# How to use total dissolved solids measurements to evaluate the performance of diffuser washers—A mill study

RIKU KOPRA, ANNA PESONEN, JARI KÄYHKÖ, AND OLLI DAHL

**ABSTRACT:** Various types of pulp washing equipment are available. Each washing device has a unique mechanical construction, and the washing principle is often a combination of dilution, thickening, and displacement washing. In this work, the performance of the pressure diffuser washer is studied.

In stepwise trials, the effect of the feed and discharge consistencies on the performance of the diffuser was studied. The effect of the downward velocity of the screen on the pressure diffuser's washing efficiency was also studied. The measurement of total dissolved solids (TDS) by a process refractometer was used as a wash loss measurement unit and the refractometer's results were used in the calculations of standardized Nordén efficiency (E10) values. The chemical oxygen demand (COD) and conductivity values were also measured and their results compared to the TDS results.

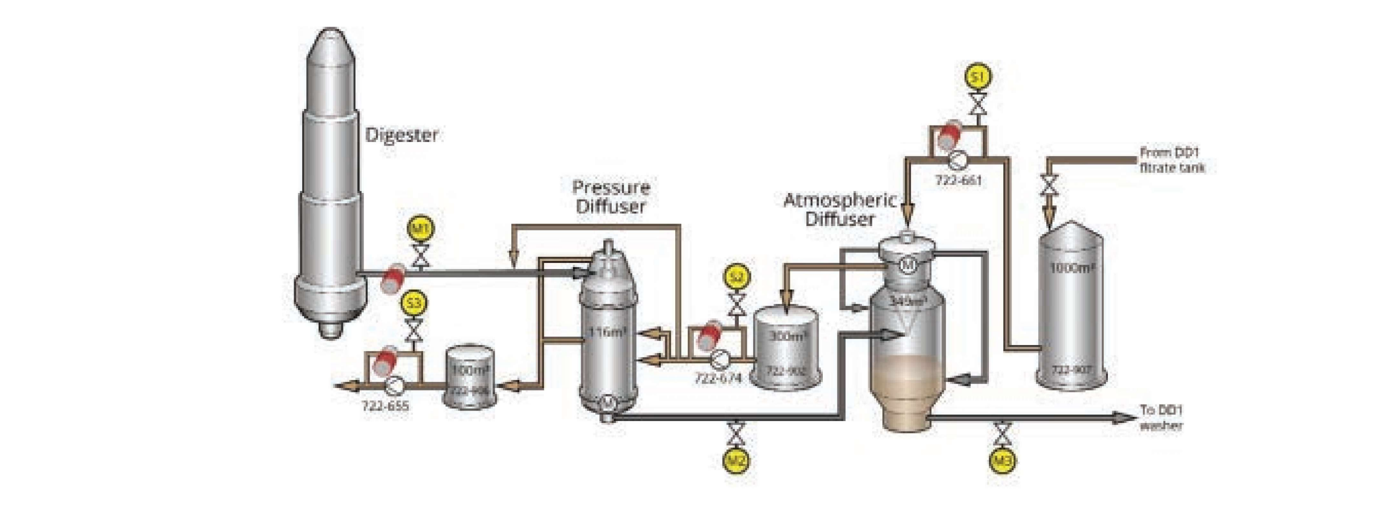
The results indicated that feed consistency has a significant effect on the performance and effectiveness of the diffuser washers in the mill. It can also be stated that when the downward velocity of the screen is adjusted to too high a level, the washing efficiency of the pressure diffuser decreases. As a conclusion from the mill tests, it can be stated that even small process parameter changes can provide enhanced diffuser washing at the beginning of the washing line, which has a direct effect on the performance of post-oxygen washing.

***Application:*** Diffusers washers are still very common washers at pulp mills in the United States. With the monitoring and control of diffuser washers' performance using the latest measurement technology, it is possible to achieve economic savings at mills. From this study, readers can learn the importance of control and monitoring of washing and the importance of accurate in-line measurements. They can also learn some new information about the reaction from different adjustments. We think this information could be beneficial for Research and Development engineers and also production personnel.

The performance of brownstock washing affects many subprocesses, such as evaporation, oxygen delignification, bleaching, and wastewater treatment; hence, it has a direct impact on the profitability of the fiber line performance. Thus, brownstock washing and post-oxygen washing should be sufficiently effective. For softwood pulp applications, typical washing efficiency requirements are approximately 15–16 of total standardized Nordén efficiency ($E_{10}$) before and 7–9 after oxygen delignification when the dilution factor is 2.5 m³/air-dried (a.d.) metric tons [1]. In an optimum situation, the operation of the washing line is monitored by online measurements, which measure all dissolved washable materials with online effectiveness calculations performed using these measurement results. However, this is not very common. The performance of the washers is mainly monitored via the variations in the levels of the conductivity measurements and by measuring and controlling the wash water amount. Closer monitoring of the samples is done mainly in optimization and troubleshooting situations and in connection with guarantee runs.

The brownstock washing system is always mill-dependent. It starts with the cooking of a continuous digester with a high heat washer in its lower section or displacement batch cooking (including pump discharge) and is followed, mainly in series, by various pieces of equipment such as a drum displacer (DD), a vacuum filter, a washer diffuser, and/or a press filter—all of which use either dilution/thickening or displacement washing principles or their combination. The target is to connect these different pieces of washing equipment in a series and attain as good a washing result as possible with a minimum amount of wash water [2].

Two types of diffuser washers used in the fiber line are examined in this study: atmospheric and pressure. The pressure diffuser was developed as a modification of atmospheric diffusers. It is built to operate at digester pressure and is most commonly positioned directly after a digester or an oxygen delignification tower. There are two types of pressure diffusers; the pulp flow direction is downward or upward. In the upward flow design, the pulp of 10% to 12% consistency enters the bottom inlet of the pressure diffuser.




***1. Installation sites of the refractometers on the pulp mill's brownstock washing line (denoted by yellow circles).***

The pulp passes up through the annulus between the screen and the baffles on the inside of the shell, forming a uniform 150-mm-thick mat of pulp. A rotating discharge scraper at the top outlet ensures uniform pulp flow through the unit. Since this is a pump-through device, the pulp is discharged with sufficient pressure to flow to the next process. The slightly conical screen causes an automatic backflush during the rapid downward stroke of each cycle. Washing is performed as a result of the lateral displacement of wash filtrate through the pulp mat. The wash filtrate enters through a series of wash baffles inside the shell. Liquor is displaced through the pulp mat and the extraction screen into the central collection chamber [3,4].

## MATERIALS AND METHODS

The experiments for this study were carried out on a Scandinavian pulp mill's softwood line (SW) diffuser washing. Stepwise trials were conducted, where the effect of feed and discharge consistencies on the performance of the diffuser washer was studied. The effect of the downward velocity of the screen on the pressure diffuser's washing efficiency was also studied. In test week I, the effect of feed consistency (7.6%, 8.0%, and 8.4%) and different discharge consistencies (7.7%, 7.9%, and 8.1%) on the pressure diffuser performance were studied. In test week II, the effect of the screen velocity and the effect of the discharge consistency using constant feed consistency (8.25%) on the pressure diffuser's washing efficiency were studied. The measurement of total dissolved solids (TDS) by a process refractometer was used as a wash loss measurement unit and the refractometer's results were used in the calculations of standardized Nordén efficiency ($E_{10}$) and equivalent wash yield ($Y_{10}$) values. The $E_{10}$ and $Y_{10}$ calculations were performed using online data, which used Tervola's procedure [5]. TDS measurement of washer losses by process refractometer has been covered in previously published reports [6-8]. The chemical oxygen demand (COD) and conductivity were also measured, and their results were compared with the TDS results. In addition, the performance of a portable refractometer was studied in the laboratory. This section presents the test arrangements, stepwise trials, and analytical methods.

### *Installation of the refractometers*

The installation sites of the refractometers (M1, M2, M3) and sample points (S1, S2, S3) on the pulp mill's brownstock washing line are shown in **Fig. 1**. The beginning of the softwood (SW) brownstock washing line consists of a continuous digester with a high heat washer in its lower section, a pressure diffuser washer, and an atmospheric diffuser washer. The measurement arrangements for the performance of diffuser washers can be monitored (changes of filtrates TDS content) and the pressure diffuser's $E_{10}$- and $Y_{10}$-values can be calculated in real time.

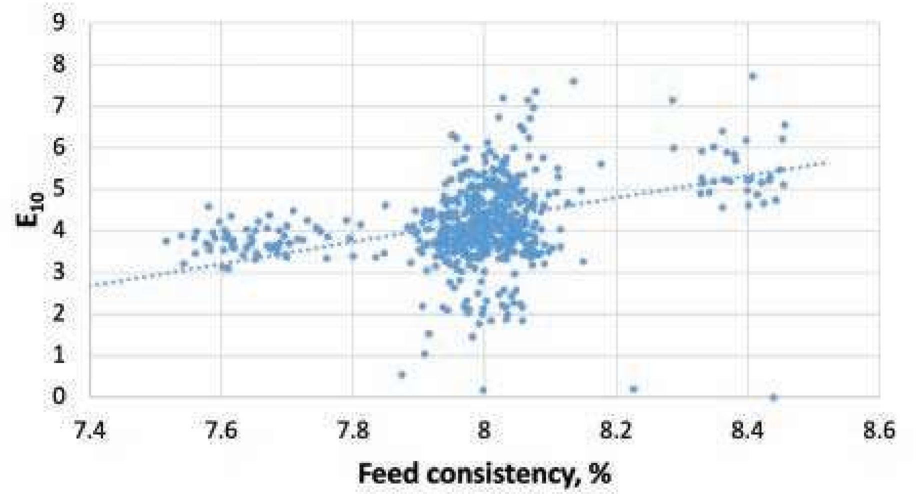
Pulp and filtrate samples were taken from the washer's inlet and outlet pulp and from the filtrates. Three sample laps were taken from all 10 test points, as shown in **Table I** (Week I) and **Table II** (Week II). From the pulp line, the filtrate sample was obtained from the pulp (by filtration through wire gauze within 30 min of pulp sampling). The conductivity of all samples was determined immediately after sampling. The TDS by laboratory standard, TDS by portable refractometer, and COD of all sam-

| Pressure Diffuser Washer Feed Consistency, % | Pressure Diffuser Washer Discharge Consistency, % |
|---|---|
| 7.6 | 7.7 |
| 8.0 | 7.7 |
| 8.0 | 7.9 |
| 8.0 | 8.1 |
| 8.4 | 7.7 |

***I. Mill experiments for Week I.***

| Pressure Diffuser Washer Feed Consistency, % | Pressure Diffuser Washer Discharge Consistency, % | Pressure Diffuser Screen Downward Velocity, m/s |
|---|---|---|
| 8.25 | 7.7 (production: 650 a.d. metric tons/day) | 1.2 |
| 8.25 | 7.7 (production: 700 a.d. metric tons/day) | 1.1 |
| 8.25 | 7.5 (production: 725 a.d. metric tons/day) | 1.2 |
| 8.25 | 7.5 (production: 725 a.d. metric tons/day) | 1.1 |
| 8.25 | 7.7 (production: 725 a.d. metric tons/day) | 1.2 |

***II. Mill experiments for Week II.***




***2. Effect of the pressure diffuser's feed consistency on the washing efficiency ($E_{10}$).***

ples were measured in the laboratory. In the portable refractometer analysis, the temperature of the samples was controlled to 40°C using a thermostat.

### *Stepwise trials*

In the test for Week I, the effect of the feed and discharge consistencies on the pressure diffuser washer efficiency was studied by changing the set point of the feed and discharge consistency. The downward velocity of the pressure diffuser screen was set to 1.2 m/s. Production was quite stable at about 725 a.d. metric tons/day. The experimental data for Week I are shown in Table I.

For Week II, the effect of the feed and discharge consistencies on the pressure diffuser's washing efficiency was studied by changing the set point of the discharge consistency. The downward velocity points of 1.1 m/s and 1.2 m/s of the screen were also studied. The experimental data for Week II are shown in Table II.

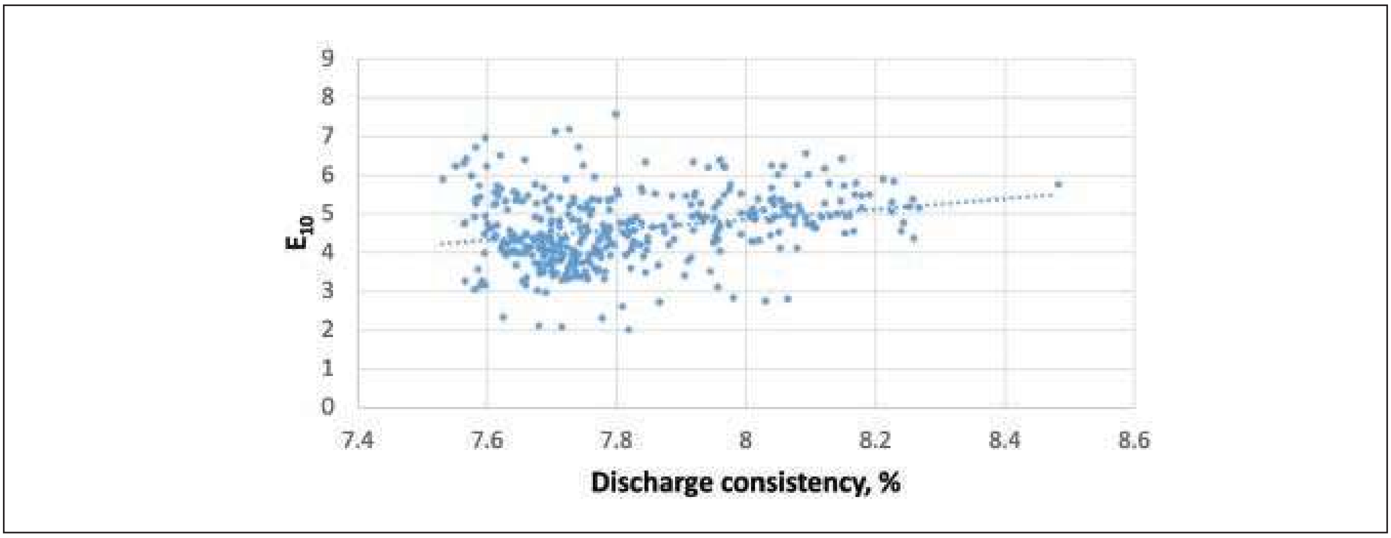
### *Analytical determinations*

The samples were analyzed by the following methods:

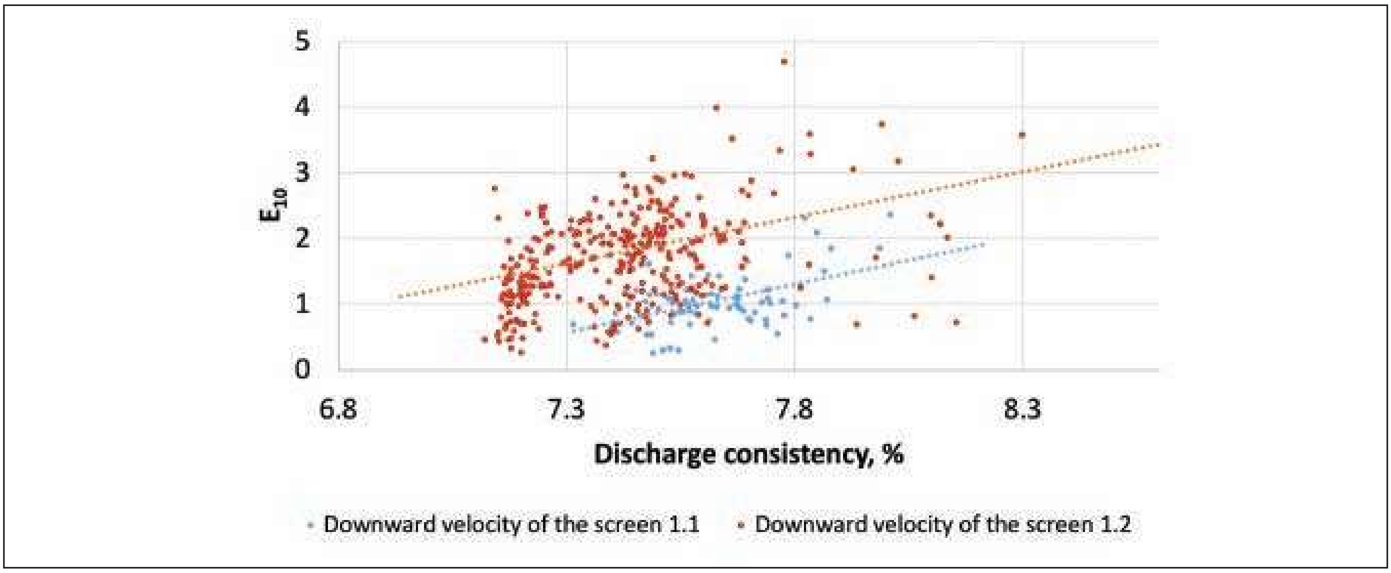
- Dry matter content (analytical): ISO 638 "Paper, board and pulps—determination of dry matter content—oven-drying method."
- Dry matter content: process refractometer (onsite) or portable refractometer (in laboratory).
- Conductivity (onsite): conductometer (Mettler Toledo; Columbus, OH, USA).
- COD in liquor: COD liquor samples were filtrated through a 1.6 µm grade GF/A paper and then analyzed with a COD analyzer (ISO 15705 "Water quality determination of the chemical oxygen demand index [ST-COD] small-scale sealed tube method").

## RESULTS AND DISCUSSION

As can be observed from **Fig. 2** and **Fig. 3** (Week I), with a higher feed and discharge consistency, the washing efficiency of the pressure diffuser increases. **Figure 3** shows that increasing the feed consistency from a value of 7.6% to 8.4% increases the $E_{10}$-value by about 1.5 units. The level of the $E_{10}$-values based on the laboratory analyses was approximately 1 unit lower than the online $E_{10}$ values. The reason for these differences with laboratory versus online $E_{10}$ values could not be fully explained. It is likely that the




***3. Effect of the pressure diffuser's discharge consistency on the washing efficiency ($E_{10}$).***

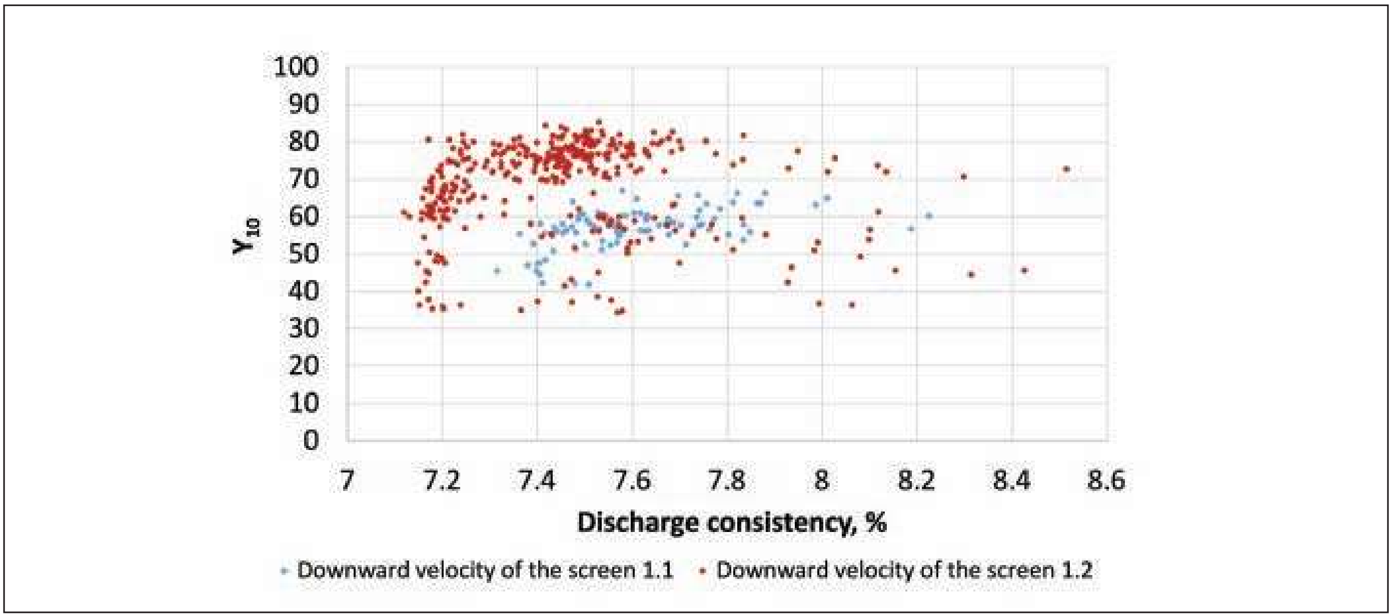



***4. Effect of the pressure diffuser's discharge consistency on washing efficiency ($E_{10}$) in two different downward velocities of the screen.***

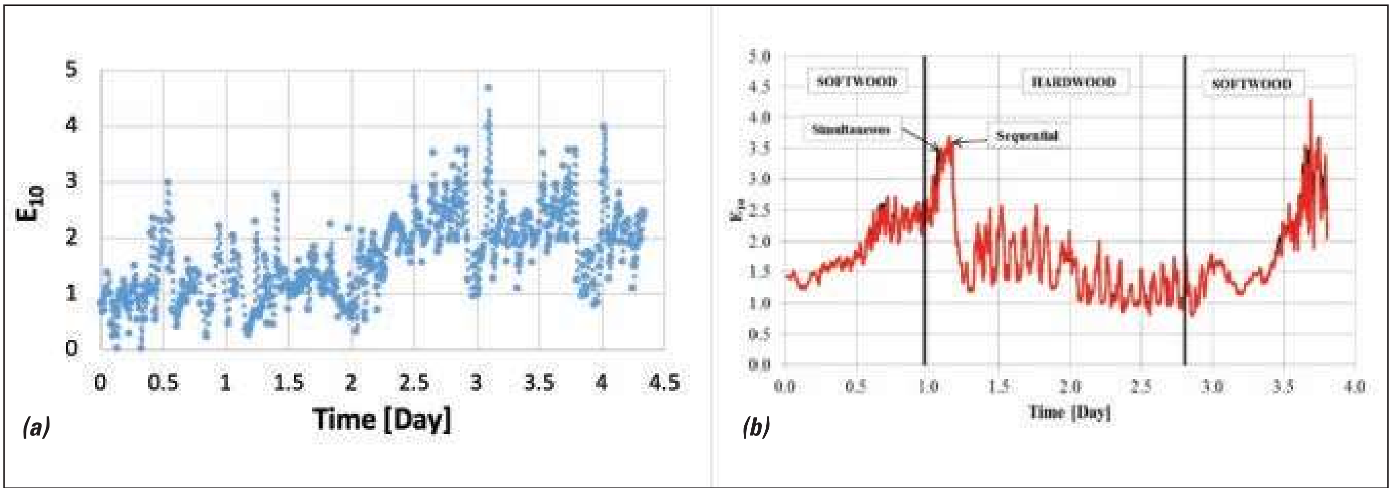
online measurement at the blown pulp level was a couple of tenths TDS percentage off, and this caused higher values for the online $E_{10}$ calculations. Feed consistencies over 8.4% were not tested, because with higher feed consistencies, and especially with higher discharge consistencies, the load on the bottom groove increases, which caused operational problems. Based on these results, for the second test week, the pressure diffuser was selected as the monitored washer. The maximum feed consistency that can be run for a long time at the mill was tested.

The experimental results for the effect on $E_{10}$ of the discharge consistency for two different downward velocities of the screen are shown in **Fig. 4**, and the effect on $Y_{10}$ is shown in **Fig. 5** (Week II). It can be seen that the $E_{10}$ values for Week II are lower than in Week I. At this time, the online $E_{10}$ values were at the same level as the values calculated from the laboratory analysis results. However, it can be seen again that the higher the feed consistency, the more effective was the pulp washing. The $E_{10}$ values are relatively low when compared to the specifications of the pressure diffuser manufacturer. Conventionally, the feed consistency of the pressure diffuser should be at a level of 10%. In addition to low feed consistency, other reasons for low $E_{10}$ values may be the condition or the openness of the screen, hydraulic problems, or other issues arising from the setting of the device. This pressure diffuser's maximum capacity is about 1600 a.d. metric tons/day. Because of the low production rate of 725 a.d. metric tons/day, the diffuser is not in the optimum operating range. In such a situation, the pulp mat may thicken too much.

In this case, a downward velocity of the pressure diffuser's screen of 1.2 m/s gives 1 unit higher $E_{10}$-values than a velocity of 1.1 m/s. In a previous study [9], similar results were obtained. It was found that when the velocity ratio between the pulp and the screen unit was in the optimum range, the pressure diffuser works well; however, at higher




***5. Effect of the pressure diffuser's discharge consistency on equivalent wash yield ($Y_{10}$) values in two different downward velocities of the screen.***




***6. (a) Online $E_{10}$ values from test week II calculated by Tervola's method [5], and (b) Tervola's [5] study sequential and simultaneous methods.***

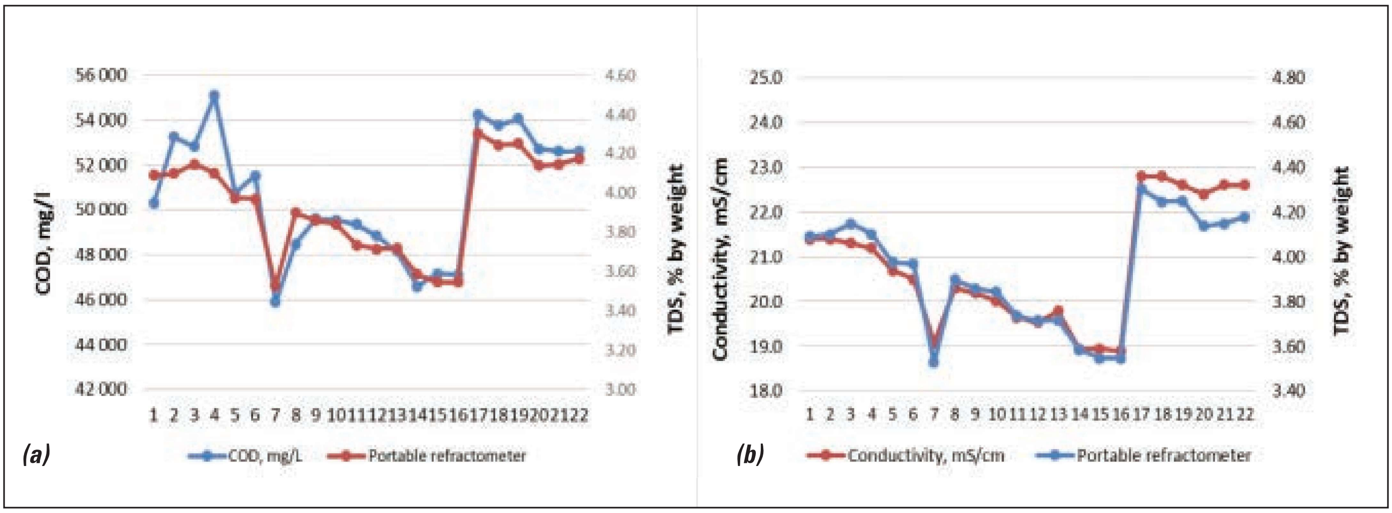
ratio values, the washing efficiency rapidly deteriorates. Lysen [10] has stated that the increase in the washing efficiency is because the distribution of the formed pulp mat is avoided when the downward velocity of the screen is adjusted correctly. If the velocity of the screen units is too fast, the formed pulp mat will be whipped, which disturbs the displacement operation. Thus, there is too little time for stable wash water displacement through the pulp mat [8].

**Figure 6a** shows the online $E_{10}$-values calculated using Tervola's method [5] for Week II. It can be seen that the efficiency of the pressure diffuser varies considerably. By measuring the washing efficiency in real-time using the TDS measurements and by adjusting the process parameter in the appropriate direction, the inefficient operation of the washers can be reduced. Figure 6b shows the results published by Tervola [5] based on continuous TDS measurements with a pressure diffuser at a different mill. The variations of his data are very similar to the current study.

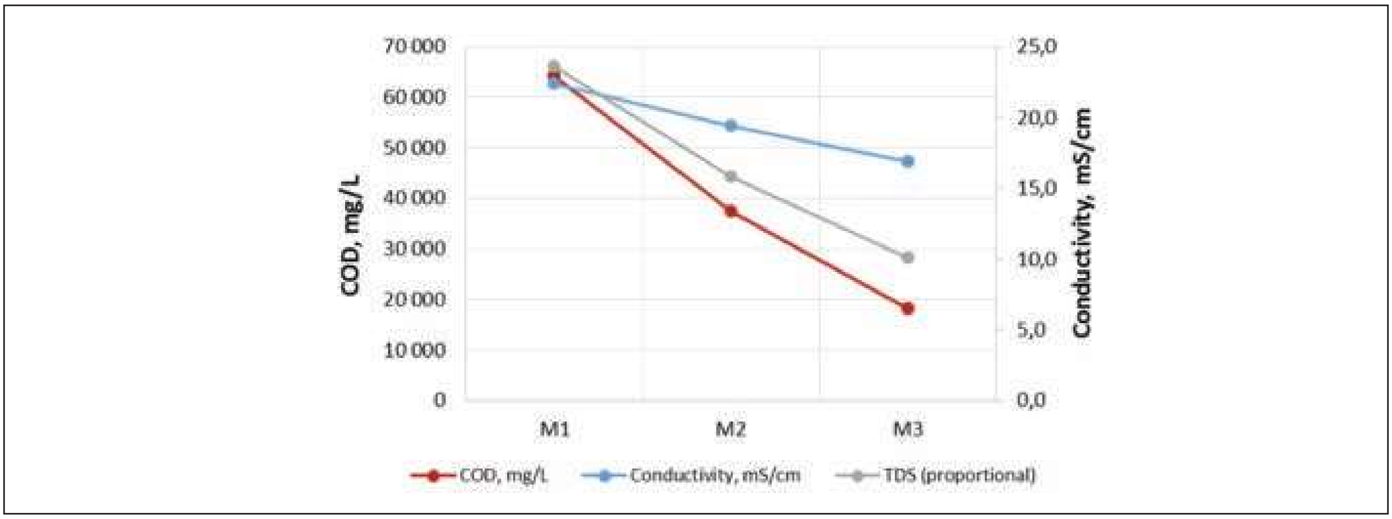
### *Pressure diffuser filtrate measurements, mill test*

**Figure 7a** shows the COD content of the SW pulp filtrate fraction (S3) when compared to the TDS measured with a portable refractometer, and Fig. 7b shows the conductivity content when compared to the TDS in the 5-day period. It can be seen from the figures that both the COD and conductivity behave similarly to the TDS. However, when comparing the COD and conductivity results over the diffuser washers, it can be seen that the organic material (i.e., COD) washes away relatively faster than the inorganic material (i.e., conductivity) (**Fig. 8**).

It was not possible to completely understand a clear reason for the better washability of the organic matter. The higher wash water temperature usually increases both the discharge of sodium and the lignin from the pulp via the leaching-out principle. However, this phenomenon in a real washer is very fast, so only the "free water" (between the fibers) in pulp suspension can be displaced and not the




***7. (a) Chemical oxygen demand (COD) content of the softwood (SW) pulp filtrate fraction from the S3 sample point shown in Fig. 1 compared to total dissolved solids (TDS) measured with a portable refractometer; and (b) conductivity content compared with TDS at the S3 filtrate sample point (Week I).***



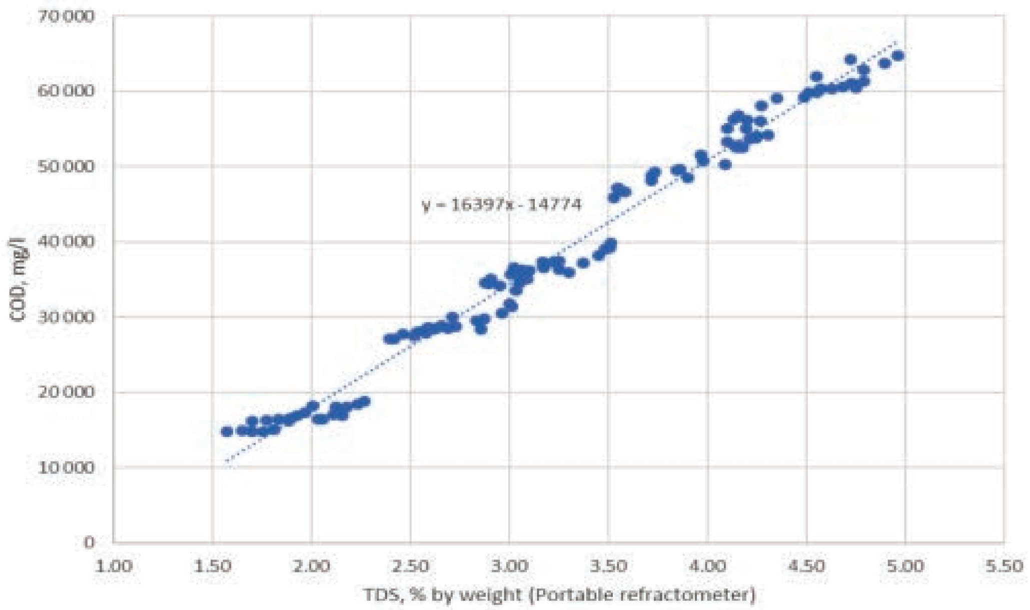

***8. COD of SW pulp filtrate fractions compared with conductivity at the beginning of the line, as measured at M1, M2, M3 refractometer sites shown in Fig. 1 (Week I).***

water inside the fibers (lumen). The high pH of the wash water heavily affects the fibers' surface charge so that non-ionized organic groups (e.g., carboxyls, phenols, hydroxyls, and hemiacetals) release hydrogen ions ($H^+$) and these ions exchange with wash water cations. This phenomenon explained the differences in the behavior of conductivity and organic matter levels. This being so, the conductivity would not give representative wash result information, and the COD would also give good wash results and be influenced by the non-washable components. Measurement using a refractometer shows the TDS content of washable compounds in the filtrate, which describes the washing efficiency relatively well.

**Figure 9** shows the observed relation between the COD content and the TDS content measured using a portable refractometer for the pressure and atmospheric diffuser filtrates of the SW line. The results show that the COD and refractometer had an excellent site-specific correlation ($R^2$ of 0.988). By setting the slope to the refractometer calibration, the refractometer can also be used for COD measurement at the mill. However, it is a good idea to check the calibration regularly (i.e., a few times a year). In addition, if two different alkali sources are used at the mill (oxidized white liquor and sodium hydroxide [NaOH]), then these calibrations may be affected.

## CONCLUSIONS

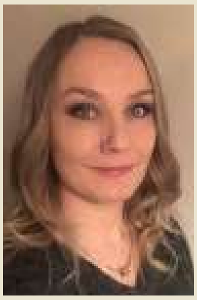
By utilizing refractometers and data analysis tools, it is possible to control the operation of the washer to an optimal value and to continuously evaluate the washing result. In this experiment, by finding optimal process values for the pressure diffuser washer and using online measurements for monitoring effectiveness, the effectiveness of the pressure diffuser could be increased at least one $E_{10}$ unit. The controlled parameters of the feed and discharge consistencies and the downward velocity of the screen had a clear impact on the operation of the pressure diffuser. In other words, it enables the improvement of the washer's efficien-




***9. COD content of filtrate fractions from diffuser washers analyzed in the laboratory versus TDS measured by a portable refractometer (Week I).***

## ABOUT THE AUTHORS

***Kopra***



***Pesonen***

***Käyhkö***

***Dahl***

Without efficient brownstock washing, kraft pulp production is not economically viable. In this study, we optimized the performance of diffuser washers. Effective brownstock washing requires reliable and real-time monitoring and control of equipment.

We have studied brownstock washing for a number of years, publishing articles in several journals and presenting our findings at conferences. Previously, we studied the optimization of the entire fiber line and a single drum displacer (DD) washer. Now we are focusing on diffuser washers.

The most difficult aspect of this study was to get the mathematical calculation based on the measurement results to work reliably. We worked with an Andritz expert on this. Through our work, we discovered the importance of accurate measurement technology for the effective control of washers. If the measurements do not give accurate results, the capacity to control the washers is diminished and money and environmental performance are lost as a consequence.

It was interesting to see that even minor changes in the operational parameter of the diffuser washers can improve the washers' efficiency. With the monitoring and control of diffuser washers' performance using the latest measurement technology, it is possible to achieve economic savings at mills.

We are now focusing on the performance of DD washers by utilizing the newest measurement technology. We are trying to discover the optimal values of the DD washers' washing stages, wash liquor distribution, and washing consistency.

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cy and reduces the level of wash losses entering the oxygen delignification stage.

The results indicated that when using different measurement methods for washer losses, the level differences remain quite constant. The results also showed clear differences between how organic and inorganic materials are washed away. Consequently, monitoring the performance of washing using only one method that emphasizes either organic or inorganic material can lead to misleading washing results. Measurement of washer losses using a refractometer shows the TDS content of washable compounds in the filtrate, which describes washing success relatively well. **TJ**

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