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Sustainability through Technology Integration by Advanced Process Control for Continuous Digester and Fiberline Stabilization

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Abstract: *APC (Advanced Process Control) is a tool that opens up an infinite number of opportunities, leading to a more efficient and profitable future. It is all about collecting information, compiling it, interpreting it, and optimising the process. As part of the mill expansion programme, TNPL commissioned a modern hardwood ECF (Elemental Chlorine Free) pulp mill along with a Chemical Recovery Island. The modern pulp mill was commissioned with APC in the continuous digester and fiberline Stabilizing Control (FSC) in the fiberline. This APC aims to maintain a consistent cooking kappa number as production rate changes. It calculates and coordinates changes in cooking temperature, chip feed flow, blow flow, white liquor flows, and other incoming and outgoing flows. The APC enables reduced quality variations and higher energy efficiency. FSC for the fiberline calculates and coordinates changes in fiberline production, kappa/brightness variations, ODL kappa reduction, wash liquor balance, and bleaching chemicals. This has resulted in an outstanding benchmark in chemical, steam, and water consumption, and in reduced downgrade of bleached pulp. FSC is based on chemical charges, residence time, temperatures, and incoming kappa/brightness. Variations in outlet kappa, brightness, and final pH are considerably reduced by implementing FSC. Sustainability in production, quality parameters, benchmark chemicals, and utility consumption is achieved through the integration of APC and FSC.*

Keywords: *Sustainability, APC, FCS, Continuous Digester, Hardwood Pulp, Technology Integration.*

1. Introduction

APC is an overarching term for control algorithms that optimise plant operations in real time. APC is an intelligent tool above a facility's foundational Distributed Control Systems (DCS). In the pulp and paper industry, APC refers to prognostic software that controls operations by continuously making positive adjustments to production variables. It minimises quality variations, reduces chemical and energy consumption, and optimises production rate. APC enables reduced quality variations and higher energy efficiency. Detailed tuning by process engineers is performed via dedicated displays.

Major benefits of APC include Increased Throughput by maximising production output while consistently driving equipment to optimal operating limits safely. Energy Reduction by dynamically adjusting variables to minimise power and fuel consumption. Enhanced Sustainability by automatically compensating for multivariable interactions and process disturbances, eliminating human-error-induced variations. Reduced Waste by producing more consistent products, decreasing the need for rework and discarding waste materials.

TNPL has implemented the Mill Expansion Plan (MEP Phase-1) at the Board plant (Unit-II), which includes the installation of a modern hardwood ECF pulp mill and a Chemical Recovery Island. The project was commissioned on 31st July 2022 and features the latest technology across all sections, with an emphasis on environmental performance and high energy efficiency. The modern pulp mill was commissioned with APC in the continuous digester and FSC in the fiberline. To implement APC, we had detailed discussions with M/S Valmet, drawing on their experience with our existing pulp mills.

At the new pulp mill, the APC consists of a production-rate change program to maintain a consistent kappa number from the digester during rate changes. It also serves as the master for all other modules. The program sets the target production, which is used in almost all APC calculations. FSC in the fiberline delivers consistent pulp quality with low specific consumption of wood chips, chemicals, water, steam and power, and low effluent generation.

The main components are: 1. Production rate change and Fiber balance, 2. Liquor balance, 3. Alkali control and 4. Temperature control

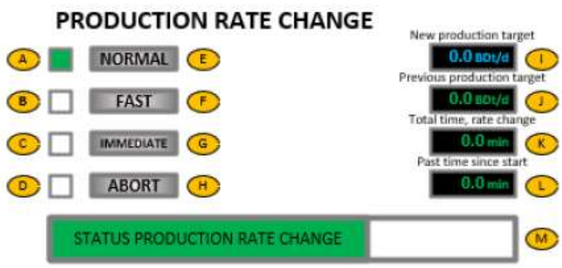
Principles and Procedures

Cooking Plant: The Cooking Plant APC overview is shown in Fig. 1. The overview presents all controls on a single display page for simplified monitoring. This includes Chip levels, Liquor levels, Liquor/Wood ratios, Alkali charges, Temperatures, Heat recoveries, and Fiber production. To activate an APC controller, the slave to be controlled should be switched from auto (AUTO) or manual (MAN) to cascade (CAS) mode. CAS mode means the controller uses an external set point, which in this case comes from APC. To deactivate an APC controller, switch the slave controller from CAS to AUTO or MAN mode. Some APC controllers can use higher-level controllers. Switching the APC controller to cascade mode will activate the higher-level controller.

Figure 1. Cooking plant APC overview

Normal production rate change

The program calculates and coordinates the appropriate changes to cooking temperatures, chip feed rate, blow flow, white liquor flows, and other inlet and outlet flows.



The normal production rate change is used when small variations in kappa number are the highest priority. During a normal production rate change, temperatures are first ramped to those corresponding to the new production rate, with a ramp time roughly equal to the chips' residence time in the cooking zone at the current production rate. After that, the chip-measuring screw speed, blow flow, white liquor flow, etc., are ramped to their new values (Fig. 2). The length of the ramp depends on the magnitude of the change in the production target.

Fast production rate change

The fast production rate change is used for unplanned changes when speed is more important than quality. In this case, the H-factor will not remain constant during the change, causing variations in the kappa number. The cooking temperature is ramped quickly to the temperature relevant to the new production rate (Fig. 3). After that, the chip screw, blow flow, etc., are ramped to the new production level.

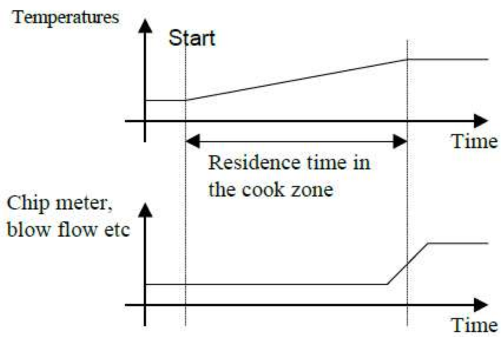


Figure 2. Normal production rate change (increasing)

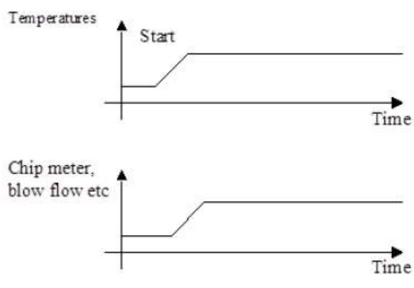


Figure 3. Fast production rate change (increasing)

Fiber production control

The controller is allowed to adjust the flow within a limited range around the nominal flow. The nominal flow is calculated from the production target and an adapted slurry consistency by controlling the following parameters.

- Control of the chip volume flow
- Control of the ImpBin chip level
- Control of the digester chip level
- Control of the blow line consistency

Liquor Balance

The system is configured with two liquor-level control strategies. The operator display selects which alternative to use, enabling the appropriate controllers.

Liquor level control alternative 1: The liquor level in ImpBin is controlled by liquor flow into ImpBin. Feedforward is calculated from a flow balance over the ImpBin vessel. Digester liquor level is controlled by the extraction flows from the digester to the evaporation. Feedforward is calculated from a flow balance over the digester vessel. This alternative keeps the liquor level in both vessels at the target. Still, the extraction flows to evaporation will vary more than in alternative 2, which could also cause variation in other liquor flows between the digester and ImpBin.

Liquor level control alternative 2: ImpBin liquor level is controlled by extraction flows from the digester to evaporation. Feed forward is calculated from a flow balance over the whole cooking plant. In this mode, the ImpBin liquor level is allowed to vary within a range, i.e., like a “buffer”. Digester liquor level is controlled by liquor flow into ImpBin. Feed forward is calculated from a flow balance over the digester vessel. This alternative maintains the liquor level in the digester at the target while allowing the liquor level in ImpBin to vary within a specified range. The extraction flows to evaporation will be more stable compared to alternative 1, which will contribute to an overall more stable cooking plant.

Alkali control

White liquor charge to Impbin and digester: The white liquor charges to the Impbin and the digester are controlled at the first APC alkali control level. The purpose is to automatically set the correct white liquor flows, independent of production.

Alkali charge to Impbin and digester: The purpose of the alkali charge controllers is to maintain a constant alkali charge in the digester and in the Impbin. The total alkali is the sum of alkali in black and white liquors. The residual alkali concentrations in the black liquor flows are measured by the alkali meters. The alkali charge controllers compensate for variations in black liquor flow and alkali concentrations by adjusting the white liquor charges. During maintenance or before calibration, the residuals used for alkali charge calculations can be based on lab values (Fig. 4).

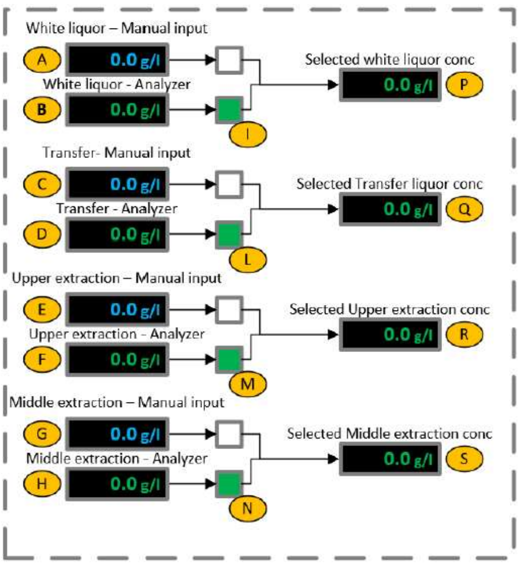


Figure 4. Switching between lab and analyzer values

Temperature control: The main purpose of temperature control in the Impbin top is to optimise the heat balance. The control is divided into three levels (Fig. 5). The top mix temperature control calculates the mixture temperature of chips and black liquor in the Impbin top. The remote set point for the mix temperature controller is derived from the rod temperature control. The purpose is to keep the heat input stable and at a nominal level.

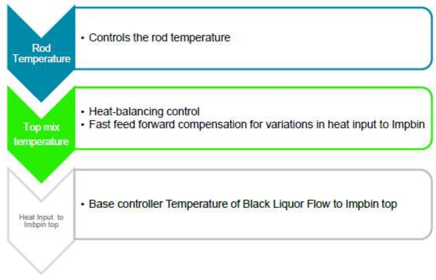


Figure 5. Temperature control across ImpBin

H-factor Control

The H-factor describes the total extent of reaction, a combined effect of the retention time in the cook zone (a function of the production rate) and the cooking temperature. An increased cooking temperature or retention time increases the H-factor. To keep the H-factor constant, changes in the production rate are always accompanied by changes in the cooking zone temperature.

If the production rate, for example, increases, the reaction rate must also increase to maintain a constant Kappa number in the blow line. The H-factor controller therefore increases the cooking temperature according to the H-factor equation. The H-factor control calculates the remote set point for the cooking zone temperature.

Kappa Control

The kappa number, a measure of delignification, is controlled by the kappa feedback control, which adjusts the H-factor target based on the measured kappa (lab or in-line kappa analyzer) and the kappa set point. There is a long delay between a change in temperature and its appearance in the blow line kappa, and at least when a kappa analyzer is used, there will be many kappa samples per process dead-time. For this reason, the controller uses a special process model that accounts for changes already underway. It calculates one H-factor adjustment for each kappa value analyzed and entered. The goal of the kappa feedback is to handle slow variations in wood composition and other cooking conditions and to maintain the kappa number average at its target.

Fiberline Stabilization Control (FSC)

The target of the FSC is to reduce pulp quality variability and to reduce operating costs to achieve the following,

- Desired kappa values
- Desired pulp brightness
- To reduce kappa and brightness variability
- To optimise chemical consumptions

Here, the controllers can be implemented for different recipes. This is fully integrated with the process design to ensure optimal plant operation. The FSC strategy will simplify decision support for the operators.

FSC functions:

1. Oxygen delignification

ODL stage control minimises variations in kappa and final pH while reducing chemical charges. It depends on alkali charge, oxygen charge, residence time, temperature and incoming kappa values. Compensations for variations in incoming kappa are made using feedforward on the incoming kappa measurement. Corrections for errors in outgoing kappa are made using feedback from the outgoing kappa measurement.

The temperature in the reactor is controlled using an H-factor algorithm that compensates for changes in the production level. This results in correct chemical charge and temperature adjustment.

2. Bleaching

In addition to the standard instruments, a kappa & brightness analyzer is required to run the FSC. The following is the analyzer position (Table 1).

Table 1: Kappa analyser sampling position

Kappa	ODL Out
pH	ODL Out
Kappa	D0 IN
Brightness	D0 IN
pH	D0 Out
Kappa	EP Out
Brightness	EP Out
pH	EP Out
Brightness	D1 out
pH	D1 Out

Results and Discussion

To ensure sustainability in process parameters, quality, production, and trouble-free plant operation, APC & FSC tools were utilised. Data for March 2026 were analysed for the suitability study (Figs 6 to 21).

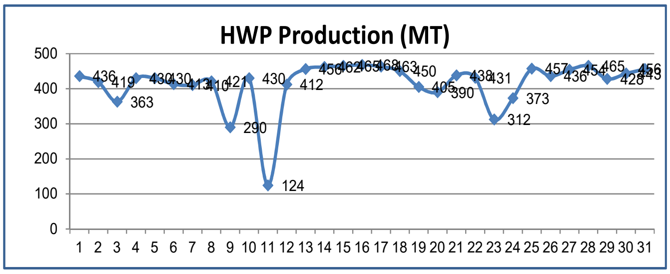


Figure 6. Pulp Production for the month of March 2026

The average bleached pulp production for the month of March 2026 is 413.9 MT/D (design capacity is 400 MT/D) (Fig. 6). The digester performance for the month of March 2026 has been summarised in Table 2.

Table 2: Digester performances for the month of March 2026

S No	Parameters	UOM	Month Average
1	Bleached pulp production	MT	413.9
2	Blown pulp brightness	%	36.1
3	Blown pulp Kappa	-	17.5
4	WBL RAA	gpl	11.3
5	WBL TS	%	16.4

With APC for the continuous digester, we achieved sustainable results (Figs 7 to 10). The average digester blow pulp brightness in March 2026 was 36.1%, indicating a sustained trend throughout the month (Fig 7).

The average digester blow kappa for the month was 17.5 (Fig 8). Weak Black Liquor (WBL) residual alkali (RAA) was 11.3 gpl (Fig 9), and WBL total solids were 16.4% for March 2026, indicating a sustainable trend with APC.

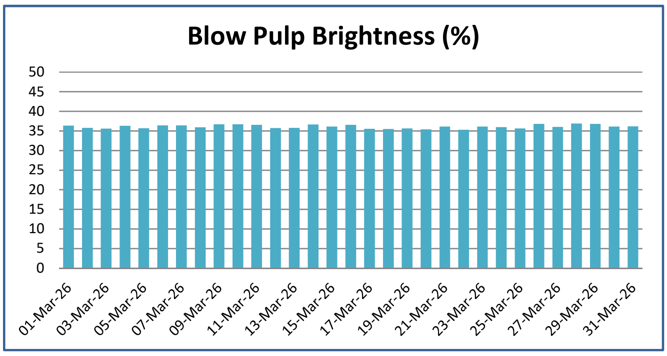


Figure 7. Blow pulp Brightness (%) for the month of March 2026

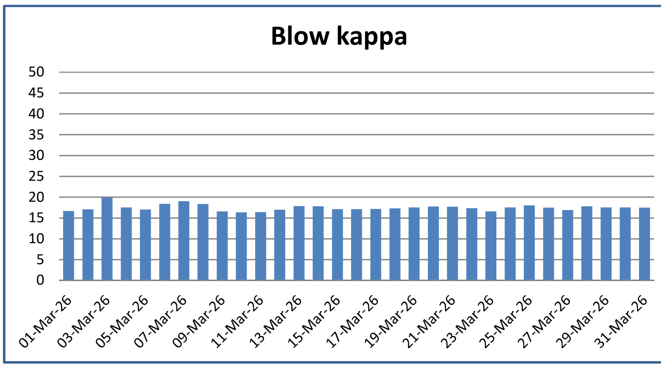


Figure 8. Blow pulp Kappa number for the month of March 2026

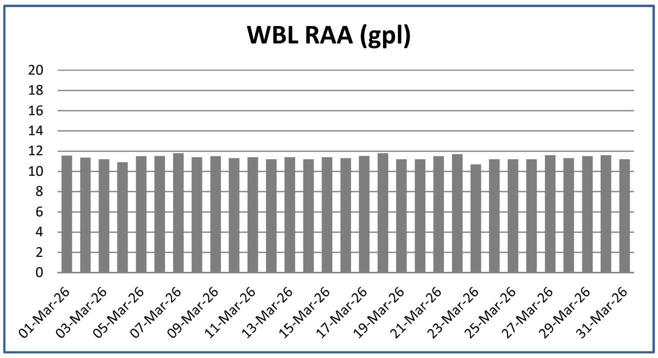


Figure 9. WBL RAA (gpl) for the month of March 2026

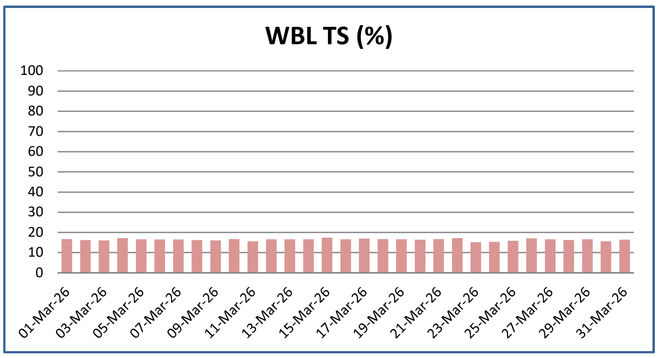


Figure 10. WBL total solids (%) for the month of March 2026

Similar to the APC for the cooking plant, FSC is implemented for the fibre line section, which includes the hot-stock screening, washing, ODL, and bleaching stages. FSC primarily targets ODL kappa reduction and optimization of bleaching chemicals.

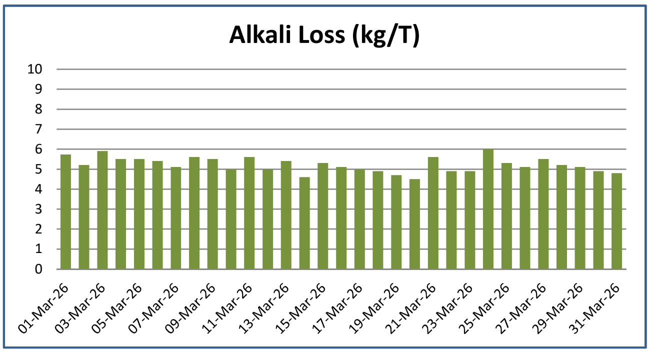


Figure 11. Post ODL Alkali Loss (kg/T) for the month of March 2026

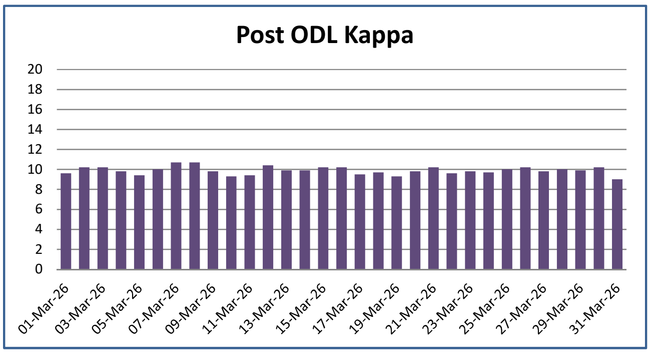


Figure 12. Post ODL Kappa for the month of March 2026

The alkali loss after ODL was 5-6 kg/T (Fig 11) for the month of March 2026. Post-ODL kappa was measured at 9-10. This low alkali carryover and kappa were achieved by the FSC controller, which adjusted the ODL chemicals and temperature with respect to the blow pulp kappa and the ODL kappa target value

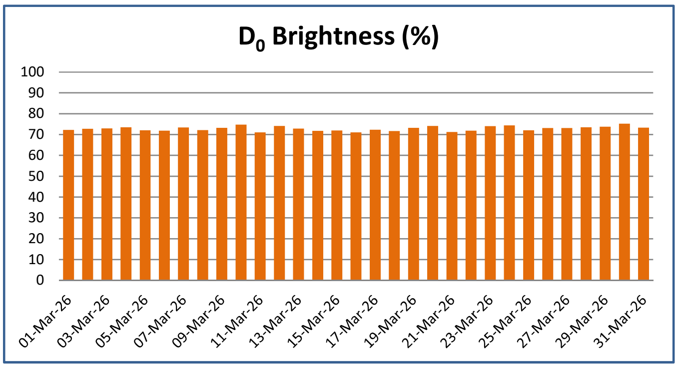


Figure 13. D0 Brightness (%) for the month of March 2026

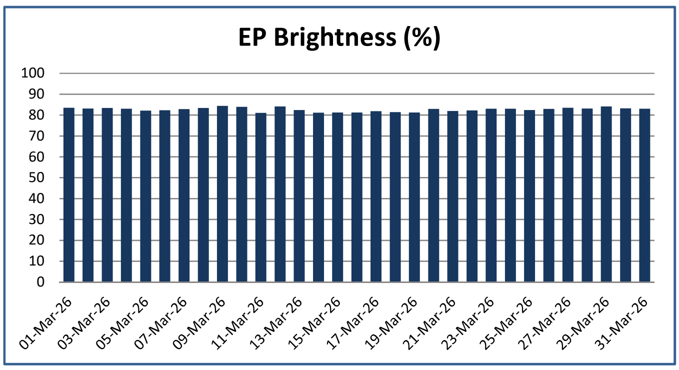


Figure 14. EP Brightness (%) for the month of March 2026

FCS has very good control over the use of bleaching chemicals, based on our target and input variations. The main aim of FSC is to maintain pulp brightness across bleaching stages with optimised chemical usage. Average D0 brightness was 70%, EP brightness 82%, and D1 brightness was 88% (Figs 13-15).

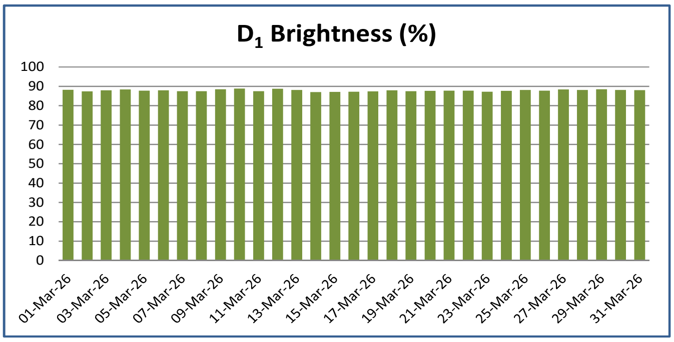


Figure 15. D1 Brightness (%) for the month of March 2026

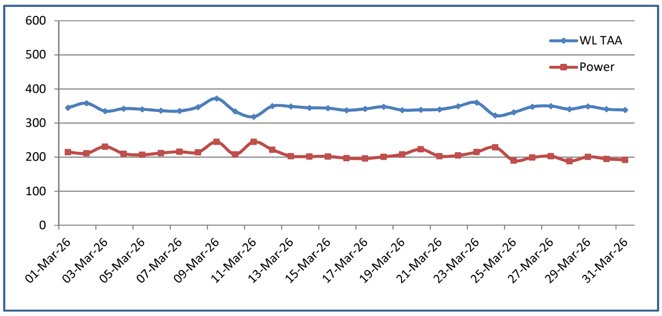


Figure 16. Specific consumption of WL & Power for the month of March 2026

The overall performance of the pulp mill for the month of March 2026, in terms of steam, power, white liquor, chlorine dioxide, hydrogen peroxide, and caustic consumption, was at a sustainable level, as shown in Figs. 16-21.

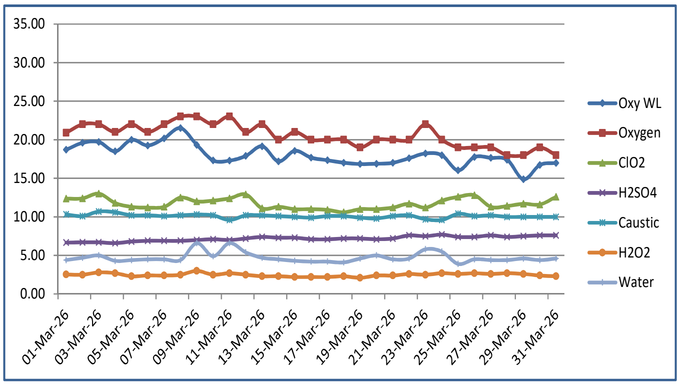


Figure 17. Specific consumption of Chemicals for the month of March 2026

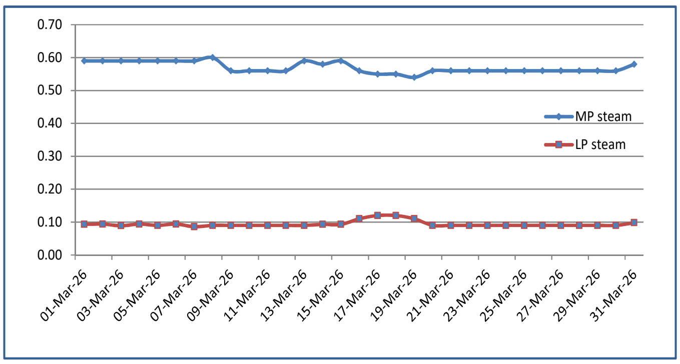


Figure 18. Specific consumption of Steam for the month of March 2026

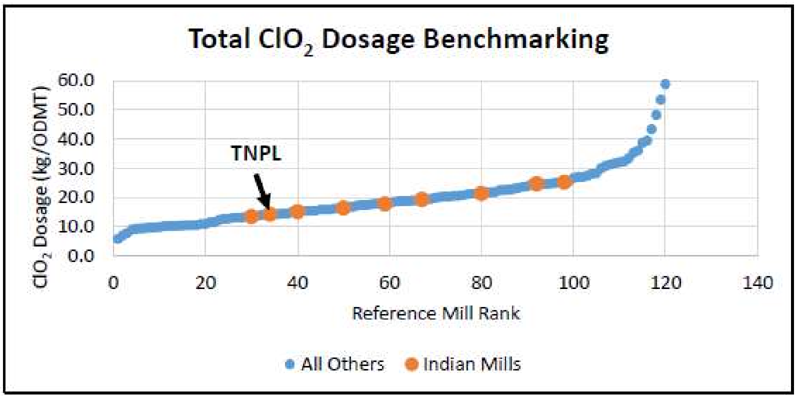


Figure 19. ClO_2 consumption comparisons with other mills

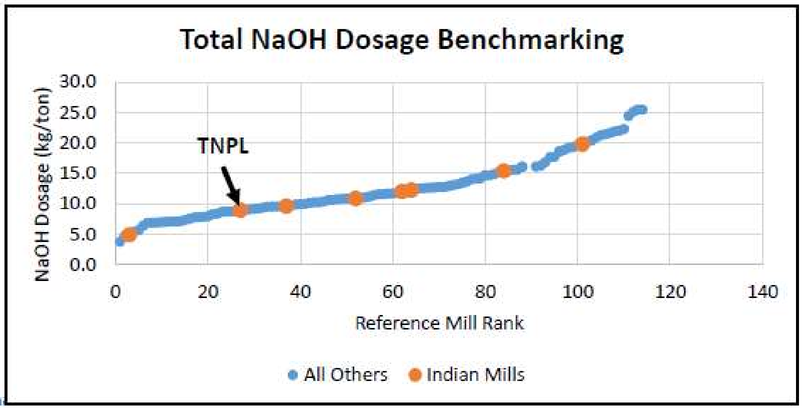


Figure 20. Caustic consumption comparisons with other mills

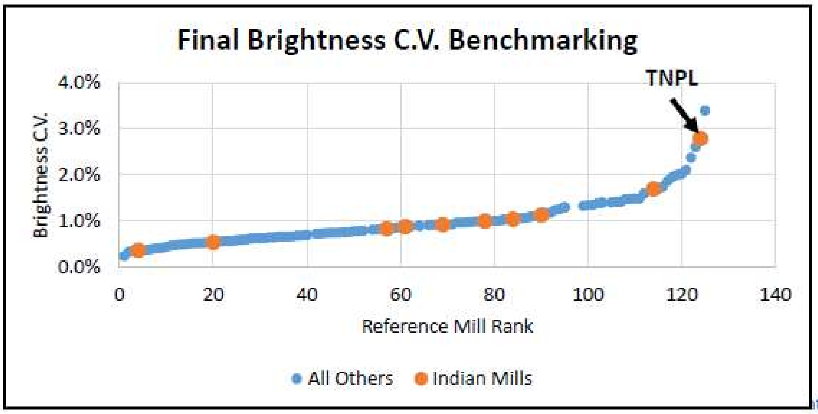


Figure 21. Bleached pulp brightness comparisons with other mills

Conclusion

The modern pulp mill was commissioned with APC in the continuous digester and FSC in Fiberline. This APC aims to maintain a consistent cooking kappa number during production rate changes. It calculates and coordinates changes in cooking temperature, chip feed flow, blow flow, white liquor flows, and other incoming and outgoing flows.

As desired, the performance of APC and FSC is well proven, as shown in the results and discussion. Very good sustainability in maintaining process parameters, quality, and chemical consumption has been reported. By adopting APC for continuous cooking and FSC for fibreline stages, the best sustainable results and better control over process operations can be achieved cost-effectively.