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Operational Retrofit Strategies for Enhanced Bioresource Utilization and Reliability of a Black Liquor Recovery Boiler

Abstract: *The pulp and paper industry relies highly on renewable bioresources to achieve energy security and sustainability, with black liquor, a biomass derived fuel serving as the primary energy carrier in chemical recovery operations. However, variations in raw material availability and its characteristics affect operational consistency and efficiency. Further, it results in operational constraints, especially elevated concentrations of non-process elements (NPEs), posing significant challenges to recovery boiler reliability and lifespan due to accelerated corrosion and severe flue gas path fouling.*

This paper highlights the retrofit implemented in a 1300 TPD Soda Recovery Boiler with 1,00,000 operating hours following a comprehensive study. Instead of a conventional one-to-one equipment replacement approach, operation-specific design modifications and process optimizations were implemented, focusing on superheater metallurgy upgrades, flue gas path fouling mitigation, combustion air system improvements, emission control enhancements and targeted energy efficiency measures.

Post-retrofit performance indicates a substantial reduction in pressure part-related downtime, reduced flue gas path fouling, enhanced operational flexibility and reduced stack emissions. The results affirm that tailored retrofit strategies can significantly improve recovery boiler reliability and enable effective utilization of renewable bioresources, thereby supporting sustainable and resilient mill operations.

Keywords: *Black liquor, Recovery boiler, Retrofit, Flue gas fouling, Process optimization, Sustainability.*

Introduction

The Indian Pulp and Paper Industry has consistently demonstrated its commitment to sustainability by its progressive shift towards renewable energy, aligning with global standards. The industry predominantly uses renewable resources like wood and recycled fiber but leveraging biomass byproducts like black liquor, bark, wood scraps, sludge and wash water for energy and producing higher value materials has greatly reduced its fossil fuel dependence and waste generation providing circular solution for raw material and energy. This has resulted in energy security and low cost of production.

Among the major biomass byproducts, Black liquor acts as a primary energy source and contributes significantly to a mill's energy self-sufficiency. Therefore, effective utilization of black liquor is crucial. With increased use of mixed hardwoods, agro-residues and recycled fiber in Indian mills, a more strategic approach has to be followed for effective utilization of renewable bioresources, particularly black liquor with high non-process elements (NPEs).

2. Recovery Boiler:

Recovery boiler is an essential component of the chemical recovery cycle in the pulp and paper industry, making the process both economically viable and environmentally sustainable. It performs a dual, contrasting function of burning the concentrated black liquor for steam generation while simultaneously recovering valuable inorganic cooking chemicals. This distinctive nature of the recovery boiler makes its operation highly critical. However, variations in biomass quality, inorganic loading and seasonal raw material availability result in high NPE concentrations, leading to fouling, corrosion and reduced runnability and any major breakdown can lead to production outages and costly repairs involving huge sum.

Tamilnadu Newsprint and Papers Limited (TNPL) Unit-1 operates a Soda Recovery Boiler with a black liquor solids firing capacity of 1300 TPD, commissioned in the year 2008 as part of the mill development

program. Using black liquor, approximately 12.0 lakh MT of renewable steam is generated and around 2.3 lakh MT of coal is saved every year. By the year 2020, the boiler had accumulated approximately 1,00,000 hours of operation. Statutory norms and emerging operational constraints necessitated a detailed Remnant Life Assessment (RLA) study.

3. RLA Study:

An RLA study is a comprehensive testing process for an equipment operating for a longer period of time to evaluate its current condition and determine the remaining safe operating life to prevent failures, ensure safety and facilitate life extension programs. Under Indian Boiler Regulations (IBR), 1950, RLA is mandatory for aging boilers operating at a temperature of 400°C & above and for all boiler parts operating in the creep range of the boiler after they are in operation for 1,00,000 hours [1]. Hence, an RLA study which included visual examination, thickness survey, magnetic particle testing, penetrant testing, ultrasonic testing, hardness testing, video endoscope, metallographic examination and deposit analysis was carried out in the pressure parts including steam drum, economizer, boiler bank, water wall and superheaters. The study highlighted that external corrosion has severely affected the outermost tubes of Primary superheater 1B (PSH1B) and secondary superheater (SSH) coils, evidenced by oxidized shallow pits and significant thickness reduction with some tubes measuring only 2.5 mm to 3.1 mm from the original thickness

of 5.5 mm (Figure 1). The corrosion was attributed to high NPE content combined with high metal working temperatures. The ash in the superheater region mainly contains 40-60 wt% chlorides as NaCl+KCl and 15-25 wt% potassium as K (mostly KCl). The presence of high potassium and chloride content likely lowers the melting point of superheater deposits to less than 550°C (based on Cl/(Na+K) and K/(Na+K), mole %), increases ash stickiness resulting in sticky deposit accumulation and accelerated corrosion [2,3].



Figure 1 Superheater tube external corrosion and thickness reduction

Microscopic examination performed on the fractured tube to determine the cause of its failure further substantiated the reason for superheater corrosion. Samples were taken from inner diameter (ID), outer diameter (OD), core and fractured region of the tube and optical micrographs were examined at 100x and 500x magnifications (Figure 2). The ID and core regions exhibited a uniform and stable microstructure with intact grain boundaries with no evidence of cracking, void formation or significant degradation. These regions showed minimal exposure related damage, indicating that the base material retained its original metallurgical condition and did not contribute to failure initiation. In contrast, the OD and fractured regions showed pronounced microstructural deterioration. The OD revealed external oxidation, non-uniform grain structure and localized material degradation consistent with exposure to elevated temperatures. Higher magnification images of the fractured region showed grain boundary separation, micro-voids and cavitation, features characteristic of creep damage resulting from prolonged high-temperature service under sustained stress. Hence, the failure of the superheater tube is attributed to long-term overheating leading to creep rupture originating from the outer diameter, aggravated by external oxidation.

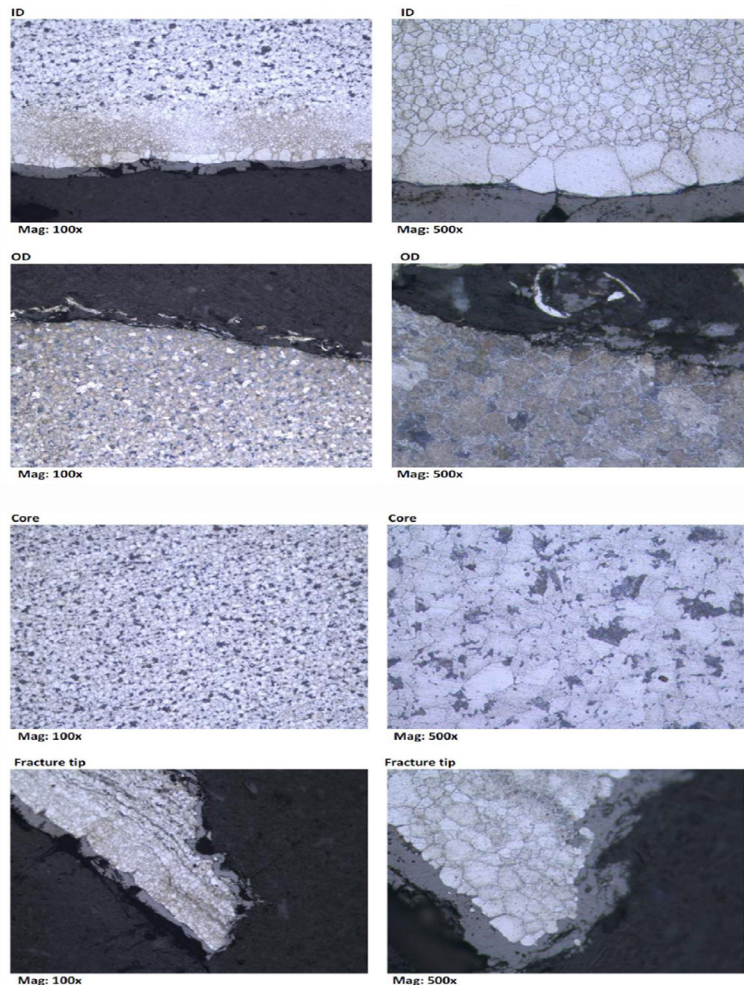


Figure 2 Microscopic examination of a fractured superheater tube.

4. Plan for Retrofit:

The RLA study threw light on the shortcomings that has to be addressed for a sustained boiler operation. Hence a detailed study was carried out to increase the reliability of the boiler as the whole mill operation hinges on its satisfactory performance. After a lot of brainstorming sessions, it was decided to opt for revamping of the sections that were considered critical.

“But instead of opting for a conventional one-to-one equipment replacement approach, operation-specific design and process modifications were implemented”

These modifications aimed at improving boiler longevity, operational reliability, thermal efficiency and effective utilization of renewable bioresources, particularly black liquor with high non-process element (NPE).

The primary objectives of the retrofit project were to:

- Extend the operational life of critical pressure parts and improve boiler runnability & availability.
- Enhance effective utilization of renewable bioresource with high NPE content by improvising on the existing design.
- Support sustainable and resilient mill operations through process optimization.

5. Major Operation-Specific Modifications Implemented:

5.1. Superheater:

In order to withstand the high metal temperature, the metallurgy of the PSH1B and SSH coils were upgraded from ASTM A213 Grade T11 to ASTM A213 Grade T22. T22 gives superior high temperature strength, creep and oxidation resistance. Also, in the original design of SSH coil arrangement, the outer 2 tubes out of the 5 tubes were of jumper coil type resulting in significant difference in tube lengths. In the revised configuration, all the 5 tubes were arranged in a uniform pendent type, resulting in uniform tube cooling.

Furthermore, the metal working temperature of SH1B was high due to its arrangement directly above the furnace resulting in high thermal stress. Hence, a new de-superheater system was introduced between SH1A and SH1B, providing an additional temperature control mechanism. As a result of the above measures, the average metal working temperature came down from 475-485°C to below 450°C (Figure 3).

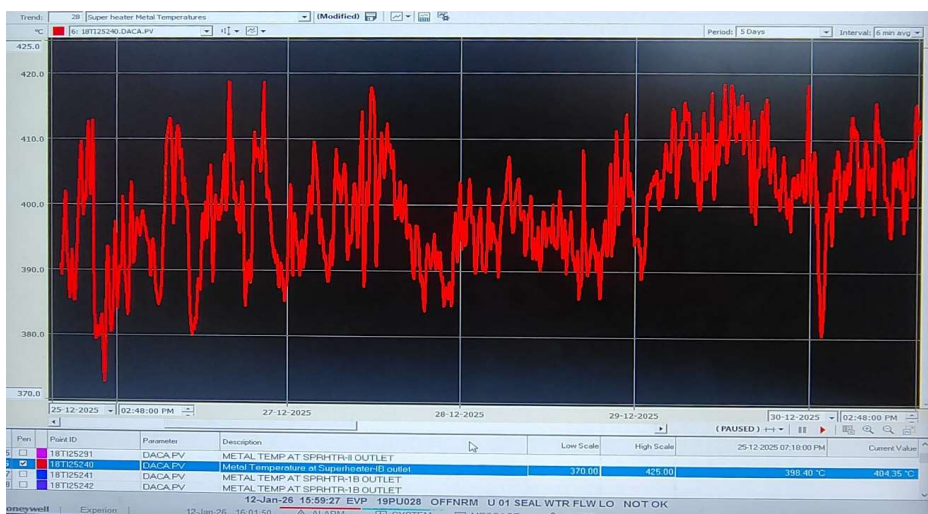
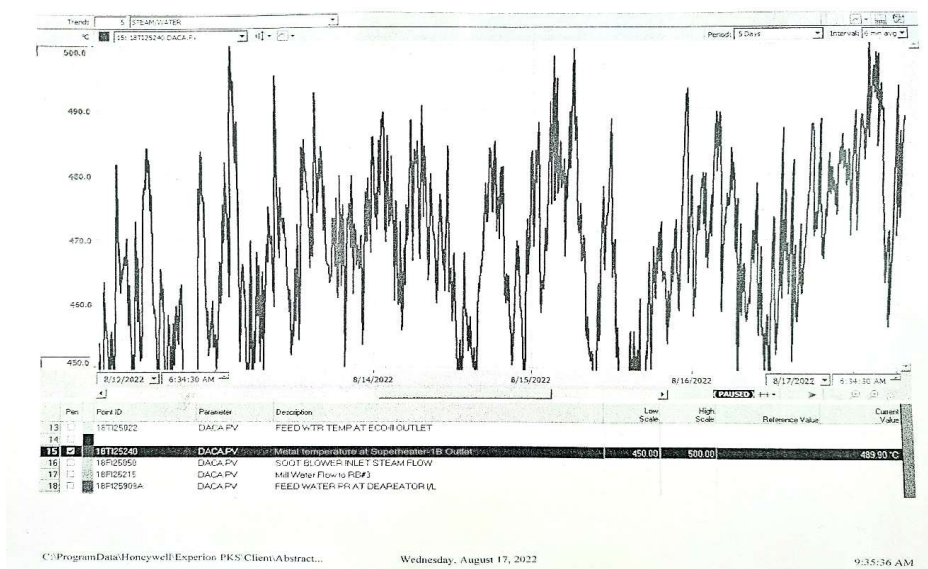


Figure 3 Superheater metal temperature trend comparison- 6 min avg data of 5 days. Temperature range- Top trend: 450-500°C, Bottom trend- 375-420°C

5.2. Flue Gas Path:

One of the critical factors limiting the runnability and availability of recovery boilers is flue gas path fouling. The formation of molten or sticky ash deposits causes serious problems such as reduced heat transfer efficiency, flue gas path plugging/fouling and accelerated corrosion. The ash melting temperature, primarily decided by its chemical composition, results in different flue gas path fouling profiles at different mills.

In TNPL unit-1, the chloride (as NaCl) is at 22-30% and potassium (as K) is at 5-12% in ESP ash, even with the ash purging system in line, confirming that operational mitigation alone was insufficient without design intervention. As a result, flue gas path fouling was extensive forcing the boiler to be stopped for water wash every 2 months. The following measures have been implemented to mitigate the issue:

- ★ The high fouling area was identified in the transition zone from screen tubes to boiler bank and a new sootblower was installed in that location (Figure 4).
- ★ Nine existing sootblowers in and around the transition area were replaced with new sootblowers along with indexing mechanism.
- ★ The travel time of the nine new sootblowers were increased from 4.5 minutes to 6.0 minutes by RPM reduction for better sootblowing efficiency.

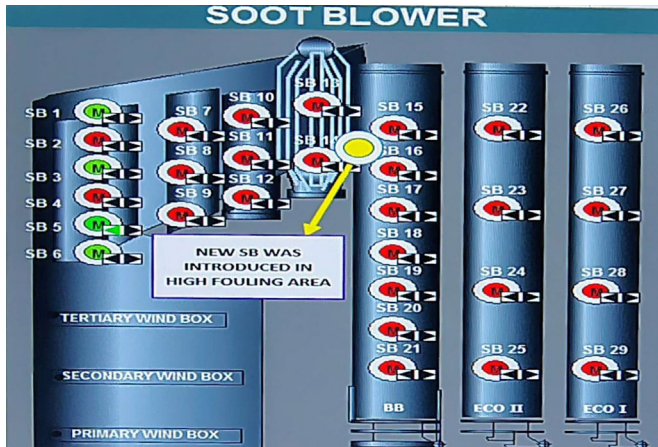


Figure 4 Location of the new sootblower in high fouling area

5.3. Air System:

Tertiary air:

Tertiary air in Recovery boilers ensure complete combustion of the black liquor and uniform gas distribution throughout the furnace optimizing heat transfer. To mitigate variations in the black liquor availability, prevent liquor carry over and ensure complete combustion, sizing of the tertiary air fan and its drive was increased.

Air temperature control:

The combustion air (primary and secondary air) entering the boiler must be heated above 160°C for proper black liquor firing and achieving required smelt reduction efficiency. LP and MP steam are used in the Steam Coil Air Pre-Heater (SCAPH) system to preheat the air to required temperatures. Whenever the boiler was operated at different loads, with different feedstock combination ratio (bagasse & hardwood), air requirement varied continuously. Since, the steam supplied to the SCAPH system was controlled manually, the combustion air temperature was not constant. Hence, control valves and closed loop operation were introduced for temperature control in the MP steam section of both Primary and Secondary SCAPHs resulting in better combustion air temperature control and MP steam conservation.

5.4. Emission Control:

The boiler was originally designed with two Electro-Static Precipitators (ESPs- ESP A&B). In 2017, to meet out TNPCB norms and avoid downtime, an additional ESP chamber (ESP-C) was erected. Since, the ESP-C was erected and commissioned while the boiler was in operation, scope for even distribution of flue gas across the chambers could not be achieved. Whenever a breakdown occurs in any one of the ESPs-A or B, due to constraints in the flue gas distribution to ESP-C chamber, the boiler MCR rating was reduced. Using the opportunity of the retrofit shutdown, a Computational Fluid Dynamics (CFD) study was carried out (Figure 5) and the existing flue gas duct was modified for even gas distribution across any two ESP chambers that are in line.

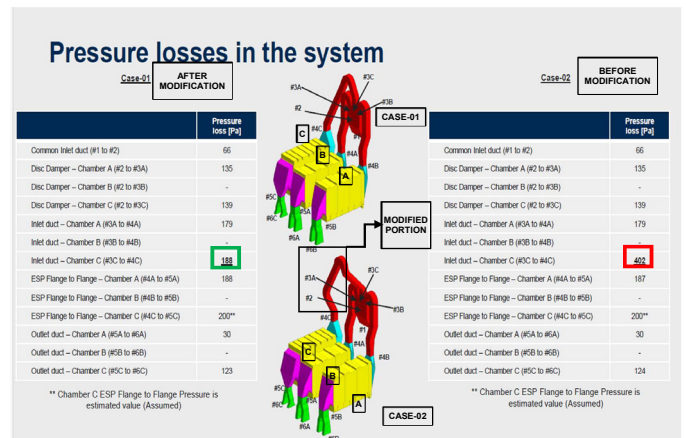


Figure 5 Modification carried out and subsequent reduction in pressure drop.

It can be inferred from the CFD study in Figure 5 that by carrying out the modification in the transition duct (#3C to #4C) from Economizer to inlet duct of ESP-C (1st from the left of the three chambers in series), pressure drop is greatly reduced (from 402 Pa to 188 Pa) providing for even flue gas distribution and efficient collection in the ESP.

The other major constraint was the accumulation of ESP ash in the guide vanes of inlet funnel duct of ESP-A&B chambers. The ash gets accumulated over a period of time and will suddenly fall off, tripping the ash conveying system. Modification was also carried out in the inlet duct to prevent the ash built-up.

By replacing the ESP internals of the original chambers and by carrying out the flue gas duct modifications, emission has been brought down from 100 mg/Nm³ to less than 50 mg/Nm³.

Additionally, even when a breakdown occurs in any one of the ESPs-A or B, the boiler is operated at full MCR with ESP A & C or with ESP B & C as a result of the improved flue gas distribution.

6. Energy Saving Measures Implemented:

- ★ Replacement of flue gas ducting from Economizer to ESP inlet- Power drawn by ID fans reduced by 1500 units/day.
- ★ Intermittent operation of Boiler bank, Economizer#1 and #2 ash conveying system- Power consumption reduction by 550 units/day.
- ★ Modification in feed water pump impeller- Power consumption reduction by 3000 units/day.
- ★ Replacing the combination of CE type and splash type black liquor firing guns with only splash type guns for improved combustion efficiency.

7. Results Achieved:

The operation and site-specific modifications in the retrofit shutdown delivered the following key outcomes:

- ★ Zero downtime due to pressure part related maintenance in FY2023-24 and FY2025-26 compared to downtime which peaked to 380 hours in FY2022-23 (Figure 6).

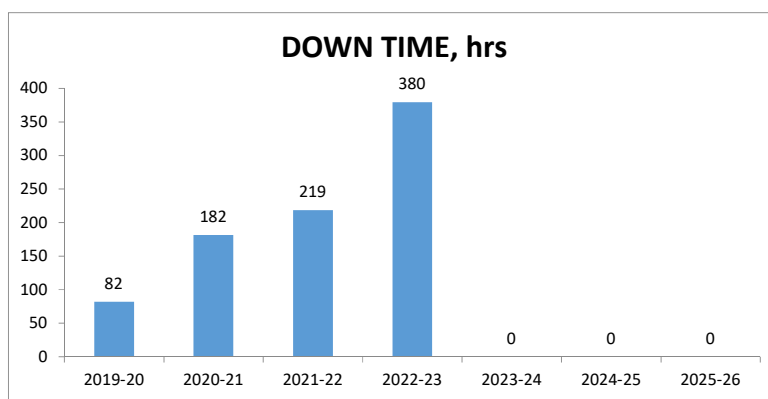


Figure 6 Downtime chart.

Considering an average increase in Recovery boiler operation of 200 hours per year, an additional 11,500 MT of black liquor dry solids is fired producing 33,000 MT of renewable steam.

★ Despite high NPE levels (Cl: 22–28%, K: 5–12%), flue gas path jamming due to ash fouling was significantly reduced.

As a result, frequency of boiler stoppage for water-wash shutdowns has reduced from 6 times per year (once every 2 months) to 3–4 times per year (once every 3–4 months) (Figure 7)

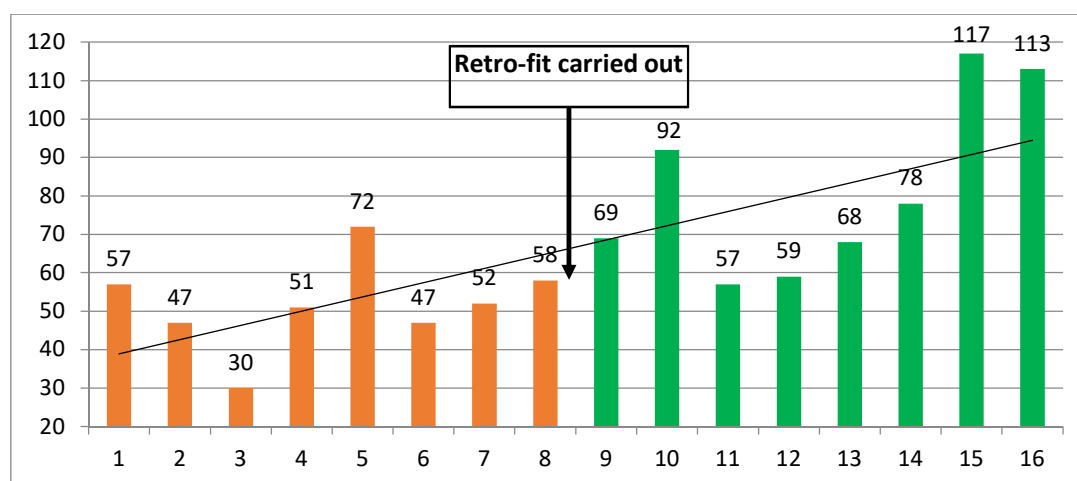


Figure 7 Chart showing no. of days between successive shutdowns due to tube leak and for water wash (last 16 shut downs).

★ Achieving stack emission less than 50 mg/Nm³ allows us to reduce the risk of non-compliance due to operational fluctuations, meet Sustainable Development Goals (SDGs) and more importantly, public trust.

★ By firing 11,500 MT of additional black liquor dry solids, 6000 MT of coal is saved and 0.11 million tons of CO₂e emission is avoided.

The planned retrofit shutdown focused on interventions backed by detailed diagnostics and mill operating experience delivered key significant improvements by enhancing the utilization of the bio resource (black liquor) with high NPE content, increased boiler availability, improved renewable energy recovery, reduced power & steam consumption and less emission. Ultimately, a more resilient and cost-effective recovery boiler operation is achieved towards our aim of renewable energy adoption, self-sufficiency and a greener future.

Acknowledgement:

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