AFT SimAudit and its Use in the Simulation and Optimization of Pulp Screen Systems

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AFT SimAudit™ is a software program that has been developed to efficiently optimize pulp screen systems based on a combination of auditing and simulation capabilities. The software uses state-of-the-art mathematical models and a detailed characterization of pulp and contaminants to predict system performance. Debris removal efficiency, fibre fractionation, consistency variations and other parameters can thus be assessed as a function of typical hardware and process variables. The software is also integrated with auditing routines and computational tools to ensure accurate measurement of the current screen system performance. AFT SimAudit™ has been validated by comparing the predicted results to experimental results from pilot plant and mill-based screening studies. The predicted results were shown to have good agreement with mill and pilot plant measurements. Case studies are presented to demonstrate the value of simulation in real-world situations.

INTRODUCTION

Pressure screens are used to improve pulp quality by removing contaminants that reduce the appearance and strength of paper. In addition, quality can be improved by fractionating fibres for targeted processing or for use in specialty paper products [1]. Despite the widespread use of screening systems, ensuring the optimal performance of a screen system is difficult due to the large number of interacting design and operational variables, which include: system configuration, reject ratio, dilution flow rate, screen cylinder type (either holed or slotted), contour height, aperture size, etc. The optimal design and operation of screening systems requires an accurate and predictive model of the complex behavior of screens in order to apply an engineering approach to this design challenge.

One of the first commonly-used models of pressure screen performance was proposed by Nelson [2]. In this model, an empirical equation was used to describe the relationship between the contaminant removal efficiency and the mass reject ratio of the screen.

Gooding and Kerekes [3] modeled the flows in a pulp screen and defined an analytical relationship between debris removal efficiency and mass reject rate. The constants in the relationship were related to the separation of particles at a single aperture. In a separate study, theoretical predictions based on this same model were shown to agree with experimental results [4].

The concepts of barrier screening and probability removal were discussed by Gooding and Kerekes and included in their analysis: Barrier screening is defined as the complete removal of contaminants larger than the aperture size. Probability screening occurs when the contaminants are smaller than the aperture and their removal is less than 100%. The likelihood of a "probability contaminant" passing though the screen aperture depends on a range of factors such as the particle shape and flexibility as well as the flow field near the aperture.

Fibre fractionation is a process based entirely on probability screening since the smallest dimension of the fibres is less than the aperture size. Since contaminants have a broad distribution of sizes, their removal is governed by a combination of barrier and probability removal.

The importance of developing accurate models of screen performance is evident from the many recent theoretical and experimental studies that have been published [5-10]. These studies document the development of advanced, mechanistic-based models of contaminant removal efficiency; fractionation efficiency and consistency and the associated validation in pilot plant and mill studies.

Despite their power, these relationships describe the performance of individual screens, not screen systems. Screen systems are what determine product quality in mill operations. Some simple spreadsheet-based programs exist for making mass balances of mill screen systems. The spreadsheet programs do not, however, have integrated databases which, for example, include the dimensions of different screens. They cannot be quickly and easily configured to handle complex screen systems, including feedback. They are not typically designed to analyze a distribution of fiber lengths and a range of debris sizes. Most importantly, these spreadsheet programs do not have any predictive power. These programs do not have the capacity to *simulate* the effect of changes in process and hardware variables.

AFT SimAudit™ has all of these features. This paper considers how the fundamental relationships which describe individual screens are used to develop a comprehensive model of screen systems. AFT SimAudit™ also has an easy-to-use, graphical simulation environment that enables rapid development of screen system simulations. The simulation is integrated with an advanced audit feature that includes statistical data reconciliation [11] to ensure the best estimate of the screen system performance. Validation studies are made which compare AFT SimAudit™ predictions with pilot and mill performance and its use is demonstrated in a mill study. Finally, case studies are presented to demonstrate the value of AFT SimAudit™ in optimizing screen systems.

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Simulation and Audit Tool

AFT SimAudit™ is built on the most current mathematical models of screen performance. AFT's screening knowledge database and a statistically-rigorous audit system are also integrated into the software. Commercial software is used as a platform for implementing the advanced models and database information. This easy-to-use, graphical front-end allows rapid development of mill models and assessment of "what-if" scenarios. Figure 1 shows a simulation of a 3-stage screening system with a reject refiner in a Scandinavian TMP mill prepared using AFT SimAudit™.

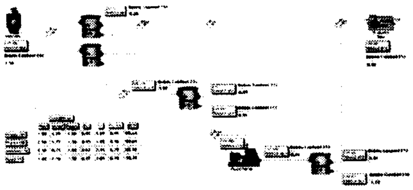

Figure 1. An AFT SimAudit™ simulation of a typical TMP screening system.

The simulation includes a database of screen types, rotor types and screen cylinder types for all major manufacturers, which allows all of the screens in the system to be quickly and accurately characterized. These and other features of the simulation are described below.

Advanced Pulp and Debris Characterization

Pulp type significantly affects the performance of the screen and screen system, with fibre length being the main property affecting performance. Figure 2 shows the length distributions for some typical pulp types, demonstrating the large differences in fibre length distributions between pulps.

To account for the effect of different pulp types AFT SimAudit™ uses the entire fibre length distribution and tracks 25 fibre length classes. The simulation is capable of reading data files produced by a FQA, Kajaani FS-200 or other commercial fibre length analyzers directly.

The benefit of tracking the detailed fibre length distribution is that it accurately calculates the degree of fractionation during each stage and throughout the entire screen system. Every screen will fractionate to some degree and alter the fibre length distribution between the feed, accept and reject lines. AFT SimAudit™ assesses these changes along with their cumulative impact on screen and screen system performance.

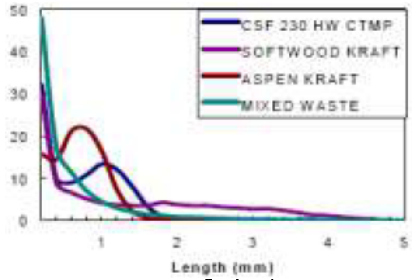

Figure 2. Fibre length distributions of various pulp types

AFT SimAudit™ also characterizes the size distribution of debris to accurately reflect the changes in debris content and character in the various screen stages. The debris size distribution enables the simulation to base its efficiency estimates on a combination of barrier and probability screening, depending on the relative size of the debris and the screen cylinder characteristics.

Mathematical Model

AFT SimAudit™ uses mechanistic and empirical models developed in various laboratories worldwide [3, 5, 6, 9, 10] in combination with AFT's screen performance database.

Following Gooding and Kerekes [3], the change in concentration of pulp and debris across a screen is derived using a plug-flow model of pulp screening. Figure 3 shows a cross-sectional element of a screen where Q is the axial flow rate upstream of the differential-element, c_u is the upstream concentrati--on of pulp or contaminants and P is the

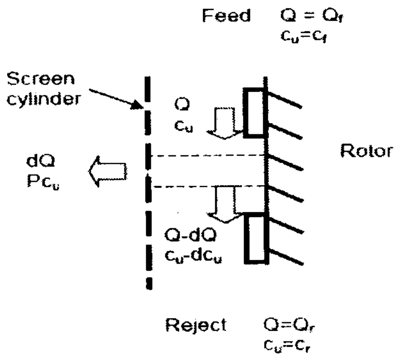

Figure 3. Mass balance through a cross-sectional element of the screen.

passage ratio of pulp or contaminants.

Passage ratio is defined as the ratio of the concentration of pulp (or debris) passing through the screen, c_s, to the upstream concentration of pulp (or debris), c_u, i.e.,

$$P = \frac{C_s}{C_u}$$

Assuming a plug flow condition in the screening zone, a simple material balance across the differential element gives:

$$Qc_u = Pc_u dQ = (c_u - dc_u)(Q - dQ)$$

Integrating this expression from the feed port to the reject port in a screen results in

$$\frac{C_r}{C_f} = R_v^{P-1}$$

where R_v is the volumetric reject ratio. This equation relates the concentration change of pulp and debris across a screen to the volumetric reject ratio, R_v

By employing a combination of mechanistic models and empirical correlations for passage ratio, the simulation is able to accurately predict the consistency change, change in fibre length distribution (i.e. fractionation), and debris removal efficiency for all of the key screening operational and design variables.

Data Reconciliation

Accurate measurements of screen system performance are inherently difficult due to the variability of the measurements, i.e., flow, consistency and debris content. Debris measurements can be especially difficult if the debris content of the pulp is low. An accurate audit requires several samples to be taken over an extended period of time, with each sample in turn being a composite of several samples. However, even with this large number of samples, there is still the opportunity to have a significant error.

To reduce uncertainty, AFT SimAudit™ uses data reconciliation techniques, with redundant data, to minimize the impact of measurement error. It assumes that the measurements are an unbiased estimate of the debris content, consistency or flow rate. In its simplest form, data reconciliation calculates an estimate of the error in the measurement from the redundant data and attempts to distribute this error to reduce the overall variation.

The basic concept of data reconciliation is best explained by considering a simple flow balance: Consider a single pulp screen with feed, accept and reject flow rates given by Q_f, Q_a and Q_r, respectively. In theory, the flow rates will balance, such that,

$$Q_f = Q_a + Q_r$$

However due to error in the actual measurements this seldom happens. The measurement error can be estimated by calculating the error in the flow balance, i.e., the magnitude of the measurement error, e, is estimated as

$$e = Q_f - Q_a - Q_r$$

In order to reduce the error in the flow measurements, flow rates are reconciled such that the estimated error is redistributed amongst the measurements to ensure a flow balance. In particular, each flow (i.e. feed, accept and reject) is adjusted by a fraction of the error, e, such that the fraction is proportional to the expected relative uncertainty of the measurement. For the example of the feed flow, one assigns a fraction of e that is proportional to the ratio of feed flow rate to total measured flow rate, i.e.,

$$\hat{Q}_f = Q_f + e\frac{Q_f}{Q_f + Q_a + Q_r}.$$

Similarly, one adjusts the accept and reject flow rates as

$$\hat{Q}_a = Q_a + e\frac{Q_a}{Q_f + Q_a + Q_r}$$

and

$$\hat{Q}_r = Q_r + e\frac{Q_r}{Q_f + Q_a + Q_r}$$

where $\hat{Q}_f$, $\hat{Q}_a$ and $\hat{Q}_r$ are the new estimates of flow rate through the screen. The feed, accept and reject consistencies and debris contents can be reconciled in a similar way. Furthermore, the entire system can be reconciled by taking advantage of any redundant measurements in the system [11].

AFT SimAudit™ automatically reconciles all flows in the system, ensuring the most accurate estimate of screen performance. These estimates ensure the best possible simulation.

Validation

In order to validate the predictive ability of AFT SimAudit™, a series of pilot plant and mill studies were conducted. Numerous configurations of screen cylinders, rotors and different pulp characteristics were used to establish a comprehensive validation.

Shive removal efficiency

Shive removal is essential to TMP screening and measurement technology exists to accurately determine the shive mass and size distribution. These detailed measurements make this parameter especially suitable for AFT SimAudit™.

A series of screening trials were conducted at STFI's pilot screening facility. Shive removal efficiency was determined for a wide range of rotor types, cylinder types, consistencies, flow rates and feed pulp freeness (i.e. CSF) levels.

The range of test conditions was:

- CSF	84 - 360 ml
- Consistency	0.9 - 2.5 %
- Slot size	0.15 - 0.25 mm
- Volumetric reject rate	4-35 %
- Slot velocity	0.8 - 2.5 m/s

Measured efficiency was compared to the predicted efficiency using AFT SimAudit™ as shown in Figure 3. This figure demonstrates the strong predictive ability of the simulation, with the mean error equal to 6.5%.

In a separate study, a series of trials

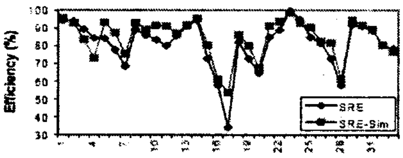

Figure 3. The experimental and predicted shive removal efficiencies.

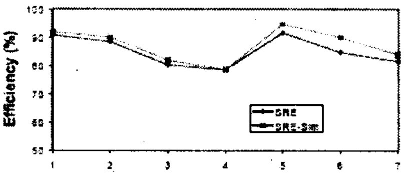

Figure 4. Experimental and predicted shive removal efficiencies for a single screen cylinder.

examined the shive removal efficiency for a single screen cylinder with varying CSF, reject and accept flow rates. The test conditions were:

- CSF	84 - 130 ml
- Consistency	0.9 - 2.2 %
- Volumetric reject rate	4-27 %
- Slot velocity	1.4 - 2.5 m/s

Figure 4 shows that under controlled conditions, the correlation between experiment and simulation can be very high, with the mean error less than 2%. The debris was characterized with a PQM analyzer to accurately establish the debris size distribution. Knowing the debris size distribution is crucial, not only for accurately calculating the efficiency of an existing system, but for predicting the efficiency of simulated systems.

Fibre fractionation

Fractionation is an increasingly important objective for many screen systems. This is especially true in TMP screening where selective refining of the long and coarse fibres can significantly improve the tensile strength and the surface and printing characteristics of the pulp [12]. Fractionation can also be a detrimental consequence of screening. For example, in kraft pulping it is desirable to retain the high quality, long fibre fraction.

AFT SimAudit™ predicts fibre fractionation and calculates the changes in fibre length distribution throughout the screen system. This enables the design of screen systems that can tailor fractionation for the mill requirements.

Fundamental equations have been developed to describe the effect of a wide range of design and operating variables on fractionation [9]. The accuracy of these equations has been confirmed in pilot plant trials. In this study, the predictive ability of the AFT SimAudit™ is examined in trials at two pulp mills: a Scandinavian TMP mill and a North American recycle ONP mill.

The Scandinavian TMP mill used wedgewire screen cylinders with a low contour height. The mean fibre length of the feed, accept and reject streams of the primary and secondary screens was measured and compared to the predicted values. Table 1 shows not only the ability of AFT SimAudit™ to accurately predict fractionation across a single screen, but to evaluate fractionation over the entire system.

Table 1. Simulation of fractionation at a Scandinavian TMP mill provided a comparison of fibre lengths (length weighted length, mm).

	Mill Primary	Mill Secondary	SimAudit Primary	SimAudit Secondary
Feed	1,61	1,80	1,61	1,77
Accept	1,48	1,56	1,49	1,49
Reject	1,80	1,90	1,77	1,94

The results from a similar study at the North American ONP mill are shown in Table 2. The simulation was again shown to provide a good prediction of fibre fractionation.

Table 2. Comparison of predicted and measured fibre lengths at a North American ONP mill (length weighted length, mm).

	Mill Pri.	Mill Sec.	Mill Tert	SimAudit Primary	Sim. Sec.	Sim. Tertiary
Feed	1.40	1.59	1.74	1,34	1.42	1,63
Accept	1,33	1.47	1.55	1.30	1,30	1,54
Reject	1.44	1.74	1,70	1,43	1,63	1,74

Power consumption

Power estimation and audit functions are also included in AFT SimAudit™. The rising cost of energy has made power reduction a priority at many mills and simulation allows them to evaluate the savings to be gained by eliminating a screen, using a different type of rotor or by simply reducing rotor speed.

The power estimation function built into AFT SimAudit™ considers such factors as: screen size, pulp consistency, rotor type and rotor tip speed. The strong correlation between the measured and predicted power is shown in Figure 5 for AFT's Gladiator HC™ rotor. The data represent a wide range of experiences, including both mill installations and pilot plant trials.

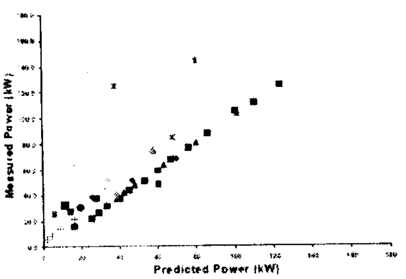

Figure 5. The strong correlation between measured and predicted power for a range of mill cases attest to the quality of theoretical power consumption model.

To better support decision-making in mills, AFT SimAudit™ includes a value-analyzer function, which expresses the benefits of a particular scenario in dollar-terms. The benefit of replacing a rotor with a more energy-efficient design can be seen in both engineering and economic terms to quickly make the cost-benefit analysis. A similar economic function is available to assess the value of reducing fiber losses from a screen system.

Stickies removal efficiency

"Stickies" removal is an essential concern of many deinked pulp mills. Slot width and passing velocity are two key variables in the operation of a deink mill. One seeks to run with the minimum slot width to maximize the degree of barrier screening and overall stickies removal efficiency. Mills will also monitor slot width in cases where the particular mode of wear at the mill leads to widening of the slots.

The sensitivity of stickies removal efficiency to slot width is shown in Figure 6 for both mill data and AFT SimAudit™ predictions. Note that AFT SimAudit™ is calibrated for each case (in this case for the 0.15 mm slot width) and so agreement at that point is not significant. What is meaningful is that AFT SimAudit™ enables one to predict the impact of changes in slot width to efficiency. There is some deviation between the prediction and the actual measurement as one moves further from the calibration point. This may be due to differences in the size distribution of the debris between the two cases. The size distribution of debris was not given along with the mill-based efficiency measurements and thus a default size distribution of debris was used for AFT SimAudit™ predictions.

Slot velocity is another critical variable in screen system optimization. Mills

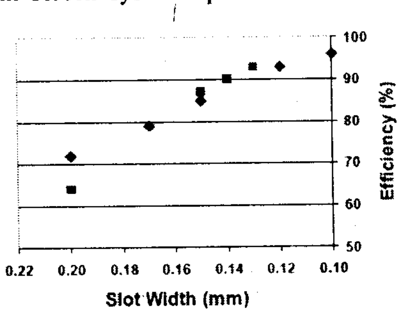

Figure 6. Sensitivity of stickies removal efficiency to slot width as measured in mill trials (in red) or estimated with AFT SimAudit™ .

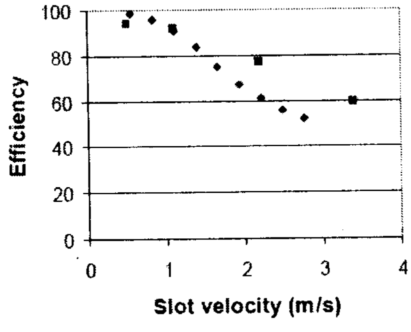

Figure 7. Sensitivity of stickies removal efficiency to slot velocity as measured in mill trials or estimated with AFT SimAudit™.

may increase slot velocity when increasing mill tonnage, in order to minimize capital equipment requirements or as a consequence of reducing slot width. Figure 7 compares data for mill-based measurements and AFT SimAudit™ predictions. AFT SimAudit™ has been calibrated to the mill data at a slot velocity of 1 m/s. The overall form of the two curves is quite similar, although the simulation results predict a sharper decrease in efficiency than was found in practice. As discussed for Figure 5, insufficient information about the size distribution of debris in the experimental measurements may be the cause for these differences. The character of the stickies (e.g. compressibility) may also be different.

Mill Case Study

After extensive validation testing, AFT SimAudit™ has been used to improve several screening processes by (1) optimizing current operation, (2) identifying and prioritizing screen cylinder and rotor replacements, (3) ensuring successful implementation of new cylinders and rotors and reviewing mill systems for possible energy savings. The following is a mill case study made for a recycled paper mill.

The mill produces approximately 240 tons of multi-layer boxboard per day. A detailed audit of the screening system revealed that the screens processing the pulp used in the bottom layer had poor runnability and high fiber loss.

The system balance was not easy to establish, as this particular mill had only reject flow meters. Despite this difficulty, a comprehensive audit was conducted using both simulation and data reconciliation to establish an accurate estimate of efficiency and fibre loss. In addition, a variable reject rate trial was conducted to establish the sensitivity of contaminant removal to reject rate on these screens.

The simulation was used to identify which new screen cylinder would provide the required efficiency while maintaining good runnability. The audit clearly showed that despite the high mass reject rate in the secondary stage, the performance of this screen was unacceptable. In this case, a high contour screen cylinder with different profile type was proposed.

As a result of installing the new

cylinder and adjusting the reject rates, the fiber loss to the system was reduced by 27% without any reduction in the global efficiency. In addition, fibre fractionation was reduced so that more of the high quality, long-fibred pulp was retained in the system accepts (Table 3).

Stage	Feed Cons%	Thickening	Mass Reject%
Primary	1,5	1,5	22
Secondary	1.6	1.9	38
Tertiary	1,9	1,5	51
System			7.2 tpd

Stage	Feed Cons%	Thickening	Mass Reject%
Primary	1,5	1,5	26
Secondary	1,6	1,4	28
Tertiary	1,3	1,4	51
System			5.2 tpd

Table 3. Screening system parameters before and after optimization demonstrating a savings due to reduced fibre loss.

CONCLUSIONS

A predictive, screen performance model and statistical audit methodolog-y has been integrated into a graphical, easy-to-use simulation environment that enables screening systems to be quickly and accurately modeled and optimized. This tool is called AFT SimAudit™. The simulation uses a detailed characterization of the pulp and contaminants to predict the fibre length distribution changes, debris distribution changes and consistency changes caused by each screen in the system.

The simulation predictions of removal efficiency, fractionation efficiency and consistency changes are shown to correspond well with experimental results in a series of pilot plant and mill scale screening trials. In addition, it has been demonstrated how the combined simulation and audit features can improve mill screening system performance. Both by lowering the system reject rate and reducing fibre loss, as well as reducing fractionation. The usefulness of AFT SimAudit™ has been extended by adding facilities for analyzing power consumption and providing economic assessments of power and fibre loss savings.

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