pressure exceedance per hour fell under the lower limit, the torque setpoint was automatically increased a certain amount. **Table I** illustrates the function of the floating torque setpoint.

DD2 Feed Pressure	
Control max (%)	60.00
Control min (%)	35.00
DD2 Torque	
Control max (%)	60.00
Control min (%)	35.00
Control of DD2 Torques Target	
Status	Off
Correction step (kNm)	5.00
Correction interval (min)	30.00
Lower correction limit (feed pressure exceedance/h)	5.00
Upper correction limit (feed pressure exceedance/h)	15.00
Quantity of feed pressure upper limit (exceedance/h)	58.00
E-Values	
DD1 E-values	
Limit, red	3.00
Limit, yellow	4.00
DD2 E-values	
Limit, red	3.00
Limit, yellow	4.00

I. A screen capture of the configuration of the floating torque setpoint (DD2 = drum displacer washer 2; E-values = efficiency values).

The floating setpoint approach clearly answered the problem presented by changing pulp properties. However, the pulp drainability sometimes changed very rapidly, and the floating torque setpoint could not react with sufficient promptness, causing the feed pressure to drop to an inadequate level. To address the problem of rapid changes in pulp properties, a lower limit for feed pressure was also set up. The lower limit for feed pressure worked in the same manner as the upper limit, changing the controlling parameter from torque to feed pressure and raising the feed pressure to an adequate level.

Calculation of payback time

The payback time was calculated according to bleaching chemical consumption and steam used in the evaporation stage.

Savings in bleaching chemical consumption were obtained by calculating the change of NaOH and H_2O_2 consumptions and money used in these chemicals. The savings were calculated with Eq. (1):

$$\mathit{Pulp\ COD\ to\ bleaching} * \frac{\mathit{COD\ decrease}\ (\%)}{100} * \mathit{Consumption\ of\ bleaching\ chemical\ per\ 1\ kg\ COD}$$

An estimated-value based on literature and mill trends was used to evaluate H_2O_2 and NaOH consumption per 1 kg of COD.

Savings in steam energy consumption were calculated by first calculating the change in the amount of water to evaporation using Eq. (2):

$$((\mathit{Average\ black\ liquor\ flow\ to\ the\ evaporation\ plant} * \mathit{Original\ black\ liquor\ density}) * (1 - (\frac{\mathit{Black\ liquor\ dry\ solids\ average}}{\mathit{Black\ liquor\ DS\ to\ evaporation\ after\ optimization}})))$$

Savings due to the decrease in steam energy consumption were then calculated using Eq. (3):

$$\frac{\mathit{Change\ in\ water\ amount\ to\ evaporation}}{\mathit{Specific\ Energy\ Consumption\ of\ the\ evaporation}} * \mathit{Energy\ price}\ (\mathit{steam})$$

Analytical determinations

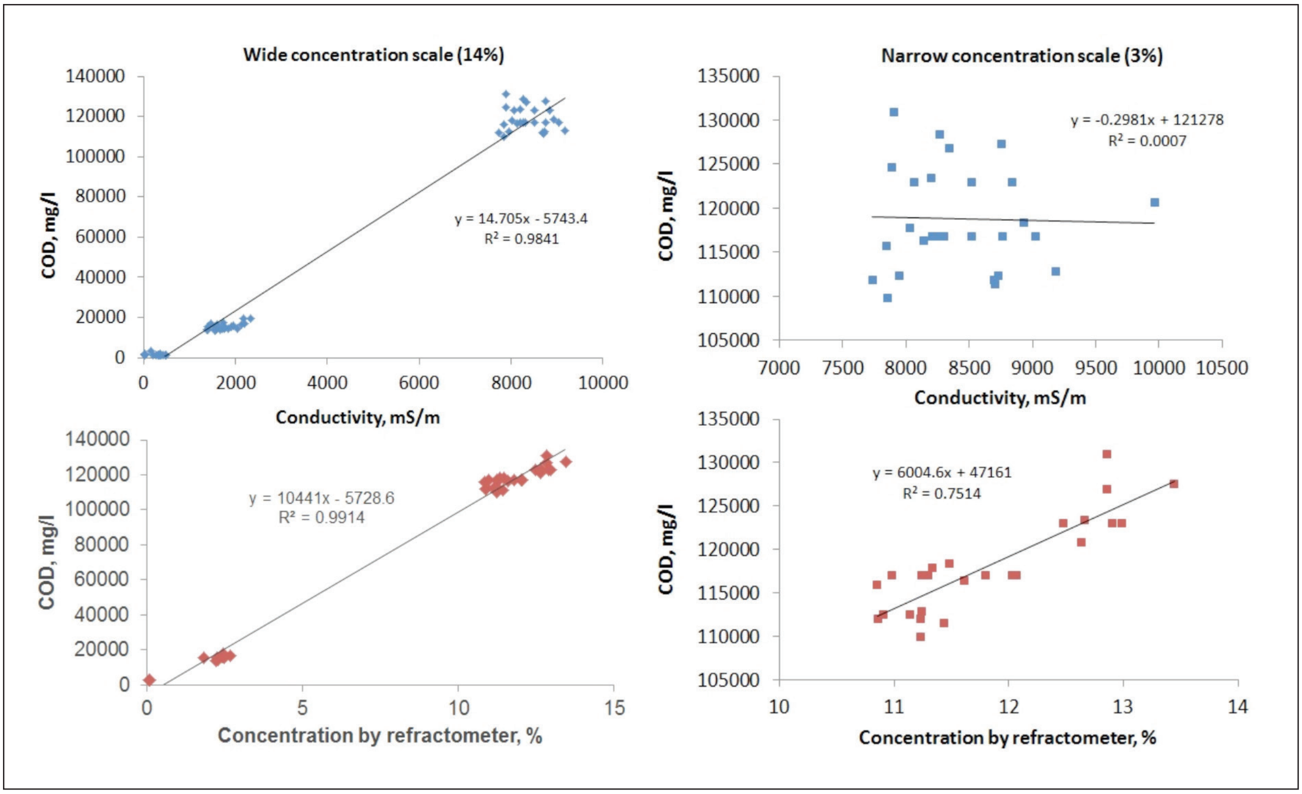
Analyses were made during the calibration of the refractometers and as a series of analyses to define the chemical situation of the washing line. Samples were analyzed by the following methods:

- TDS (analytical), SFS 3008 "Determination of water, sludge and sedimentations dry matter and residue ash"
- TDS (online), refractometer
- Conductivity (analytical), SFS EN27888 "Water quality. Determination of electrical conductivity"
- Conductivity (online), Mettler Toledo conductometer
- Consistency, SCAN – C17:64 "Pulps – Determination of stock concentration (Rapid method)"
- Chemical oxygen demand (COD) pulp, SCAN – CM 45:91 "Pulp (wet, never-dried chemical pulp) COD and TOC removable by washing"
- COD liquor: COD liquor samples were filtrated using a 1000 μm paper and then analyzed in a COD analyzer, as described in SCAN – CM 45:91

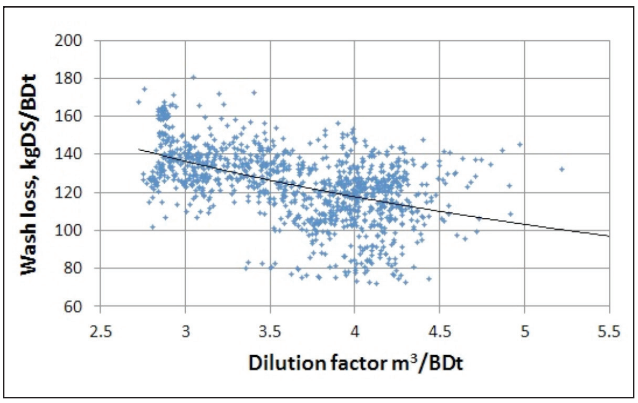
RESULTS AND DISCUSSION

Correlation of COD and real time measurements in a wide and narrow scale

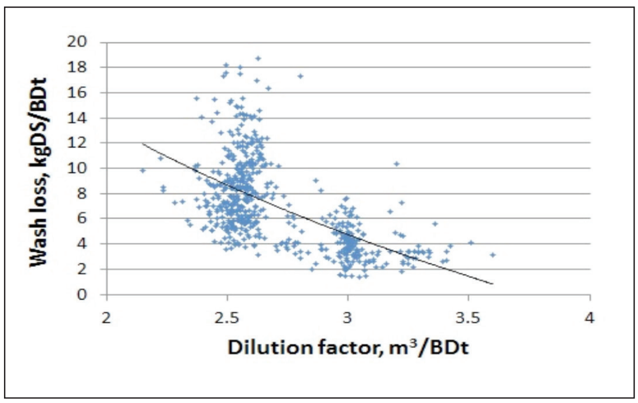
Figure 3 represents the correlation of COD and real time DDS measured by refractometer and conductivity in a wide and a narrow scale. It can be seen that the refractometer measurement correlated significantly with COD, even in the narrow concentration range. The reason for this is that the refractometer measures both organic and inorganic dissolved substances as a sum parameter and there was abundant organic lignin that has a fairly high refractive index. In the narrow range, conductivity did not have any correlation with COD.



3. Correlation of chemical oxygen demand (COD) and real time dissolved dry solids (DDS) measured by refractometer and conductivity in a wide and a narrow scale.



4. Effect of the dilution factor (DF) on kilograms of dry solids per bone dry metric ton (kgDS/b.d. metric ton) wash loss from drum displacer (DD) washers DD1 and DD2.

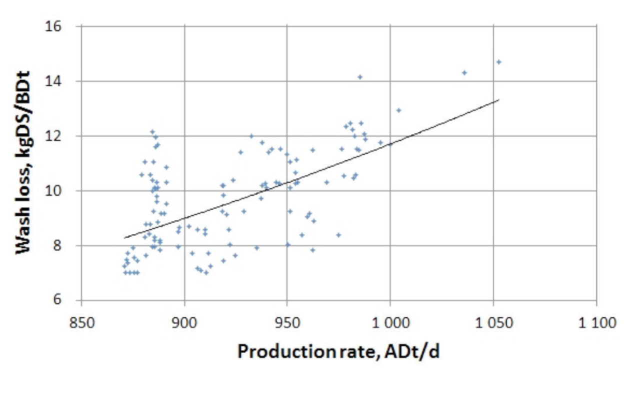


5. Effect of DF on kgDS/b.d. metric ton wash loss from washer DD3.

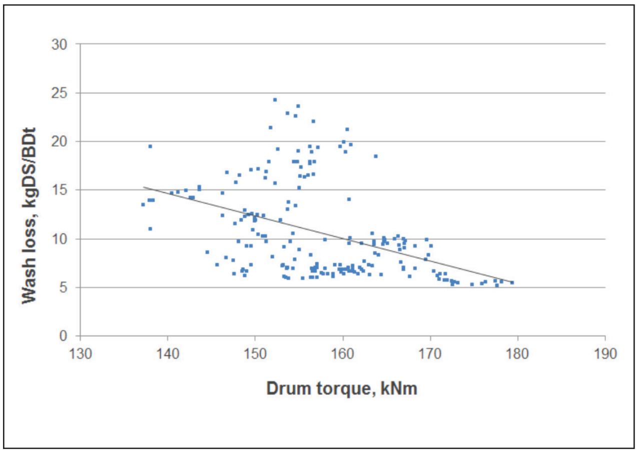
Effect of DF, production rate, and torque on wash loss

Figure 4 shows the combined effect of the DF on wash loss from DD1 and DD2 washers, and **Fig. 5** shows the effect of the DF on wash loss from the DD3 washer. The wash loss was obtained by refractometer measurement. The ratio of kilograms chemical oxygen demand per bone dry metric ton (kgCOD/b.d. metric ton) to kilograms dry solids per bone dry metric ton (kgDS/b.d. metric ton) in DD1 and DD2 washers is approximately 1.4, which means 100 kgDS/b.d. metric ton is matched with around 140 kgCOD/b.d. metric ton. From the result, it can be stated that an increase in the DF clearly decreases the wash loss. The relative effect of the DD3 DF on wash loss is significantly higher than in the case of DD1 and DD2. With DD3, the DF level is lower than that of the whole washing line due to washer bypass. A bypass was used during the experiment to balance the levels of the filtrate tanks.

Figure 6 shows the effect of the production rate on wash loss, measured by refractometer and expressed as kgDS/b.d. metric ton. The result is measured at washer DD3. The DF of the washing line was 3.5 m^3/b.d. metric ton during the entire trial. These results suggest that a higher production rate increases washing loss, especially when the

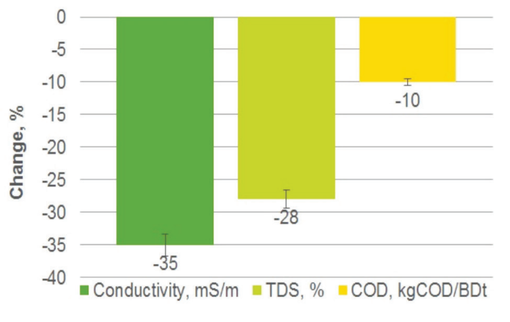


6. Effect of production rate on wash loss in kgDS/b.d. metric ton, measured by a refractometer.

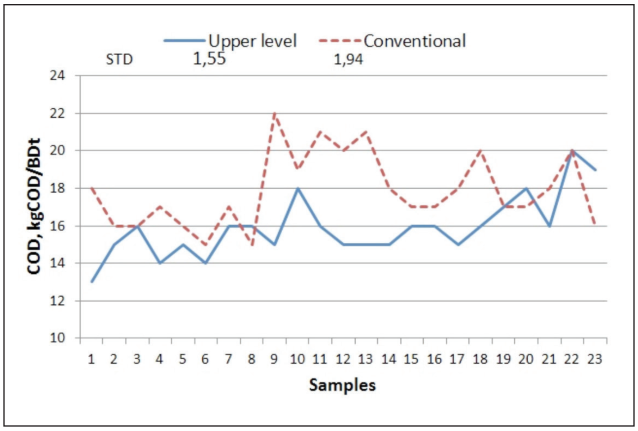


7. Effect of drum torque on wash loss.

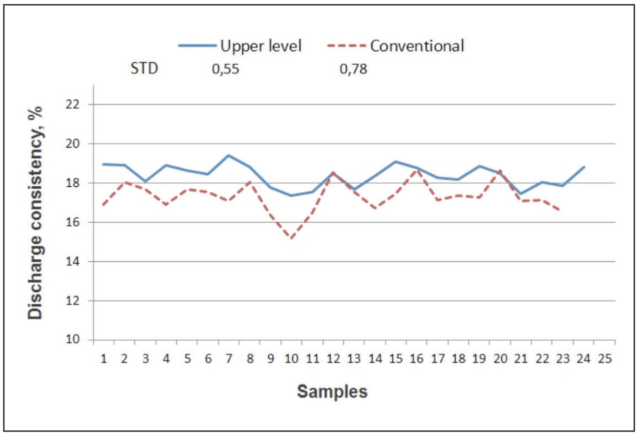
Control system	Conventional	Upper level
Production ADt/h	40,7	40,7
Dilution factor m³/BDt	3,87	3,77
TDS from liquor leaving the washing line, %	~14,5	+ 0,4
Wash loss to bleaching, kgCOD/BDt	18,1	16,2



8. Conventional and upper level control test results over comparable periods of two weeks.



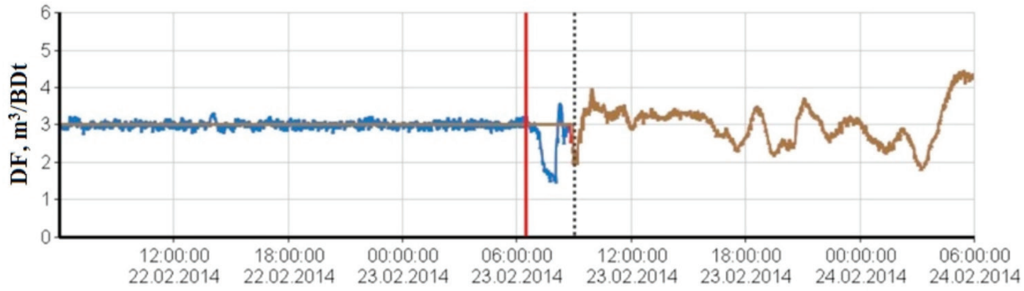
9. Wash loss, measured as kilograms of COD per bone dry metric ton (kgCOD/b.d. metric ton), during conventional and upper level control.



10. Discharge consistencies during conventional and upper level control periods.

production rate is taken higher than in normal operation. Ways to minimize wash loss include maintaining steady and sufficiently high washer feed consistency. For DD washers in particular, it is important to control the drum rotation speed so that the consistency in the drum is homogenous and the shower water is adjusted to obtain the desired dilution factor.

The drum torque control seemed to have a positive effect on the performance of the washer. **Figure 7** illustrates that the higher the torque is, the smaller and more stable the wash loss. When the torque was taken under 160 kNm, the washing result collapsed, resulting in a significant increase in wash loss. Experience during the trials suggested that the level at which the washing result collapses depends on the stock properties and, therefore, could vary greatly. In other words, when the drum torque was kept constant and stock properties were changed, feed pressure decreased too much and formed pulp cake that was too runny. The most important stock property was fiber length. The fiber length of softwood sawdust pulp, which was sometimes used as additional pulp, was longer than that of hardwood pulp.



11. Effect of DF control on the measured DF.

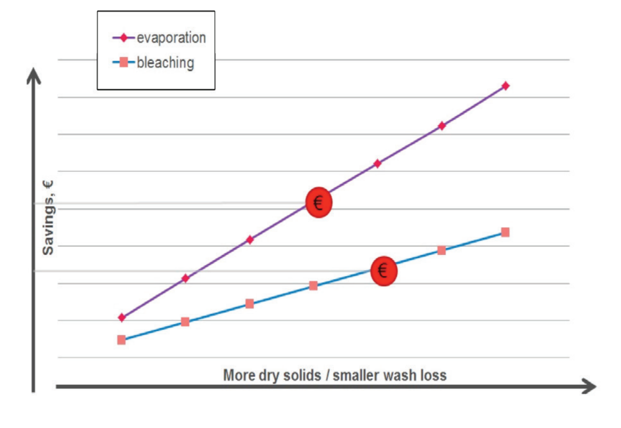
12. E -value and efficiency traffic lights on the operation monitor of the upper level control.

Upper level control

The results illustrated in **Fig. 8** suggest that the introduction of the upper level control system and refractometers had a significant effect on the performance of the washing line. Wash loss, measured in total COD, dropped by up to 10% at the same time that the concentration of the washing liquor leaving the washing line increased by 0.4%. The production rate was the same over both periods and other important variables were also kept constant. Wash loss measured by conductivity experienced the most significant decrease, while TDS decreased slightly less. This result is consistent with theory, since conductivity measurement emphasizes the inorganic portion of the TDS, which are easier to wash out than organic compounds like lignin.

Figure 9 shows the DD3 washer's wash loss (measured as kgCOD/b.d. metric ton) during conventional and upper level control, and **Fig. 10** shows discharge consistencies over the same two-week period. It can be seen that by using upper level control, wash loss (measured as kgCOD/b.d. metric ton) was lower and less erratic, as was consistency. By using an upper level control system to control the DF of the washing line and by using real time wash loss measurements as control feedback, it is therefore possible to reduce the amount of wash loss and simultaneously decrease the amount of used wash water.

Figure 11 illustrates the effect of DF control on the measured DF during a 48-h period. In the figure, DF control is in use until the red vertical line. After the black dotted line, the washer is operated in a conventional way by manually adjusting the amount of washing liquid. During both periods, the production rate varied between 31 a.d. metric tons/h and 41 a.d. metric tons/h. The period between the two lines experienced process disturbances and cannot be considered reliable. The results showed that the upper level control balanced the DF. During conventional control, part of the pulp is



13. Payback time for the investment.

washed with an excessive amount of water, while part of it is washed with an inadequate amount of water.

Figure 12 demonstrates the efficiency "*traffic lights*" on the control monitor screen. "*Traffic lights*" show operators how effectively washers are functioning. The use of refractometers enabled the calculation of the efficiency (E)-value online for the washers. The performance parameters were created in the operation system and placed on the upper level control monitor. Furthermore, these "*traffic lights*" were placed on the monitor screen next to the E_{APE} value (Actual Process E-value) to indicate whether the washer efficiency was poor (light red, E-value below 4), adequate (light yellow, E-value 4 – 5.5), or excellent (light green, E-value above 5.5).

The payback time for the investment was calculated according to the results obtained in the performance trial. The investment made included the engineering, the hardware for the upper level control system, and 8 refractometers. The payback time according to the performance trial was around 3 months. **Figure 13** illustrates the investment payback time period.

CONCLUSIONS

The results suggest that by using an upper level control system to control the DF of the entire brownstock washing line and by using real time wash loss measurements as

ABOUT THE AUTHORS

Brownstock washing was a popular topic in the 1980s and 1990s. We chose to research brownstock washing and real time control of washing now because of renewed environmental and economic interest about it in the pulp industry. Efficient brownstock washing improves the recovery of spent chemicals, reduces the consumption of reagents in the subsequent bleaching, and limits effluent load from the bleach plant. It also has a positive effect on pulp quality and prevents deposition problems. So, without effective washing, the economic viability of chemical pulp production is affected.

We have studied brownstock washing for several years and published articles via several conferences and journals. First, we undertook mill investigations in washing before and after oxygen delignification. The next step was to concentrate on optimization of a single pressure filter performance. Then, we controlled the performance and economy of the whole brownstock washing line. Based on our prior research, we received the opportunity to realize this higher level control study at the Scandinavian pulp mill. This is a logical continuation of our previous works, like the article in *TAPPI J.* 10(9): 27(2011).

In the current research, it was a challenge to start operating the DD washers according to torque control. The washers used were already older generation and, for example, had hydraulic motors instead of electric ones. We addressed this by observing the washer's response after parameter changes using system trends and data analysis tools. Finally, we learned the reactions of different adjustments and controlled the washer using torque to adjust drum rotation speed.

It was interesting to discover the importance of accurate measurement technology for an effective control of the line. If the measurements are not giving accurate results, the capacity to control the line is diminished and, consequently, money and environmental performance are lost. The most interesting part of this research was to see the effect

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of the new control strategy on other departments in the mill and to analyze those findings. We noticed that notable economic savings can be made by just very small adjustments to the washer's parameters.

Mills should note that it was possible to reduce the amount of brownstock wash loss and simultaneously decrease the amount of used wash water. The obtained decrease in wash loss significantly decreases the cost associated with the bleaching plant, as well as the environmental burden. Concurrently, the decrease in wash water consumption and the resulting increase in the concentration of the black liquor feed to the evaporation plant enhance the economical profitability of the mill.

The next step in our research is to optimize parameters like process temperature in the different stages and the amount of the deformers. In our earlier mill studies, we primarily focused on diffusers, DD washers, and drum filters. We are also planning to study one of the most common washers, wash presses, in a modern pulp mill.

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feedback and torque control of the washers, it is possible to reduce the amount of brownstock wash loss and simultaneously decrease the amount of used wash water. The key results of this study are:

- Refractometer measurements correlated significantly with COD, even in a narrow concentration range. In the same range, conductivity did not have any correlation with COD.
- Use of refractometers offers the possibility to use performance parameters, such as the E-value and the displacement ratio, to continuously monitor and develop washing efficiency.
- By using an upper level control system to control the DF of the washing line, by using real time wash loss measurements as control feedback, and by torque control of the washers, it is possible to reduce the amount of wash loss and simultaneously decrease the amount of used wash water.
- The control of the liquor balance enabled effective utilization of all wash water fed to the washing line.
- The production feed forward and real time wash loss feedback for DF control maintained the wash loss at the desired level. **TJ**

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