VAISALA

# BROWN STOCK WASHING OPTIMIZATION

## When a small percentage is worth a million

eBook

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# Introduction

*This eBook is intended for developers, managers, and operators of pulp mills.*

Recent studies show that kraft pulp processing is only economically viable if the brown stock washing (BSW) stage is operating optimally. The results of research presented in this eBook clearly demonstrate that BSW is a highly important step in the pulp production process because it not only affects subsequent production stages – such as evaporation, oxygen delignification, bleaching, and wastewater treatment – but it also has a significant impact on the economic viability of the mill as well as the end quality of the product.

In practice, evaluating the washing process is a complex task, and up until now there has not been a method that considers both the organic and inorganic fractions.

In this eBook we introduce a new measurement parameter, total dissolved solids (TDS), that considers both types of fraction and is proven to be a reliable parameter for measuring washing efficiency as it shows the real wash loss.

We also look at Vaisala's product innovation and its benefits.

For detailed product and application information, please visit the pulp, paper, and wood section of our website.

Contact our expert team to discover our full offering and discuss how we can help you to improve your process and applications.

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# Why optimize brown stock washing?

Brown stock washing happens very early in the pulping process and has a domino effect on the pulp mill's economics. Recent studies show that the washing efficiency of brown stock directly affects the mill's economic performance.

The purpose of BSW is to remove as much of the soluble organic and inorganic impurities as possible from a pulp suspension (brown stock) and to recover cooking chemicals and organics for energy recovery and steam and electricity generation – all while minimizing wash liquor or water consumption.

Chemical recovery has a significant positive impact on the economics of the process, but recovering black liquor solids is also important. Recovered organic compounds are used for energy production and have a direct effect on the consumption of bleaching chemicals and therefore the mill's environmental load.

Recovered inorganic compounds are used for regeneration of cooking chemicals; the more inorganics that are lost with the pulp, the greater the requirement for make-up chemicals in the recovery system.

Efficient BSW improves the performance of the oxygen delignification and subsequent bleaching stages by reducing the consumption of reagents. More of the spent chemicals are recovered and the effluent load of the plant is reduced. In addition, when substances like pitch and soap are removed during washing, the fiberline operates more smoothly.

### A small percentage is worth a million

A study by the Department of Forest Products Technology at Aalto University in Finland presented the case of a Scandinavian softwood mill fiberline.

The mill reduced the amount of dilution water, which increased the black liquor dry solids content by 1.4%. This in turn increased the evaporation process and led to a calculated gain of €1.2 million – a figure that could have been even higher if additional energy was sold to the grid.

In essence, BSW is affected by multiple factors that, when optimized, together can have a significant cumulative positive impact that mills cannot afford to overlook.

**€/$ 1 000 000**

**Gain**

# Pulp after different stages

## The most important factor for obtaining adequate brightness stability for pulp is the efficiency of the final washing stage.

# Traditional washing efficiency parameters

Evaluating the washing process is complex as there are multiple factors to take into account.

Traditionally there have been two main parameters used to describe the performance of washing efficiency: wash loss, which describes the amount of washable compounds in the pulp suspension which could have been removed in washing, and dilution factor (DF), which represents the net amount of water that is added during washing.

Other factors that also influence washing efficiency include:

- the inlet and outlet consistencies of the pulp
- the distribution and temperature of wash liquor
- air entrained in the pulp and liquor, and
- drum speed.

Mass balances, the displacement ratio (DR), and the Norden Efficiency Factor (E-value) are useful control tools that indicate the performance of the washing process and can be used to detect problems. However, the calculation of these variables has been difficult due to the lack of data and the lack of robust instruments capable of taking reliable inline wash loss measurements.

Conductivity is widely used for this purpose even though it is based on the measurement of the ionic sodium species in the liquor (inorganic phase) and does not directly measure the organic phase, notably lignin and hemicellulose. Similarly, chemical oxygen demand (COD) tests performed on the filtrate only indicate organic compounds.

Furthermore, off-line laboratory methods such as standard dry solids analysis, TOC, or COD analysis require considerable time, rendering them unsuitable for advanced process control.

**In summary, there are a few fundamentals that define a suitable measurement for determining real wash loss:**

1. The measurement should take into account both inorganics and organics.
2. The measurement should be inline and continuous, and must be able to be integrated into the control system.
3. The measurement must be reliable under even the most demanding process conditions.

**Vaisala has developed a measurement device tailored specifically to meet the needs of BSW covering both inorganic and organic fractions. The device measures total dissolved solids (TDS) to determine real wash loss. It enables pulp mills to measure TDS directly from pulp stock black liquor solids and make rapid adjustments to the process based on the results.**

# Introducing a parameter for real wash-loss: total dissolved solids (TDS)

TDS is a parameter for measuring washing efficiency. It takes account of both the inorganic and organic fractions, thus quantifying all washable solids. The result can be considered as the real wash loss. **(Figure 1)**.

In addition, from a practical standpoint, the evaluation of washing solids is simple, inexpensive, and repeatable.

## TDS measurements with a process refractometer

TDS is measured inline with a Vaisala Polaris™ PR53SD Process Refractometer. It calculates analysis concentrations (sum parameter) in time wash performance information while enabling a quick response to potential changes or disturbances in the process. The refractometer's output can also be calibrated to read COD.

Vaisala has over
**100 installations**
in BSW lines globally

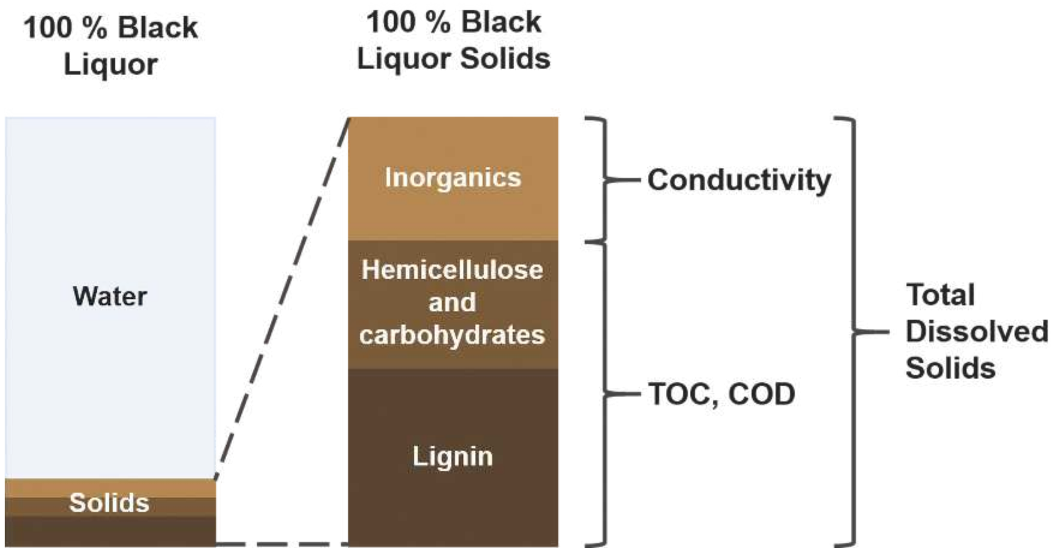


*Figure 1. Black liquor composition.*

# TDS measurements: Control strategies and benefits

When examining the overall economic relationship between operating cost and efficiency **(Figure 2)**, the first considerations are maximizing the solids yield due to its heat value in the recovery boiler and minimizing the dilution factor to reduce steam consumption in the evaporators.

The next factors to consider are the cost of make-up chemicals to compensate sodium losses and the cost of effluent treatment.

Other important considerations include the evaporator efficiency limitations faced by many mills and bleach chemical consumption in bleachable grade mills.

## Finding a balance

**Using excessive amounts of water will clean the pulp more thoroughly but skyrocket the heating and evaporation costs. Excess use of chemicals is not an option either. The key to optimal BSW is finding a balance between water and chemical use and employing inline, real-time measurement to provide accurate process data.**

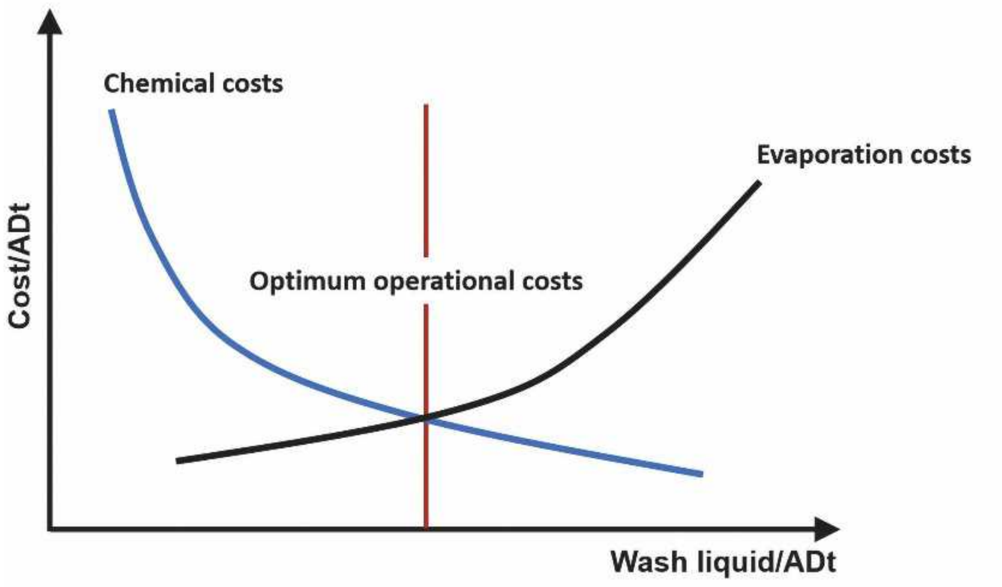


*Figure 2. The overall economic relationship between operating cost and efficiency.*

# Vaisala Polaris PR53SD Process Refractometer

The Vaisala Polaris PR53SD Process Refractometer makes it possible to continuously monitor individual process steps and control the whole washing line.

The refractometer is installed directly in the pulp or filtrate line. TDS changes are detected immediately in the feed and outlet stock lines, as well as in the incoming and outgoing filtrate lines.

The refractometer enables optimization of BSW through:

- Accurate, reliable, and continuous TDS measurements of the pulp suspension in the liquid phase for better control and continuous monitoring of individual washing stages.
- Improved economic and environmental performance of both washing and the overall pulp production process.

Once the mill has a sufficient number of inline TDS measurement instruments installed, it can calculate and optimize BSW variables such as the optimum dilution factor (DF) and displacement ratio (DR), the relative washing loss (1-Y), and the overall plant efficiency factor (E).

In its most basic form, washing system efficiency can be calculated based on TDS measurements. The ratio of dissolved solids entering the system with the pulp and leaving the system with the filtrate represents the quantity of solids removed **(Figure 3)**.

$$\%\ \text{Efficiency} = \frac{\text{Dissolved Solids to evaporation}\ \left(\frac{\text{weight}}{\text{ton of pulp}}\right)}{\text{Dissolved Solids to the washing system}\ \left(\frac{\text{weight}}{\text{ton of pulp}}\right)}$$

*Figure 3. washing system efficiency calculation*

*Vaisala Polaris PR53SD Process Refractometer*

# TDS measurements in individual washing stages: Pulp feed to washers

TDS measurement in the liquid from the blow pulp suspension after the digester enables monitoring of the diffuser operation.

Together with other measurements (e.g., filtrate and flush liquor) this provides the mill with the ability to control the performance of the washing zone in the digester. In addition, TDS measurement in the blow line allows the performance of the digester to be monitored, ensuring that it yields the correct concentration.

Vaisala recommends implementing three TDS measurement points around a continuous digester: wash liquor feed to the washing zone, flush liquor outlet, and blow line **(Figure 4).**

Combining data from these measurements enables continuous calculation of the mass balances and the creation of operating models of the digester.

Monitoring TDS in the liquor circulation flow of a batch digester helps to determine when the batch is ready.

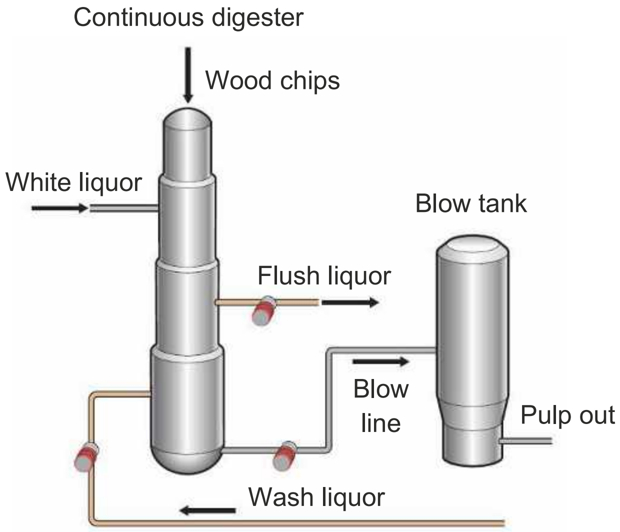


***Figure 4. Vaisala recommends implementing three TDS measurement points around a continuous digester: wash liquor feed to the washing zone, flush liquor outlet, and blow line.***

# TDS measurements in individual washing stages: Pulp feed to washers

Vaisala recommends implementing three measurement points in this stage: weak liquor inlet, liquor circulation flow, and pulp out **(Figure 5).**

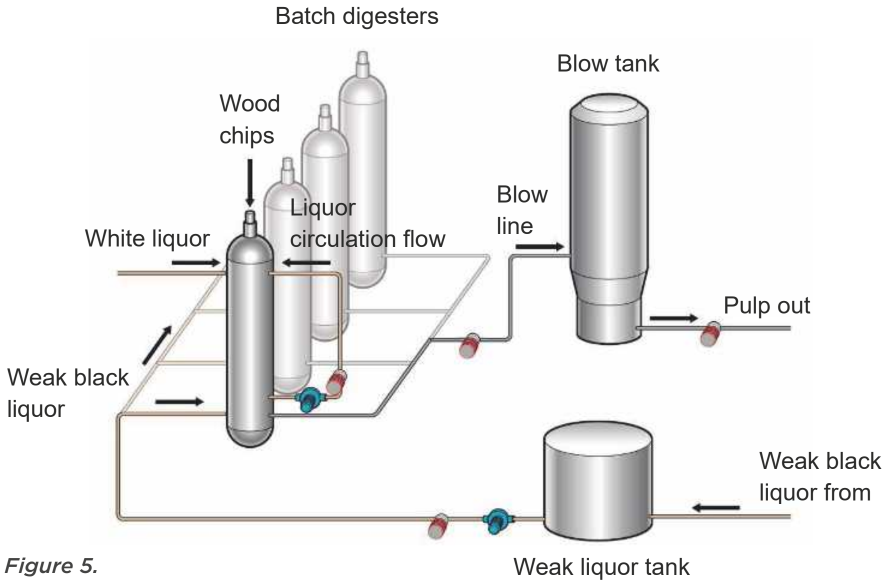


*Figure 5.*

> Without inline TDS measurements we could not see how our new high Kappa digester is performing. Blow liquor inline TDS is an excellent new tool to measure cooking efficiency and optimize the washing stage on the bottom of the digester.
>
> Pulp mill, northern Europe

# TDS measurements in individual washing stages: Digester and blow line

TDS content in the pulp suspension fed to the washing system varies continuously and significantly **(Figure 6)**. Traditional performance measurement parameters are not capable of detecting or measuring these variations accurately.

Consequently, any adjustments made to the process will be based on insufficient data and therefore have a negative impact on product quality and process economics.

The data in Figure 6 has been gathered using Vaisala's process refractometers.

Accurate and real-time inline TDS measurement of the feed pulp allows a quick response to process changes and prevents disturbances from being carried over into subsequent washing stages.

Process variables, such as the dilution factor, can be controlled in accordance with the properties of the inlet pulp and the mass balances can be continuously monitored.

> “If a variable is not measured, it cannot be controlled.”

*Figure 6: Example of a control chart showing TDS content in the pulp feed to a fiberline. This data is obtained by Vaisala Polaris PR53SD Process Refractometers.*

# TDS measurements in individual washing stages: Washing stage

The typical types of washers in pulp mills include rotary drums, diffusers, and extraction presses.

Regardless of washer type, the important TDS measurement points are the pulp inlet, pulp outlet, wash liquid feed, and wash filtrate **(Figure 7)**.

Inline TDS measurements facilitate the control of the washing stage and help to determine the optimum dilution factor, operation consistency, and optimum concentration of solids in the stream to the recovery boiler. This prevents excess water consumption in the washers and consequently reduces the consumption of energy and make-up chemicals.

Moreover, TDS measurements make it easy to continuously monitor mass balances and facilitate the creation of washing efficiency models either of a single washer or the whole washing line **(Figure 8)**. Real-time calculation of efficiency metrics such as the E-value and displacement ratio (DR) provides important information that enables operators to alter washing parameters when necessary, ensuring the best possible washing results.

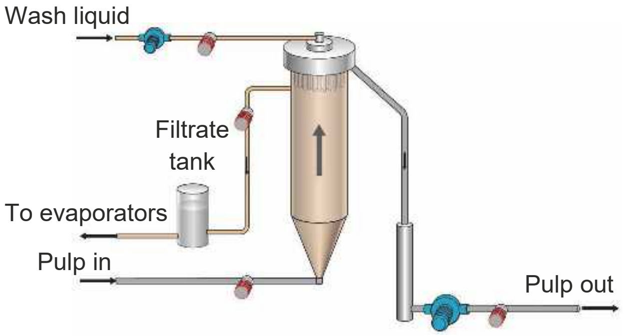


*Figure 7. Important measurement points include pulp inlet and outlet, wash liquid feed, and wash filtrate*

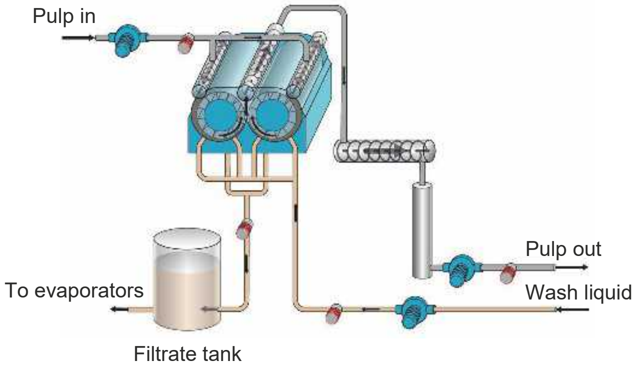


*Figure 8. Continuously monitor mass balances with TDS measurements and create washing efficiency models*

The Norden efficiency factor (E) defines the number of ideal stages required to achieve the same washing result as a given washing system or single washer. For example, a system with an E-value of 6 is equivalent to having six ideal counter-current mixing stages. Thus, the higher the value the better the washing efficiency **(Figure 9)**.

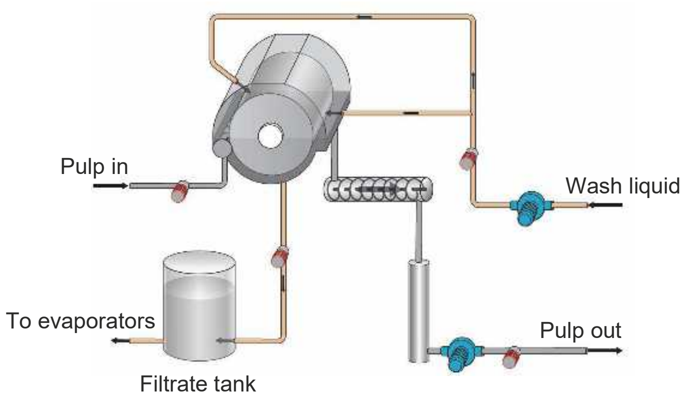
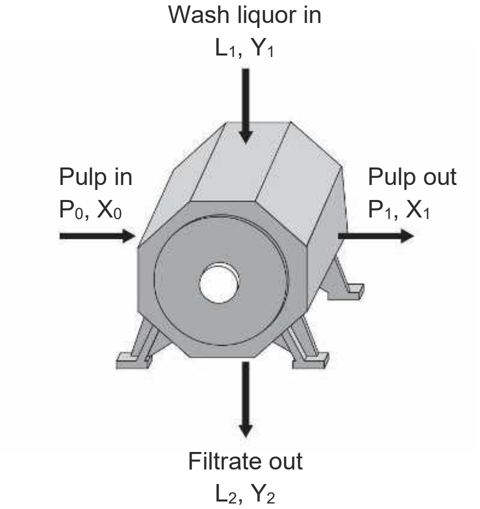


*Figure 9. Washing efficiency*

> **“With continuous inline TDS measurements, washing efficiency can be calculated and the process optimized using advanced process control systems.”**
>
> Global equipment manufacturer

$$\boxed{E=\frac{\log\frac{P_0}{P_1}\left(\frac{X_0-Y_2}{X_1-Y_1}\right)}{\log(L_1/P_1)}}$$

The DR is defined by the ratio of the actual reduction in solids content in a specific stage compared to the maximum possible reduction. Ideally, the wash water leaving the washing system should have the same dissolved solids content as the feed pulp.



$P_0$= Unwashed pulp stream
$P_1$= Washed pulp stream
$L_1$= Wash liquor stream
$L_2$= Filtrate stream
X= Concentration of dissolved solids in pulp stream
Y= Concentration of dissolved solids in liquor stream

$$\boxed{DR=\frac{X_0-X_1}{X_0-Y_1}}$$

*Figure 10. TDS measurements for washing efficiency*

# TDS measurements in individual washing stages: Pulp to oxygen delignification

It is common practice to use COD tests to estimate the wash loss to the oxygen delignification (OD) stage. However, COD tests only measure the amount of organic compounds present in the pulp suspension; many of these organics have no effect on the delignification reactions, while some may have a positive effect. In addition, inorganic compounds, which are not quantified by COD tests, can interfere with the oxidation reactions because they consume oxygen and increase the temperature in the reactors. Therefore, wash-loss measurements at the OD stage should cover all solid compounds dissolved in the pulp suspension.

Wash loss reduction in the inlet pulp to the reactors decreases the amount of alkali, which is consumed in neutralization reactions with the organic acids. Additionally, the temperature of the reactor is optimized, and the amount of oxygen decreased.

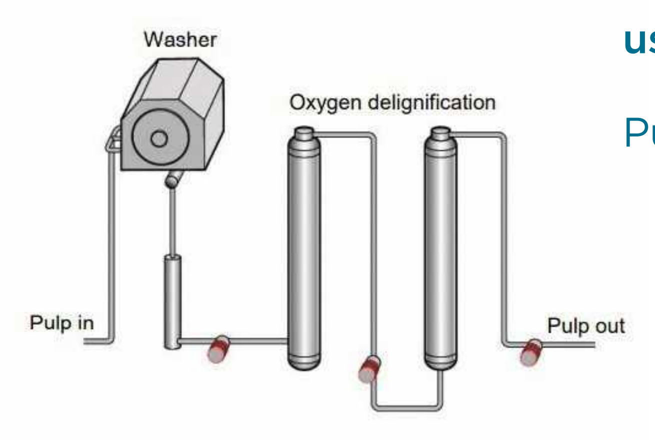


*Figure 11. In-line TDS measurements optimize the cost and performance of the OD process.*

> **“Brown stock washing and defoamer use can be optimized using inline TDS measurements.”**
>
> Pulp mill, North America

# TDS measurements in individual washing stages: Pulp discharge to bleaching

Wash loss to bleaching is usually measured by COD tests. However, many compounds that cause COD (e.g., methanol) do not have any effect on the Kappa number, viscosity, or ISO brightness of the pulp. It is important that the wash-loss measurement to bleaching is based on both organic and inorganic compounds. The remaining dissolved organics in the pulp increase the consumption of bleaching chemicals, while the inorganics may increase the final pH of the pulp slurry and necessitate the addition of acids to adjust the pH to achieve the optimum value. This increases operating costs.

Vaisala's process refractometers provide reliable continuous measurements of wash loss in the discharge pulp and make it possible to control the success of the washing process. Minimizing wash losses supports optimization of the subsequent process steps. Lower wash loss in the outlet pulp improves quality while also reducing chemical consumption in the bleaching step. Reliable measurements improve the environmental performance of the mill and reduce effluent treatment costs.

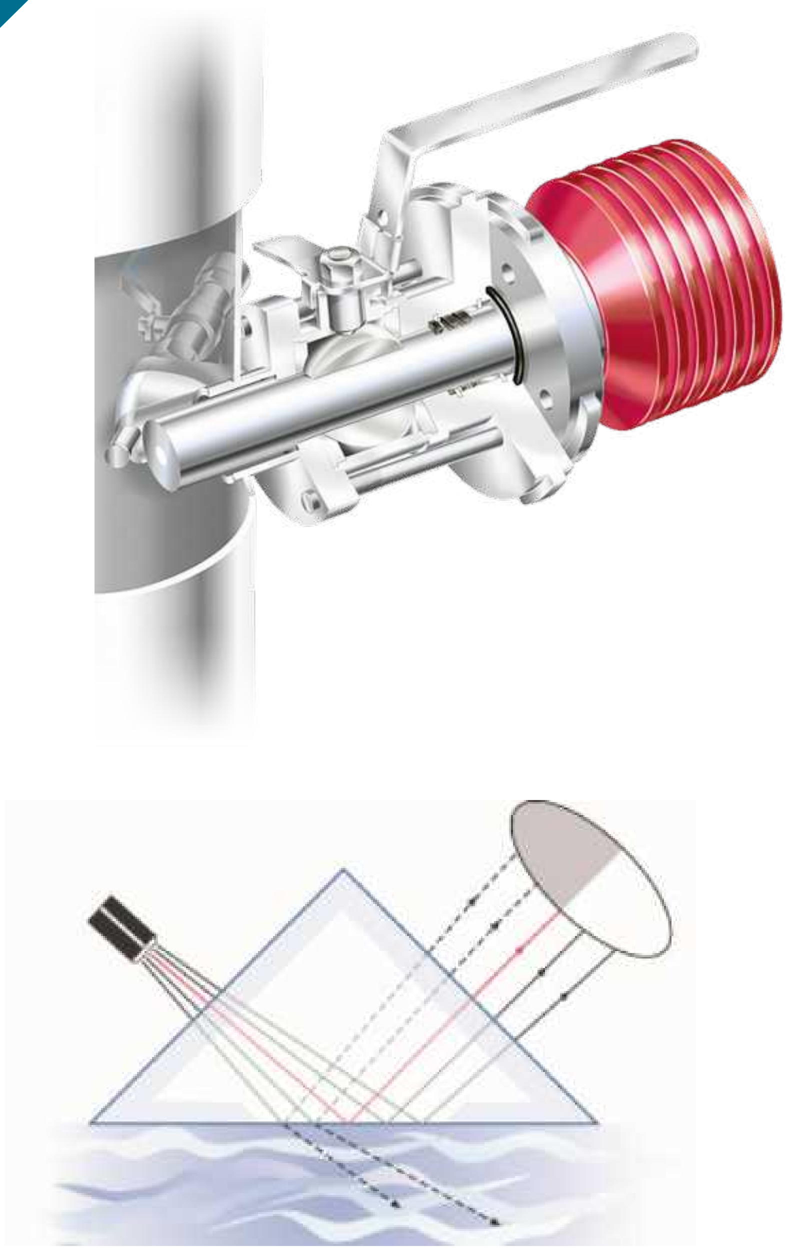


*Figure 12. Optical image detection allows sensor installation in the pulp stock line and eliminates consistency variation for accurate measurement.*

# Advanced process control for the washing line

Real-time inline TDS measurements from Vaisala's process refractometers can be used for advanced process control (APC) to enhance washing efficiency.

In APC, TDS measurements are used to:

- Adjust the dilution factor
- Control and minimize wash loss
- Monitor dry solids content to evaporation
- Ensure that the process operates within the mill's evaporation capacity
- Continuously monitor washer performance, e.g., DR or E-value (including alarm and/or automatic settings)

Vaisala recommends developing APC for the washing line as this will help to automate the control and reduce monitoring requirements, freeing up operators to perform other important tasks. All the TDS measurement instruments can be connected to the mill's own control system.

## Examples of APC strategies

### Dilution factor control

Conventionally, washers have been fed the amount of wash liquor considered appropriate depending on the conductivity of the outlet streams (e.g., filtrates). Inline TDS measurements along the washing line make it possible to automate the adjustment of the dilution factor based on TDS, liquor balance, and conductivity. This helps to achieve the correct solids content for evaporation.

### Washer-specific control

For example, drum rotation speed control in a DD-washer. This control can be built using a torque set-point given by the operator controlling the drum rotation speed to maintain constant torque. Torque control can maintain a higher and steadier washing consistency than conventional feed pressure control, resulting in higher washing efficiency.

**Wash liquor control**
Real-time TDS measurements in the pulp feed to the washing line detect changes in the concentration of the inlet liquor immediately and help to keep the concentration at the desired level throughout the whole line by using a wash liquor feedforward. This allows operators to react to disturbances immediately at the beginning of the line.

**Filtrate tank level control**
Filtrate tank levels are controlled automatically to prevent overflows and to ensure sufficient wash liquor volumes.

**Oxygen delignification control**
TDS measurement in the feed to the OD stage helps to adjust the delignification reaction parameters in accordance with the measured inlet concentration. For instance, an automatic control can be constructed and alarms can be set up to indicate if the TDS content exceeds the optimal setpoint. This helps to identify the correct chemical dosage and determine if there is a need to improve pre-oxygen washing parameters in order to avoid a rise in reactor temperature.

# Summary

BSW optimization is important in order to increase production rates while maintaining stability, minimizing steam and chemical consumption, improving washing efficiency and bleaching plant operation, avoiding process disturbances, and substantially reducing operating costs. An optimized washing line has a positive impact on the economics of the pulping process as well as the environmental load of the mill.

Vaisala is a global leader in weather, environmental, and industrial measurements. Building on over 80 years of experience, Vaisala provides observations for a better world, with space-proof technology exploring also Mars and beyond. We are a reliable partner for customers around the world, offering a comprehensive range of innovative observation and measurement products and services. Headquartered in Finland, Vaisala employs approximately 1,900 professionals worldwide and is listed on the Nasdaq Helsinki stock exchange.

K-Patents Oy, an industry leader and supplier of K-PATENTS Process Refractometers, was acquired at the end of 2018 by Vaisala. Following the acquisition, all K-Patents group companies are part of Vaisala.

Contact our expert team to discover our full offering and discuss how we can help you to improve your process and applications.

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