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A Case Study of AI-Driven Pulp Bleaching: Achieving Significant

Ganesh Bhadti*
Director (Operations)

B V Sivakumar*
DGM(CS)

D. Radhakrishnan*
CM (CRP)

** Seshasayee Paper and Boards Limited, Unit Erode.*

Abstract:

The pulp and paper industry faces increasing pressure to optimize operations, minimize environmental impact, and maintain product quality. Traditional pulp bleaching methods, relying on fixed parameters and operator experience, often struggle with raw material and process variability, leading to chemical over-consumption, inconsistent quality, and increased environmental burden. This paper explores the transformative potential of Artificial Intelligence (AI) in revolutionizing pulp bleaching, specifically at Seshasayee Paper and Boards Limited (SPB, Unit Erode). By leveraging machine learning, advanced data analytics, and predictive modelling, AI-driven solutions enable precise control and optimized chemical usage. These systems learn from historical and real-time data, dynamically adjusting process parameters to minimize chemical consumption while consistently achieving target brightness. This paper presents a case study showcasing the practical application of AI at SPB in a real-world pulp bleaching scenario, demonstrating significant improvements in chemical usage, potentially brightness consistency, and overall operational efficiency. The study highlights the benefits of AI, including reduced chemical costs, enhanced sustainability through lower effluent loads, and increased operational efficiency through automation. Finally, the paper discusses future trends, such as integrating advanced sensors, real-time data analytics, and cloud-based AI platforms for further enhancing performance and sustainability.

Keywords: *Data Analytics, Artificial Intelligence (AI), Process Optimization, Consistent quality, Sustainability.*

Introduction

Digital transformation refers to the integration of digital technology into all areas of business. In the manufacturing sector, this includes the use of advanced technologies for production processes, supply chain management, and product development, among other areas.

Digital transformation is not merely about digitizing existing processes. Instead, it involves rethinking old operating models to improve efficiency, enhance product quality, and deliver better customer service. This transformation can involve everything from automating production lines to utilizing data analytics for decision making.

Introduction to Pulp Bleaching Control:

Pulp bleaching involves a series of stages, each utilizing different chemicals to progressively lighten the pulp. Effective control of these stages requires managing several key parameters, primarily brightness and pH. Achieving target brightness levels while maintaining optimal pH within each stage is critical for maximizing bleaching efficiency and minimizing fiber damage.

Traditional control methods often rely on simple feedback loops, adjusting chemical dosages based solely on downstream measurements. However, modern bleaching plants utilize more advanced strategies, incorporating feedforward control, software sensors, and sophisticated algorithms to achieve tighter control and improved performance.

SPB Bleaching Sequence & Instrumentation

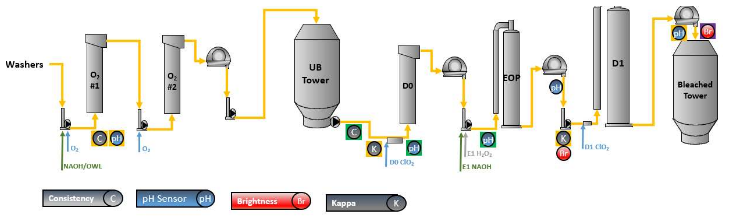

Fig 1: SPB – Bleaching sequence

This case study examines the control strategies employed in a pulp bleaching plant, focusing on the sophisticated methods used to manage chemical addition for optimal brightness and pH control. The bleaching process is crucial in pulp production, aiming to remove lignin and other impurities to achieve desired pulp brightness for various paper grades. Efficient and precise control of this process is essential for product quality, minimizing chemical usage, and reducing environmental impact.

Implementing AI Solutions for Bleach plant optimization

Integrating artificial intelligence (AI) into the paper and pulp manufacturing process is not an overnight task. It requires careful planning, execution, and continuous improvement. In this section, we explore the steps to adoption, potential hurdles, and the future of AI in this industry.

Method of Adoption

The first step in implementing AI solutions in paper and pulp manufacturing is understanding the industry's specific challenges that AI can address. This includes equipment malfunctions, quality control issues, and inefficiencies in the production process. Once these problems are identified, AI models can be developed to predict, diagnose, and rectify these issues.

Next, the necessary infrastructure for AI adoption must be set up. This includes data collection systems, data processing capabilities, and AI software. It's important to ensure that the data collected are accurate and complete, as they form the basis for AI model training.

Once the AI models are developed and trained, they can be deployed into the production environment. It's crucial to monitor their performance and make necessary adjustments to ensure they are working effectively and delivering the desired results.

Lastly, employees must be trained to work with these AI systems. This includes understanding how to interpret the AI's predictions and take appropriate action.

General Control Strategy: Feedforward and Feedback Integration:

The core control philosophy employed in our plant is the integration of feedforward and feedback control mechanisms for each bleaching chemical. The dual approach allows for both proactive and reactive adjustments, resulting in more stable and efficient operation.

• **Feedforward Control (Proactive):** This component anticipates chemical demand based on incoming process conditions. By analysing upstream parameters such as pulp flow rate, incoming pulp brightness, and other relevant measurements, the controller predicts the necessary chemical dosage to achieve the desired downstream target. This proactive approach allows for immediate adjustments, minimizing deviations from the target and reducing the impact of process disturbances.

• **Feedback Control (Reactive):** This component monitors the results of the chemical addition by measuring the output of each stage. Parameters such as brightness, pH, and residual chemical concentrations are measured downstream of each bleaching stage. These measurements are then compared to the desired setpoints, and the controller adjusts the chemical dosage accordingly to correct any deviations. This reactive approach provides continuous correction and ensures that the process stays on target despite unforeseen disturbances or model inaccuracies.

The combination of feedforward and feedback control provides a robust and effective control strategy. The feedforward component minimizes the initial deviation from the target, while the feedback component corrects any remaining error and compensates for unmeasured disturbances.

pH Control: A Critical Parameter:

pH plays a crucial role in the effectiveness of each bleaching stage. Maintaining the correct pH range is essential for maximizing the efficiency of the bleaching chemicals and minimizing fiber damage. The plant utilizes specific pH control strategies tailored to each stage, employing both direct and indirect control methods.

- pH Adjustment Chemicals: Two primary chemicals are used for pH adjustment:

  o Acid (e.g., Sulfuric Acid): Used to decrease pH. Increasing acid addition lowers pH, while decreasing acid addition raises pH.

  o Caustic (e.g., Sodium Hydroxide): Used to increase pH. Increasing caustic addition raises pH, while decreasing caustic addition lowers pH.

Stage-Specific Control Strategies in Bleach Plant:

The following sections detail the specific control strategies implemented for three key bleaching stages: D0, EOP, and D1.

D0 Stage Acid Control:

The D0 stage is typically the first bleaching stage, utilizing chlorine dioxide ($ClO2$) as the primary bleaching agent. Precise pH control in this stage is critical for optimal $ClO2$ effectiveness.

- Control Target: The primary control objective in the D0 stage is to maintain the inlet pH to the stage within a specific range.
- Control Method: The control system adjusts the acid addition rate to manipulate the inlet pH. The control strategy is based on an indirect approach, where the inlet pH is slowly varied to achieve the desired outlet pH.
- AI Modelled Software Sensor (SWS) for Feedback Correction: A software sensor plays a vital role in refining the D0 pH control, generates a correction signal for the model algorithm. This feedback loop ensures that the outlet pH remains within the desired range, even with process variations or disturbances.

2. EOP Stage Caustic Control:

The EOP stage (Extraction with Oxygen and Peroxide) is an alkaline extraction stage designed to remove residual lignin after the D0 stage. Precise pH control is vital for maximizing lignin removal efficiency.

- **Control Target:** Similar to the D0 stage, the control objective is to maintain the inlet pH to the EOP stage within a specific range.
- **Control Method:** The control system adjusts the caustic addition rate to manipulate the inlet pH. Again, the control strategy, adjusting the inlet pH to achieve the desired pH
- **Software Sensor (SWS) for Feedback Correction:** A software sensor is also employed in the EOP stage to refine pH control. The SWS generating a correction signal to adjust the inlet pH setpoint and maintain the pH within the target range.

3. D1 Stage Acid Control:

The D1 stage is another chlorine dioxide bleaching stage, typically following the EOP stage. This stage further reduces the lignin content and improves pulp brightness.

- **Control Target:** Unlike the D0 and EOP stages, the D1 stage control directly targets the vat pH (measured in the lab). This is because there is no online pH probe available at the D1 inlet.

- **Control Method:** The control system directly adjusts the acid addition rate to manipulate the vat pH. Increasing acid addition lowers the pH, while decreasing acid addition raises the pH.
- **Feedforward Control Components:** Due to the lack of an inlet pH measurement, the D1 control strategy incorporates feedforward components to improve performance. These components are D1 ClO_2 dosage and Eop Outlet Filtrate pH

Table 1: Control and Projection models

CTRL and Projection Models (FB) Only Projection Model (FF) + Positively Related - Negatively Related		Manipulated variables					Feed Forward variables			
		D0 H2SO4	D0 ClO2	Eop NaOH	Eop H2O2	D1 ClO2	FF D0 BLT	FF D0 pH In	FF Eop pH In	FF D1 BR In
Control Variables	D0 pH in	-	-							
	D0 pH out	-	-					+		
	Eop pH in			+						
	Eop pH out			+					+	
	D1 Brightness in		+		+		-			
	D1 pH out									
	Final Brightness					+				+

Control Loop Analytics & Feedback corrections for continuous improvement

The core objective of continuous loop monitoring is to automatically provide a qualitative answer of how well control loops are controlling their respective process variables and elevate attention to the user of those loops that are not performing satisfactorily. Everything else is built on top of that layer. In order to quantify the different problems a control loop may be suffering, the AI Algorithm define 4 main metrics such as Set Point Tracking, Disturbance Rejection, Oscillations, Linear Actuator issues.

The Software used a metric called COV (Coefficient of Variation) to measure how well a control loops is doing the job of keeping the process variable close to the established set point. The coefficient of variation is expressed as a percent of the PV scale. A threshold for that metric is defined at different levels to indicate when the set point tracking is acceptable or not for a given loop. As a way of measuring how well the control loop recovers from disturbances, we define a disturbance response index. The value of the index gives information on the nature of the response, that is classified into Aggressive, Good or Sluggish. The algorithm that calculates the actuator performance index looks for non-linearities in the behavior of the controller output. The significant presence of non-linearities in the behavior of the actuator position is an indication of problems like backlash, stiction or the positioner (e.g. excessive wear in the position feedback arm of a sliding step valve)

Implementing the recommended tuning parameter adjustments has significantly improved the stability of control loops important for AI based controls, as below.

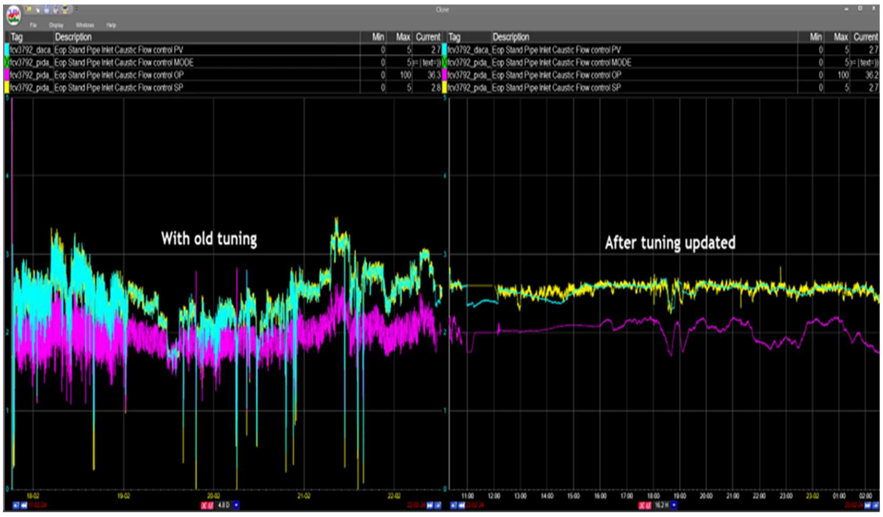

Fig 2: Impact of Tuning of valves

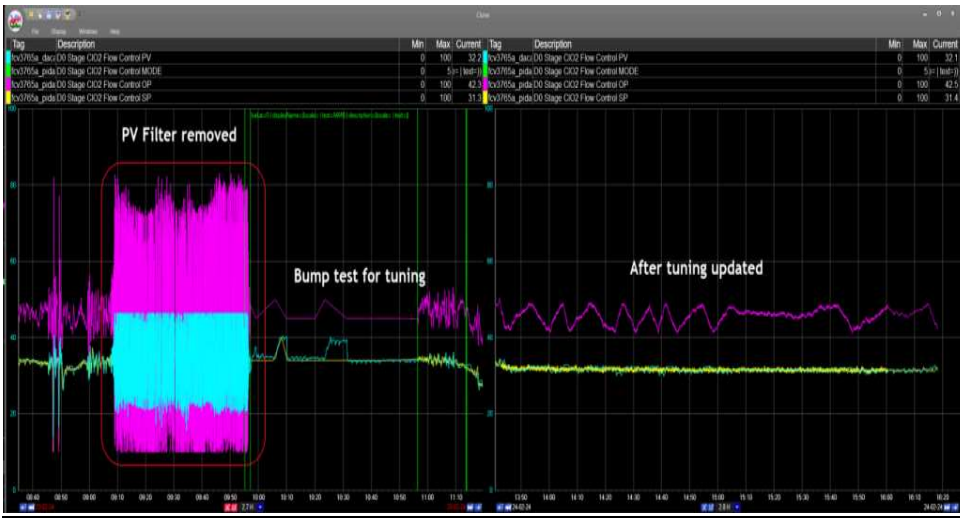

Fig 3: Impact of Tuning of valves during bump test

An automated daily report with control and performance summary contains a table of Chemical Control loops. The AI Program evaluates the loop's performance on a daily basis. A Red cell indicates an issue with the Control Loop. An issue is found out with a detailed drill in capability of the software.

Table 2 : Report on Chemical control loop summary

Manipulated Variables	Setpoint	Distrubance	Oscillation	Valve
D0 Acid (3766A)				
D0 ClO2 (3765A)				
Eop NaOH (3792)				
Eop H2O2 (3790)				
D1 Acid (3817A)				
D1ClO2 (3825)				

Software Sensors (SWS): Enhancing Control Performance:

Software sensors play a crucial role in enhancing the control performance of the bleaching plant. These sensors combine data from multiple sources, including online process measurements and offline lab analyses, to provide more accurate and reliable estimates of key process parameters.

- Data Integration: SWS integrate data from various sources, such as inline pH probes, flow meters, and lab measurements of brightness and pH.
- Improved Accuracy: By combining multiple data sources, SWS can provide more accurate estimates of process parameters than relying on individual sensors alone.
- Feedback Correction: As demonstrated in the D0 and EOP stages, SWS are used to provide feedback correction to the pH control loops, ensuring that the vat pH remains within the target range.
- Importance of Calibration: The effectiveness of SWS relies heavily on the accuracy and calibration of the underlying physical instruments. Well-calibrated and functioning instruments are essential for the SWS to provide reliable data.

Results and Discussions

1. Realtime Visualization: As part of the Control development, a real-time Dashboard & Trends are prepared in the Operator Control Room. Operators can see the future predictions for MVs and CVs on trends.

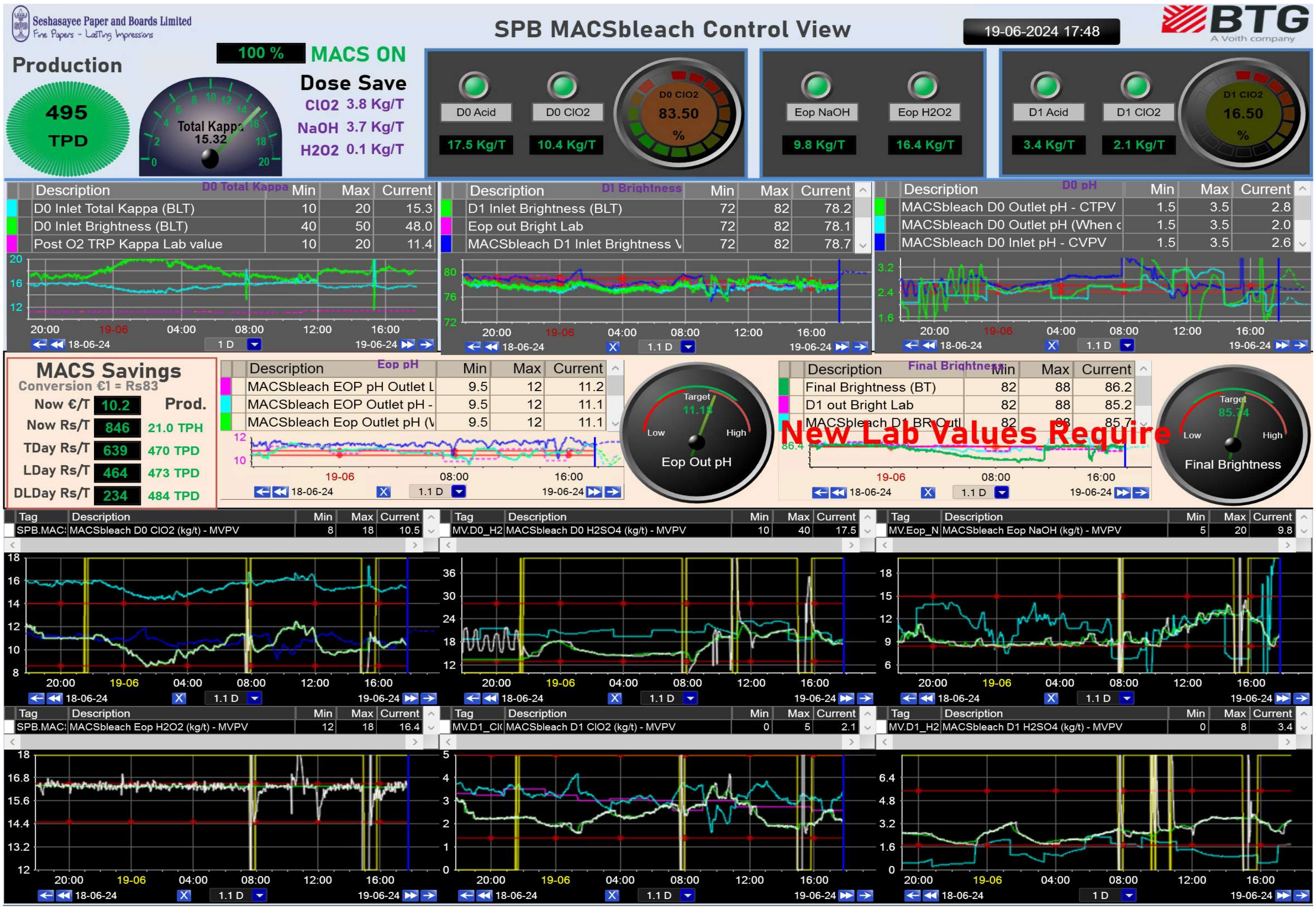

Fig 4: DCS snap shot on real-time visualisation

2. AI Based Control development and Configuration: Dynamics limit based on Kappa factor for D0 ClO2, to address the sudden swings in incoming kappa. Eop NaOH to outlet pH control, key improvement was using Eop filtrate pH in controls. D1 feed forward and feedback control to achieve maximum variability reduction in Final Brightness. D1 Acid Control, no inline pH measurement, used D1 ClO_2 & Eop Filtrate pH as feedforward and D1 vat pH (lab) as feedback signal.

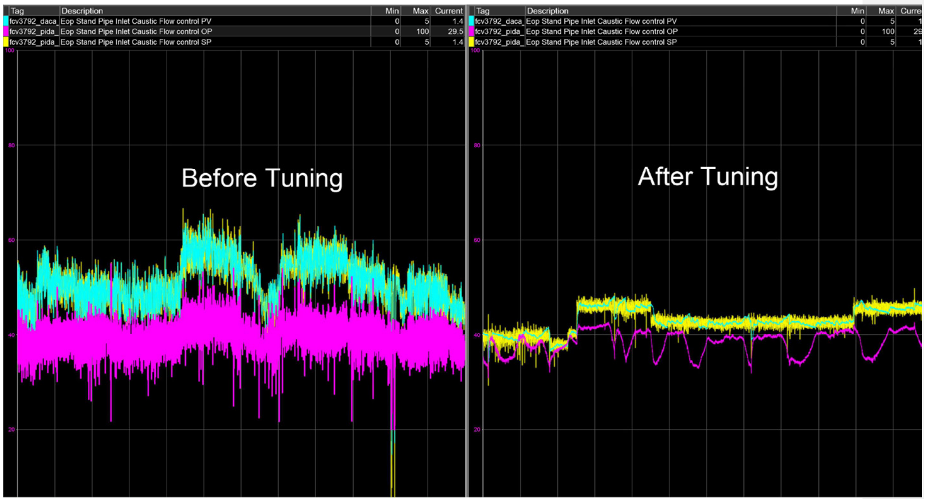

Fig 5: DCS snap shot on valve opening

3. ClO_2, Acid and Caustic Controls results before and after AI control Implementation.

   ClO_2 Savings are generated from Stagewise optimization and Brightness target variability reduction. Whereas NaOH savings are majorly generated from Optimizing the controlled pH range for Eop stage & shifting the target for Eop outlet pH range from 11-11.5 to 10 – 10.5

Table 3: Comparison on major parameters

Main Parameters Comparison		
	Before	**After**
Production	**443 TPD**	**453.5* TPD**
D0 inlet fiber kappa	**10.91**	**11.97**
Final Brightness	**85.75**	**85.79**
Total ClO2 (kg/ton)	**17.47**	**15.84**
Total NaOH (kg/ton)	**14.05**	**12.66**

- **** Production rate based on Plant demand***

Conclusion:

This case study highlights the advanced control strategies employed in a modern pulp bleaching plant. The integration of feedforward and feedback control, along with the use of software sensors, allows for precise and efficient management of chemical addition and pH control. These sophisticated methods contribute to improved pulp quality, reduced chemical consumption, and minimized environmental impact. The stage-specific control strategies, tailored to our unique characteristics of each bleaching stage, further enhance the overall performance of the bleaching process.

The use of software sensors, while powerful, emphasizes the continued importance of accurate and reliable physical instrumentation. This combined approach represents a significant advancement in pulp bleaching control, enabling optimized operation and consistent product quality.

The authors express their sincere gratitude to the management of SPB for their support and for sharing the results of this successful implementation.