Project Report on

I-IoT Enabled Continuous Real-time Temperature Measurement of CBT and SST in Aluminium Pot shell

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Date of Commission:

Phase	**Site Location**	**Date of Commission**
Phase 1 (CBT Sensor Installation)	BALCO, Korba	August 2024
Phase 2 (SST Sensor Installation)	NALCO, Angul	July 2025

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1. Introduction to XYMA

The aluminium smelting process involves extreme temperatures and the handling of molten metal, making it inherently hazardous. Continuous monitoring of the pot shell temperature is crucial for identifying anomalies early, thereby preventing safety risks such as overheating, structural damage, or equipment failure.

XYMA's advanced sensor solutions enable proactive maintenance by tracking temperature variations across critical areas such as the Collector Bars, Side Shell, and Cryolite Bath. These trends help operators detect abnormal patterns or deviations that could indicate potential issues like pot line leakage—allowing timely interventions to minimize unplanned downtime and prevent costly damages.

XYMA's **µTMapS** and **µSTMapS** are rugged, high-temperature waveguide-based sensors designed for multi-point temperature monitoring. They provide precise and accurate data across a wide range—from 25°C to 1450°C—ensuring detailed insights into the thermal behavior of aluminium smelting pots.

Integrated with I-IoT capabilities and AI-powered soft sensors, these systems generate 3D thermal profiles of the monitored assets. The onboard edge computing unit processes ultrasonic signals to extract real-time temperature data, which is then transmitted to control rooms or dashboards using secure, industrial-grade wired or wireless communication technologies.

XYMA's sensor systems are certified with **ATEX**, **CE**, and **IP** standards, making them fully compliant for use in hazardous industrial environments. The temperature data can be integrated into client DCS systems or viewed via XYMA's customizable dashboard.

Additionally, XYMA's system leverages AI to learn from temperature behaviour across pot lifecycles, enabling predictive maintenance and generating valuable process intelligence. This transforms conventional aluminium smelting into a smarter, AI-driven operation, enhancing safety, efficiency, and asset longevity.

1.1. Objectives

Continuous Real-Time Monitoring of aluminium **pot shells** using XYMA's **µSTMapS** sensors to capture:

1. **Collector Bar Temperature (CBT)**
2. **Side Shell Temperature (SST)**

- **Establishment of an I-IoT Enabled Asset Monitoring System** for predictive insights and optimization of smelting operations.
- **Reduction of Manual Intervention** through remote, automated, and accurate temperature data acquisition and transmission.
- **Enhancement of Worker Safety** by minimizing human exposure to hazardous high-temperature environments and ensuring early detection of thermal anomalies.

1.2. Phased Implementation Plan:

Phase 1 – Real-Time CBT Monitoring at BALCO: Deploy µSTMapS sensors on the collector bars of selected pots to continuously track and analyse temperature behaviour. Integration with XYMA's edge computing and dashboard systems to enable live monitoring and generate alerts for proactive maintenance.

Phase 2 – Real-Time SST Monitoring at NALCO: Extend the sensor deployment to measure side shell temperatures at NALCO smelters. This phase will include AI-based thermal trend analysis for early detection of potline health degradation and potential sidewall failures.

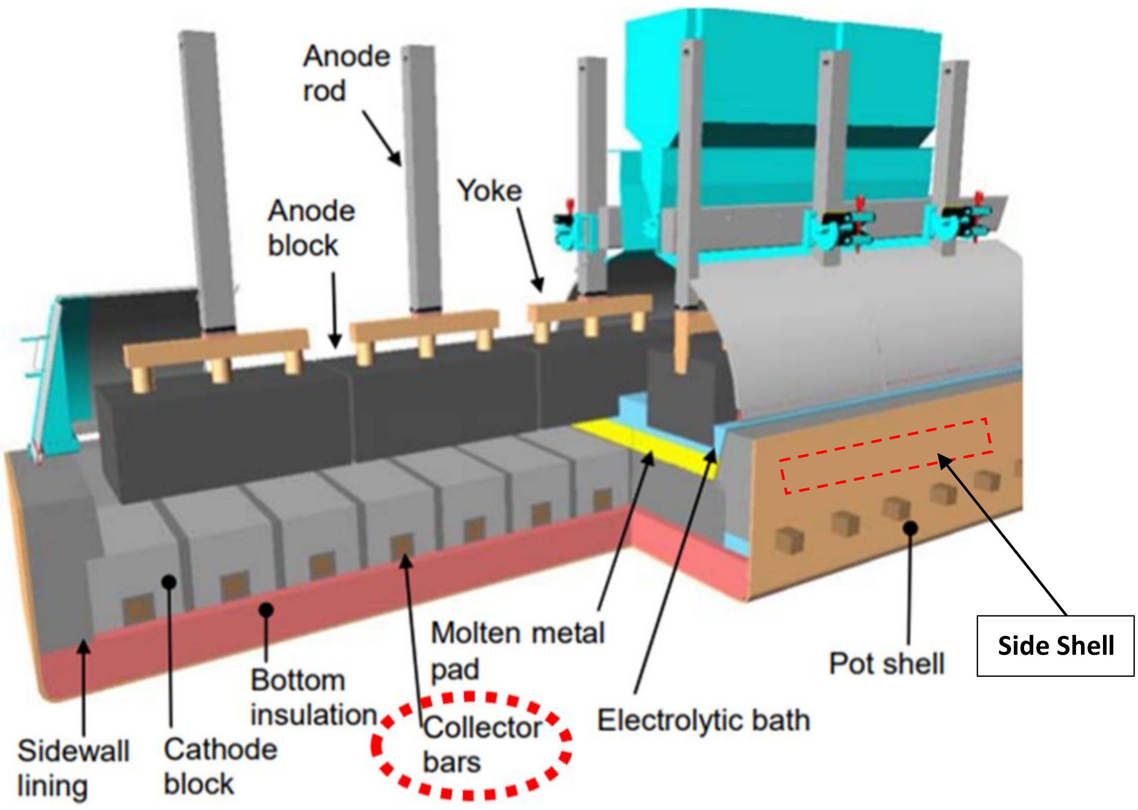


Figure 1: General aluminium smelter schematic

1.3. Scope of the work

This scope outlines the end-to-end process for deploying XYMA sensors in a live pot environment, including hazardous DC zones:

1. Design and fabrication of customized sensors tailored for high-temperature and electromagnetic environments.
2. Calibration of sensors with traceability to national standards, ensuring measurement accuracy.

3. Wireless/network-based communication setup to enable real-time data transfer to a central dashboard.
4. On-site installation of sensors with adherence to all safety protocols and live pot operating procedures in hazardous areas.
5. System commissioning to validate data flow, signal quality, and sensor functionality.
6. Real-time monitoring of sensor outputs with dashboard configuration for trend and alert visualization.
7. Weekly reporting on sensor health, performance trends, and alert indications.
8. Preparation of a comprehensive final report summarizing trial outcomes and deployment insights.

1.4. XYMA's Solution

In current measurement instrumentation technology, the limitations of traditional temperature monitoring methods, such as thermocouples and IR guns, which provide isolated and infrequent data points, delaying the detection of critical issues in aluminium smelting processes. Advanced solutions like XYMA's µSTMapS system, leveraging ultrasonic waveguide technology, overcome these challenges by offering continuous, multi-point temperature monitoring. Guided wave technology, known for its ability to propagate through complex structures and over long distances, ensures comprehensive coverage, making it highly effective in industrial settings. Real-time temperature monitoring improves safety, enhances product quality, reduces energy consumption, and minimizes downtime, while the integration of Industrial IoT (I-IoT) and AI-powered analytics enables predictive maintenance and smarter manufacturing. These advancements highlight a shift towards more efficient, safe, and data-driven operations in aluminium smelting. A sample waveguide sensor used for the temperature measurement is shown in the figure 1.

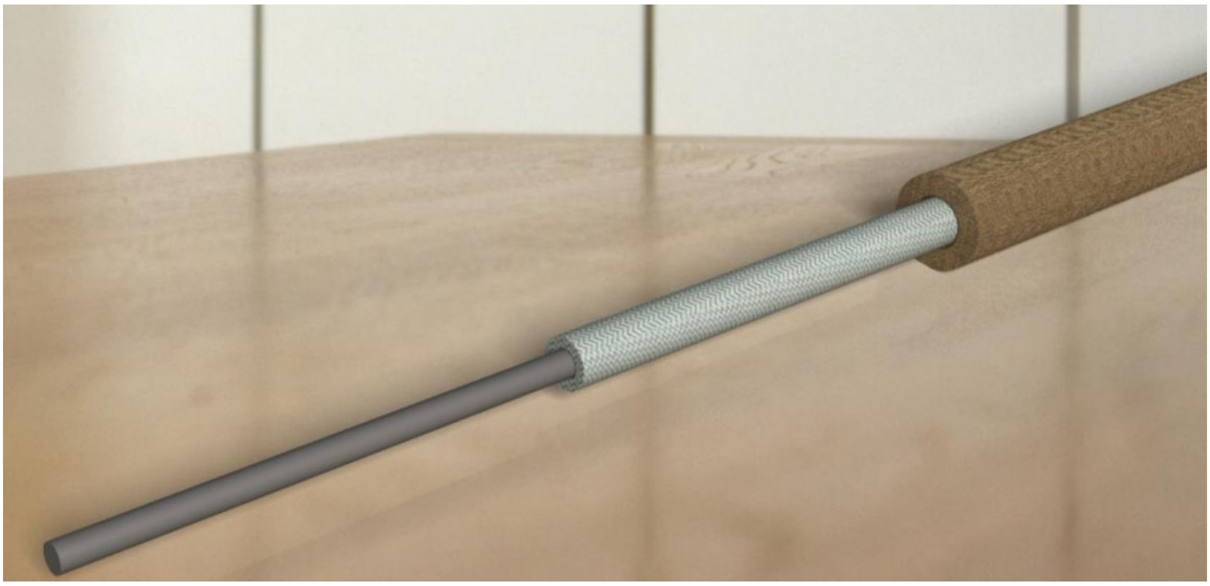


Figure 2: Waveguide with double insulation

2. Phase-1: Real time monitoring of Collector bar temperature in Pot Shells at BALCO, Chhattisgarh

2.1. Introduction

XYMA's advanced ultrasonic waveguide sensor technology has deployed at Bharat Aluminium Company Limited (BALCO), a subsidiary of Vedanta Group. This deployment focuses on optimizing the temperature management of collector bars used in BALCO's smelting process. Collector bars play a crucial role in maintaining the integrity of the smelting equipment, and precise temperature control is key to improving the bars' performance and longevity. XYMA's technology allows for constant, accurate monitoring, ensuring that the smelters operate within optimal temperature ranges, which is vital for enhancing both energy efficiency and equipment durability.

By incorporating XYMA's continuous monitoring and advanced data visualization, BALCO is able to make informed decisions that not only improve operational efficiency but also contribute to enhanced safety standards. The reduced energy consumption achieved through this real-time temperature control is expected to result in significant cost savings and lower the environmental impact of BALCO's operations. This collaboration highlights BALCO's commitment to sustainability, leveraging innovation to drive long-term efficiency and competitiveness in the aluminium industry.

2.2. Problem Statement

The current temperature monitoring technologies in aluminium smelting face critical limitations that adversely impact operational efficiency, safety, and decision-making. The predominant use of manual infrared (IR) guns for periodic measurements introduces significant **accuracy challenges** and **process inefficiencies**. With typical measurement intervals limited to once every few hours and a **temperature range of 220°C to 250°C**, the manual method suffers from a **5–10°C error margin**, making it difficult to maintain thermal consistency. These surface-only readings also fail to reflect **internal temperature gradients**, which are vital for assessing true pot health.

The **intermittent and localized nature** of these measurements results in unreliable data, missed anomalies, and human errors, leading to poor process control. As a consequence, operations experience increased **energy consumption**, **suboptimal product quality**, and a higher incidence of **pot failures**, particularly in the **side shell and collector bar regions**.

One of the most severe operational challenges is cell leakage, especially in aging potlines. These leaks are among the most dangerous failures in aluminium production. When a leak is detected, workers are forced to intervene manually to disconnect the affected cell from the potline—a procedure that involves high safety risk. In such events, routine operations are halted, and the local power infrastructure often must ramp down power to the potline by up to 50%, or in extreme cases, cut power entirely, causing system-wide instability, lost production, and increased emissions.

Despite attempts to manage this issue, **leakages still occur frequently—2 to 3 times per month**—leading to **unscheduled downtimes**, increased **maintenance costs**, and **significant**

safety hazards. These disruptions not only delay production but also strain operational continuity and system reliability. Given these limitations, there is a **critical need for an automated, continuous temperature monitoring system**. Such a solution would provide **real-time, high-resolution data** across critical pot regions—enabling early leak detection, reducing human intervention, and enhancing predictive maintenance strategies. By offering greater insight into pot behaviour, an automated system supports **proactive decision-making**, improves **safety outcomes**, and optimizes **process control**, thereby driving greater **efficiency and sustainability** across the smelting operation.

2.3. Installation Process and Technical Insights

XYMA's µSTMapS sensor was installed at critical points throughout Vedanta-BALCO 1602 & 1606 smelter of pot line 2 to ensure comprehensive Collector Bar temperature coverage. The system utilized **ultrasonic waveguide technology** to enable continuous skin temperature monitoring, a major step forward from traditional IR gun-based methods. The installation was seamless, minimizing operational disruption while positioning sensors for optimal temperature mapping across various critical zones.

Installation Timeline:

8-Sensing Points	CB23 to CB26 || Duct End – B Side	Sept'23 – Dec'23 **(3-Months)**
16-Sensing Points	CB23 to CB26 || Duct End – B Side CB23 to CB26 || Duct End – A Side	Dec'23 – Aug'24 **(9-Months)**
100 Sensing Points	CB2 to CB26 || B – Side CB2 to CB26 || A – Side	Aug'24 – Sept'24 **(1 Month)**

Table 1: Installation Timeline

BALCO 350 kA Smelter Collector Bars Configuration:

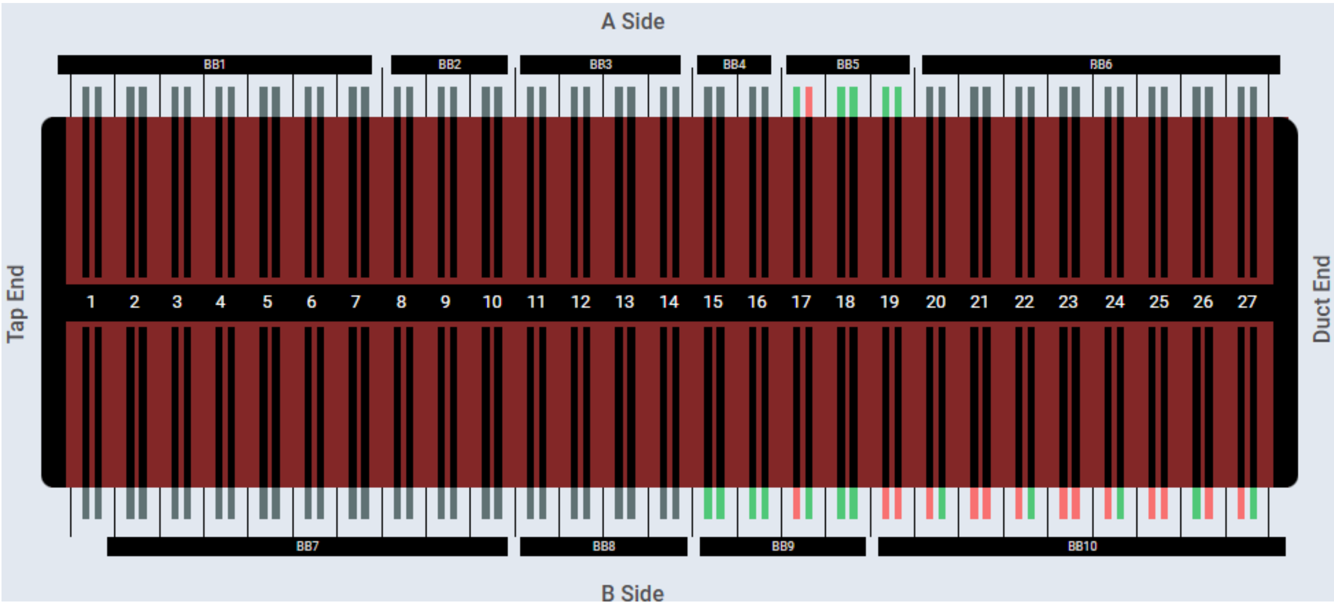


Figure 3: BALCO 350 kA Smelter Collector Bars Configuration

2.4. Installation: 1602 pot || Pot Line-2

<u>Waveguide Installation- Sept – 2023</u>

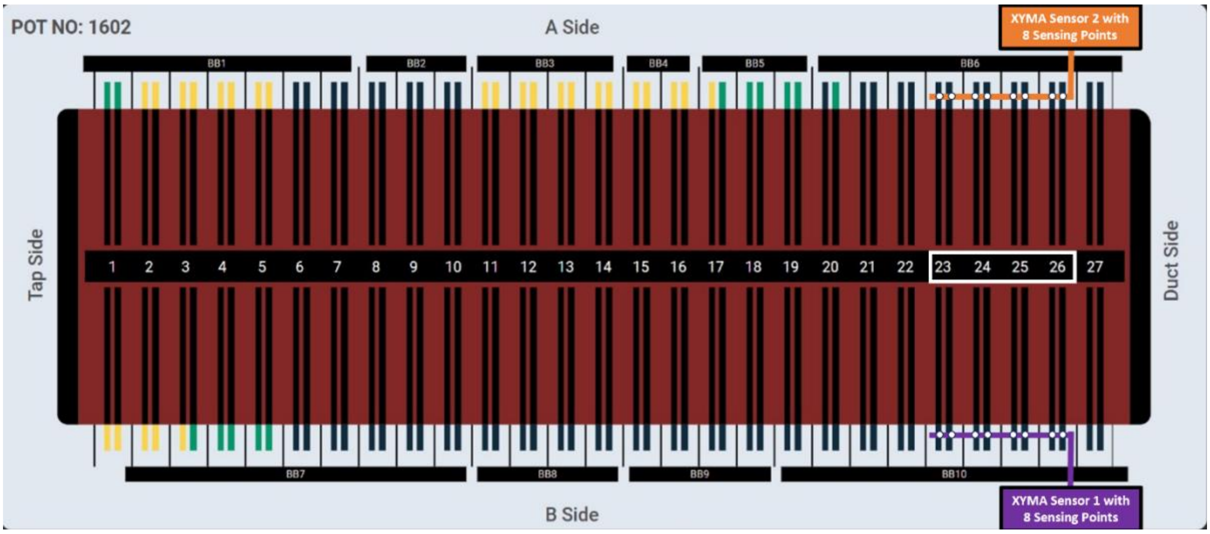


Figure 4: XYMA's Waveguide sensors in1602 pot Collector Bar instalment schematic

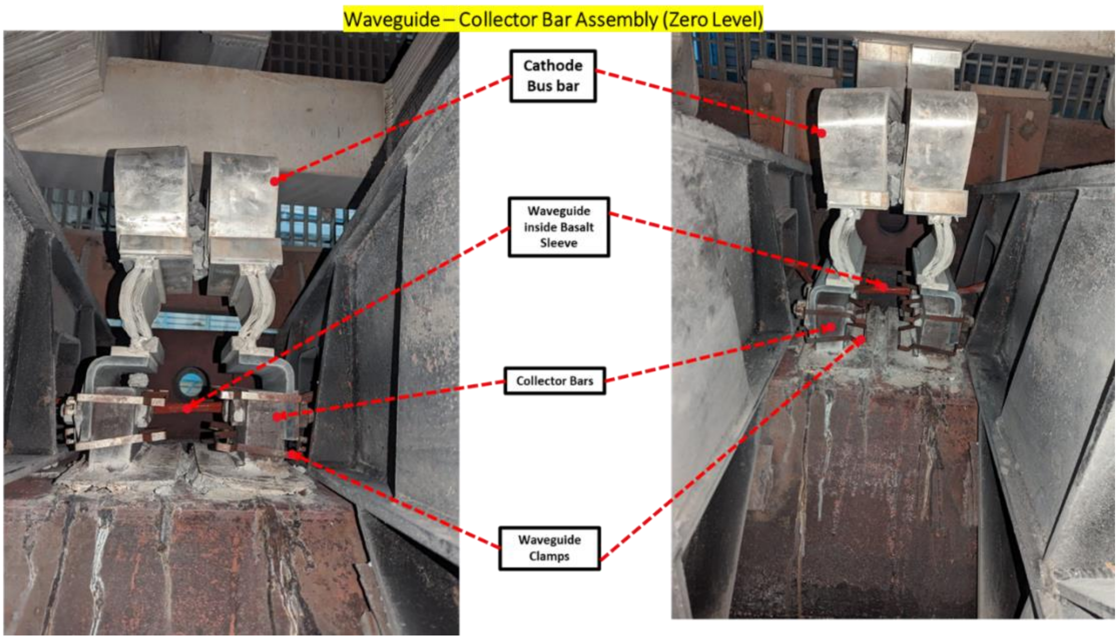


Figure 5: Collector Bar Waveguide Assembly – 1602 pot

Figure 6: Collector Bar Waveguide Assembly Schematic – 1602 pot

1) Waveguide Sensor:
- Nichrome Based Alloy
- Continuous Operating Temperature:1200°C
- Melting Point: 1425°C

2) **Silica Braided Sleeve:**
- Electrically and Thermally Insulated
- Maximum Operating Temperature: 1200°C

3) **Basalt Sleeve:**
- Electrically and Thermally Insulated
- Maximum Operating Temperature: 1000°C

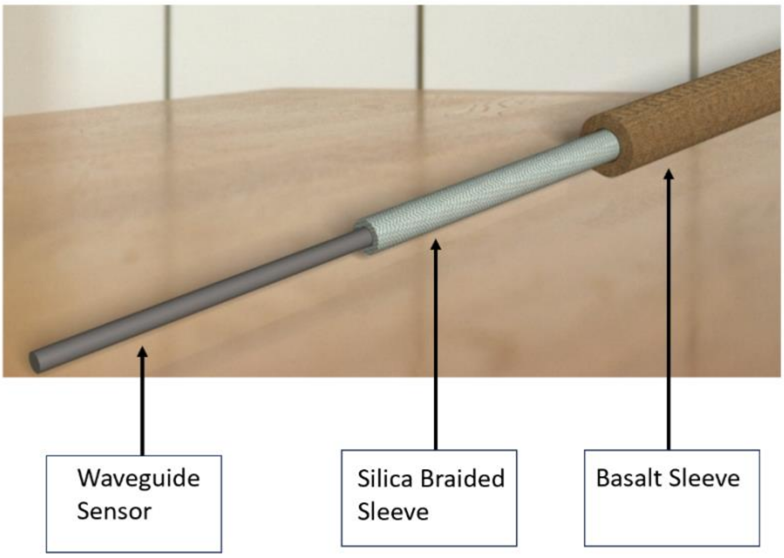


Figure 7: Waveguide with double insulation

Figure 8: Electronics Unit Shop Floor Duct side of 1602 pot – Ph-1

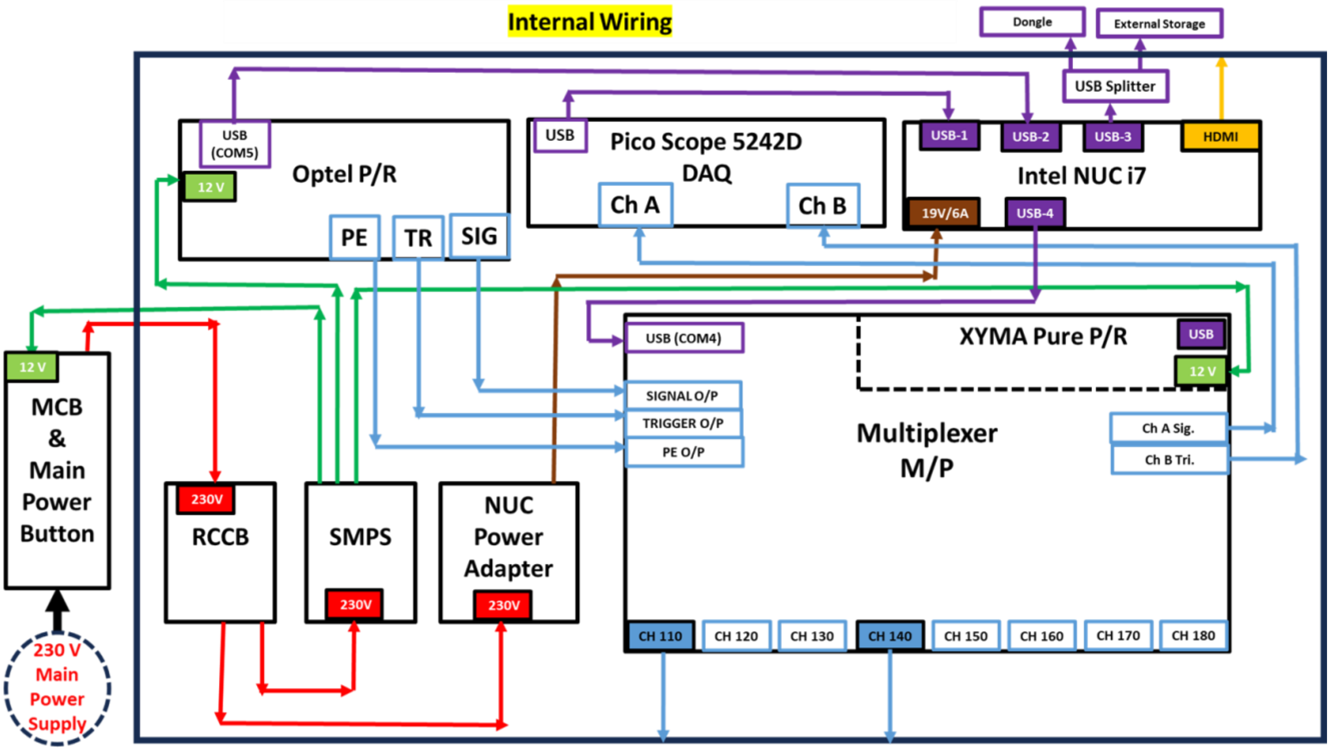


Figure 9: Electronics Unit Internal Wiring

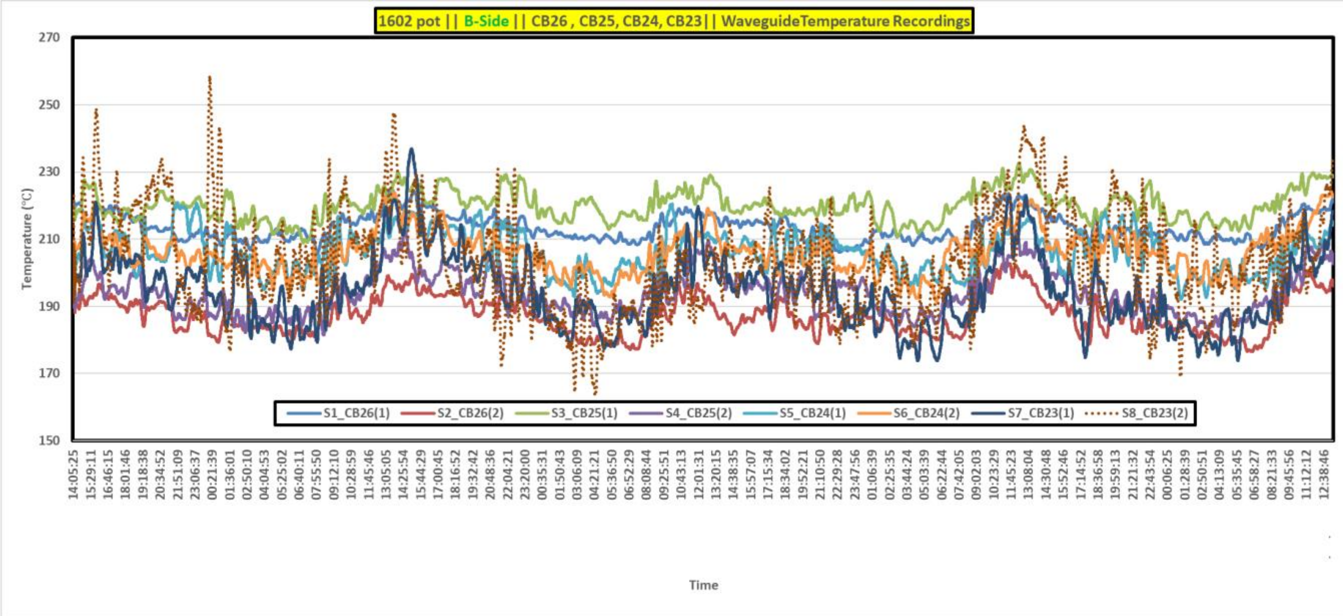


Figure 10: Waveguide Sensor Temperature Recordings B-Side CB26 to CB23 of 1602 pot

The installation-initiated on Aug-2023 completed on Sept-2023. BALCO allocated pot no.1602 of pot line-2. With above Installation Schematic waveguide sensor was installed on the Duct side of the 1602 pot, staring from collector bar numbers (CB23 to CB26) of both A-side & B-side. The installation covered a total of 16 sensing points of collector bar in 1602 pot.

The Collector bar installed Waveguide sensor temperature trends are correlated with the pot line activities of 1602 pot such as Anode Change, Beam raising & tapping. The correlation charts are proving valuable insights with pot line operations.

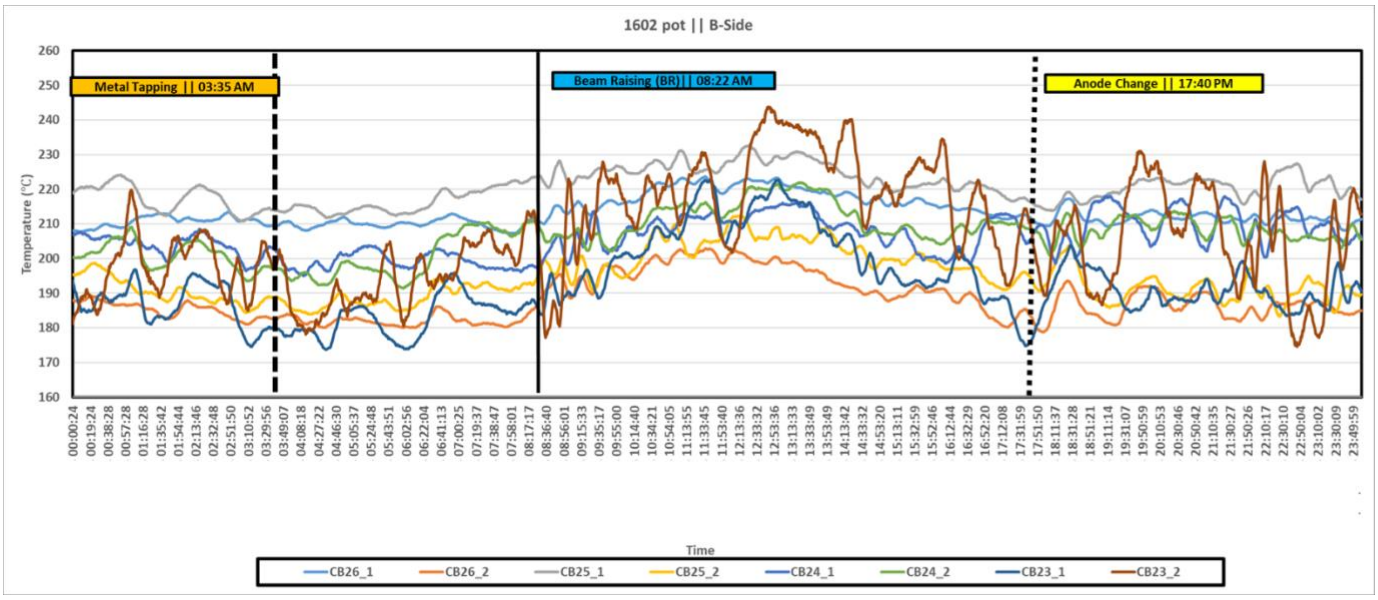


Figure 11: Waveguide Sensor Temperature Recordings B-Side CB26 to CB23 of 1602 pot with pot line Activities

2.5. Electronics & Clamps Unit Upgradation || Dec’2023

The Electronics & Clamps Unit Upgradation involves a complete overhaul of existing systems to enhance performance, reliability, and durability. It includes redesigning electronic enclosures and clamp structures, integrating high-quality components, and improving mechanical strength with corrosion-resistant materials. The firmware is upgraded to support advanced diagnostics and sensor integration, while wiring is reconfigured with proper shielding and insulation. Environmental protection measures such as sealing and coating are implemented to ensure field readiness. The process concludes with system testing, documentation, and training for seamless operation and handover.

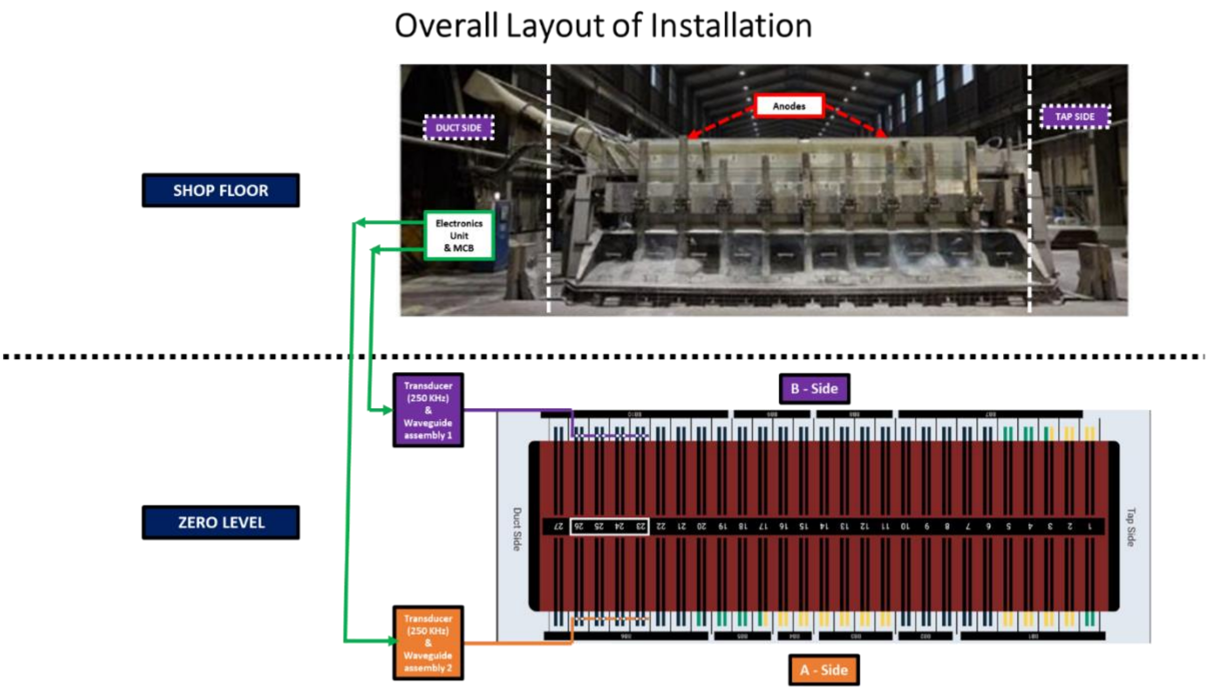


Figure 12: Shop Floor – Zero Level Overall Installation Schematic

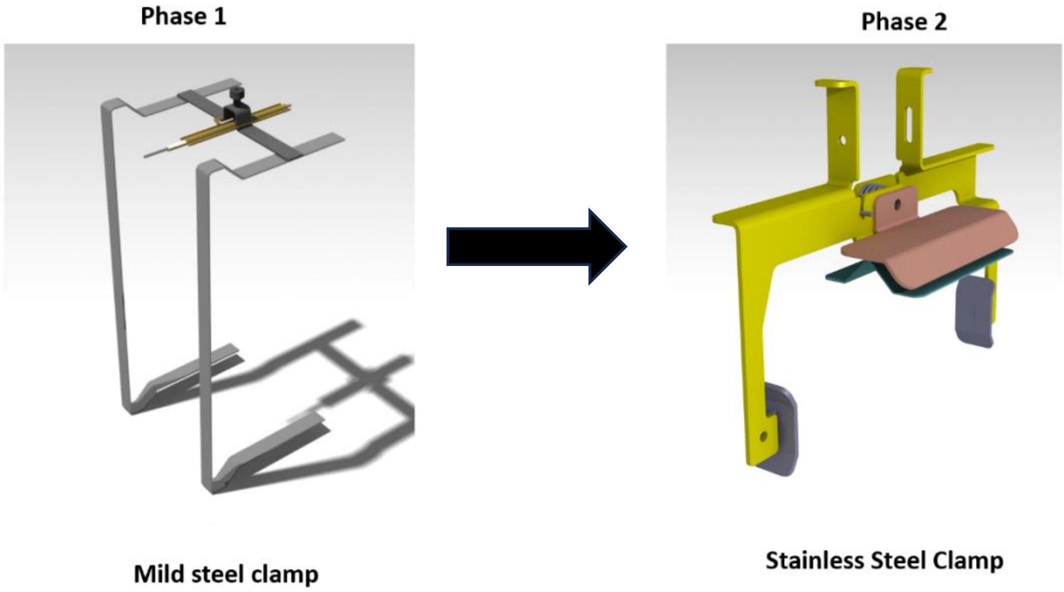


Figure 13: Upgradation of Collector Bar Waveguide clamping methods

Figure 18:
Figure 14: Final Installation of Electronics unit Shop Floor

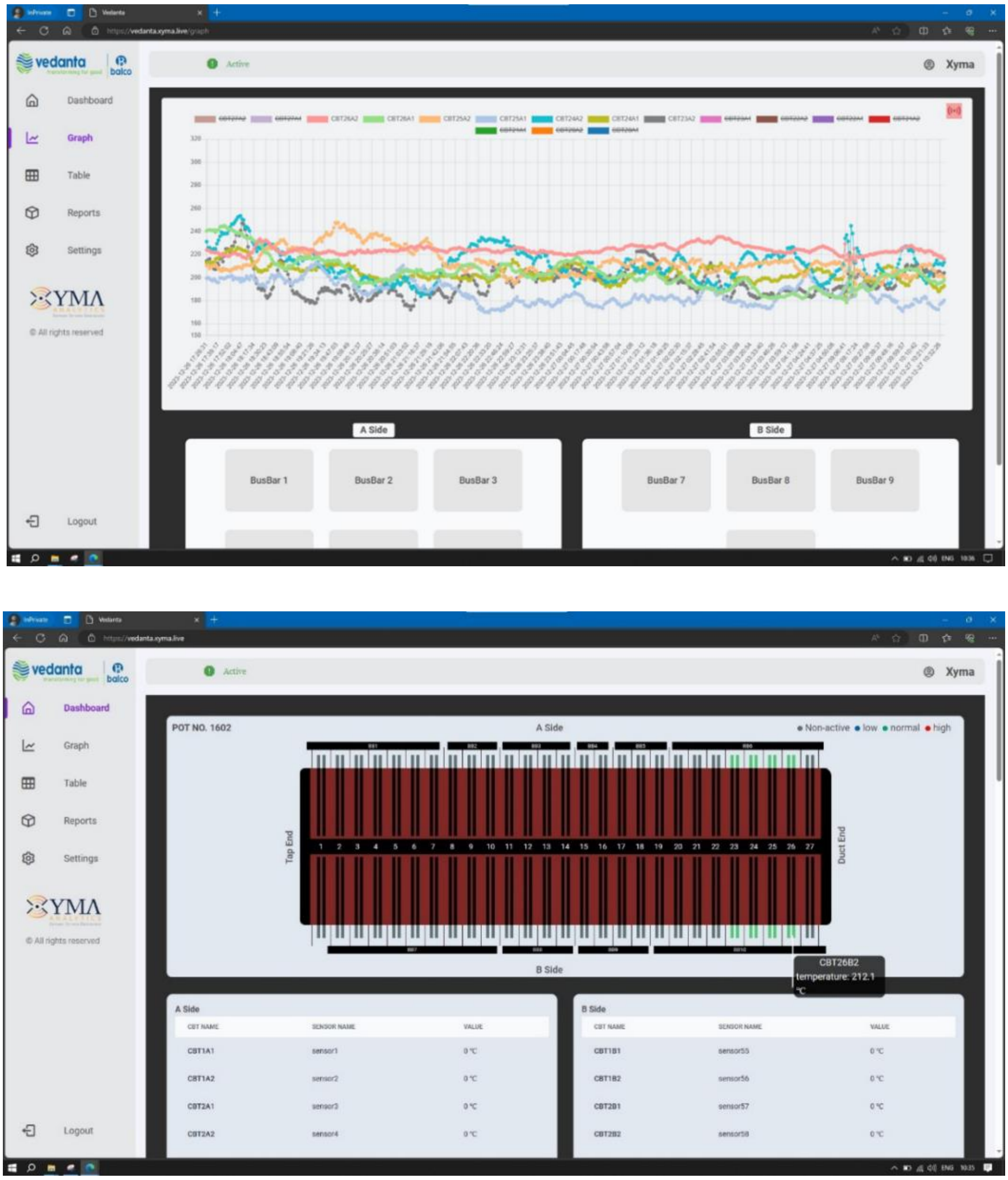


Figure 15: I-IoT Dashboard for Temperature data Visualization by Remotely of 1602 pot

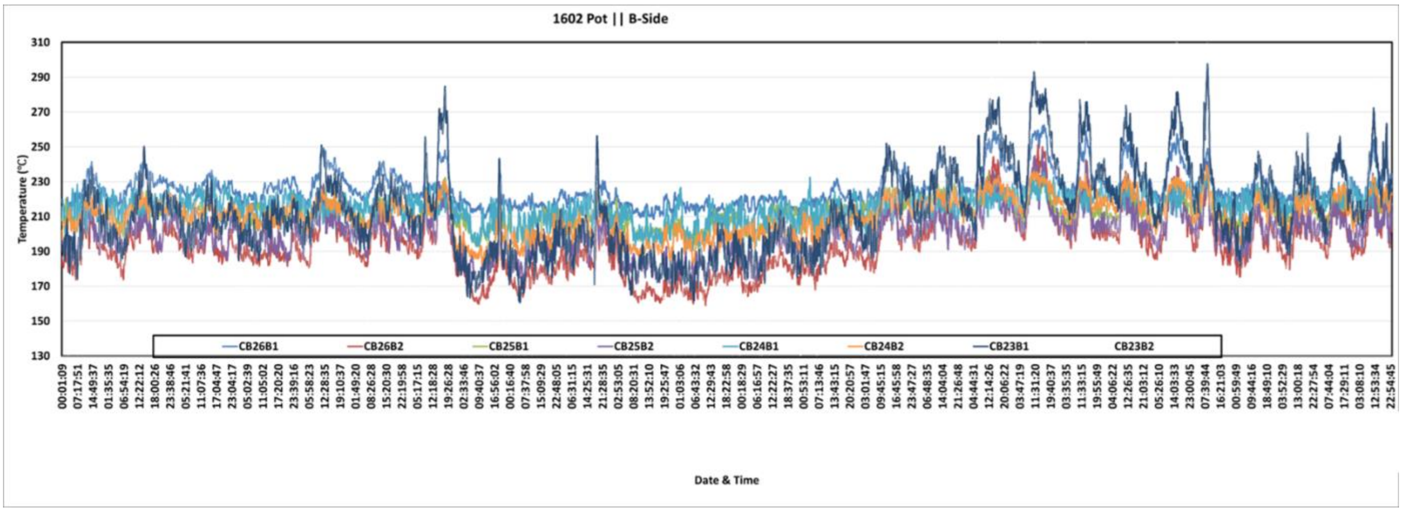


Figure 16: Continuous Collector bar installed Waveguide Sensor readings for 30 days of 1602 pot

The installation was initiated & completed by December 2023. With minor upgradation of the electronics unit in the shop floor was completed. Notable difficulty with the clamping methos of Waveguide sensor with the collector bar was observed. So, a now clamping methos was developed & installed in the operation.

By the end of complete process was initiated, the waveguide sensor continuously collected Collector Bar temperature data from **Dec'23 to Aug'24 (9 Months)** of Duct side of 1602 pot of pot line-2, staring from CB23 to CB26. A 30-days of Waveguide collector bar temperature reading was shown in above figure 20.

A I-IoT based dashboard established to Visualize the collector bar temperature trend & cloud-based temperature database management tool was also provide as per the request from the BALCO team. The snap of the I-IoT dashboard to visualize & manage the Collector bar temperature data was shown above figure 20.

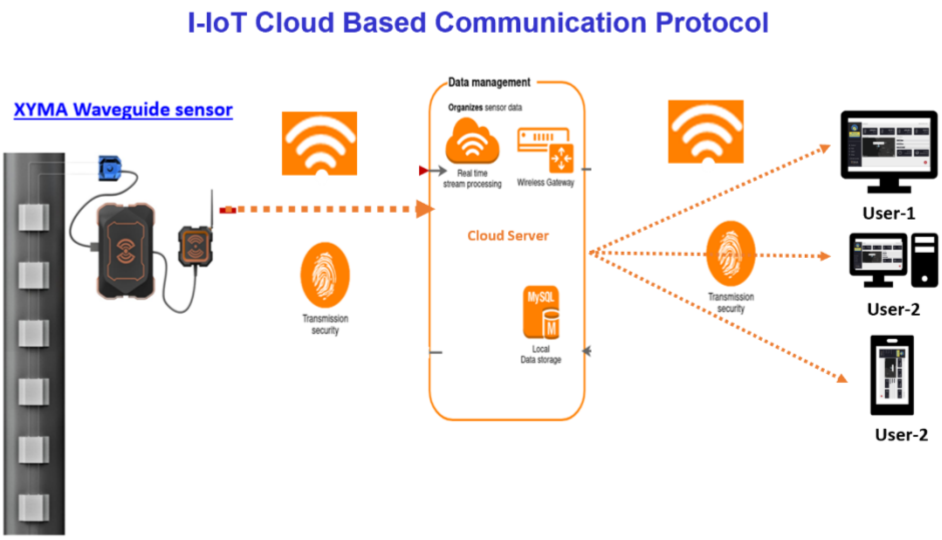
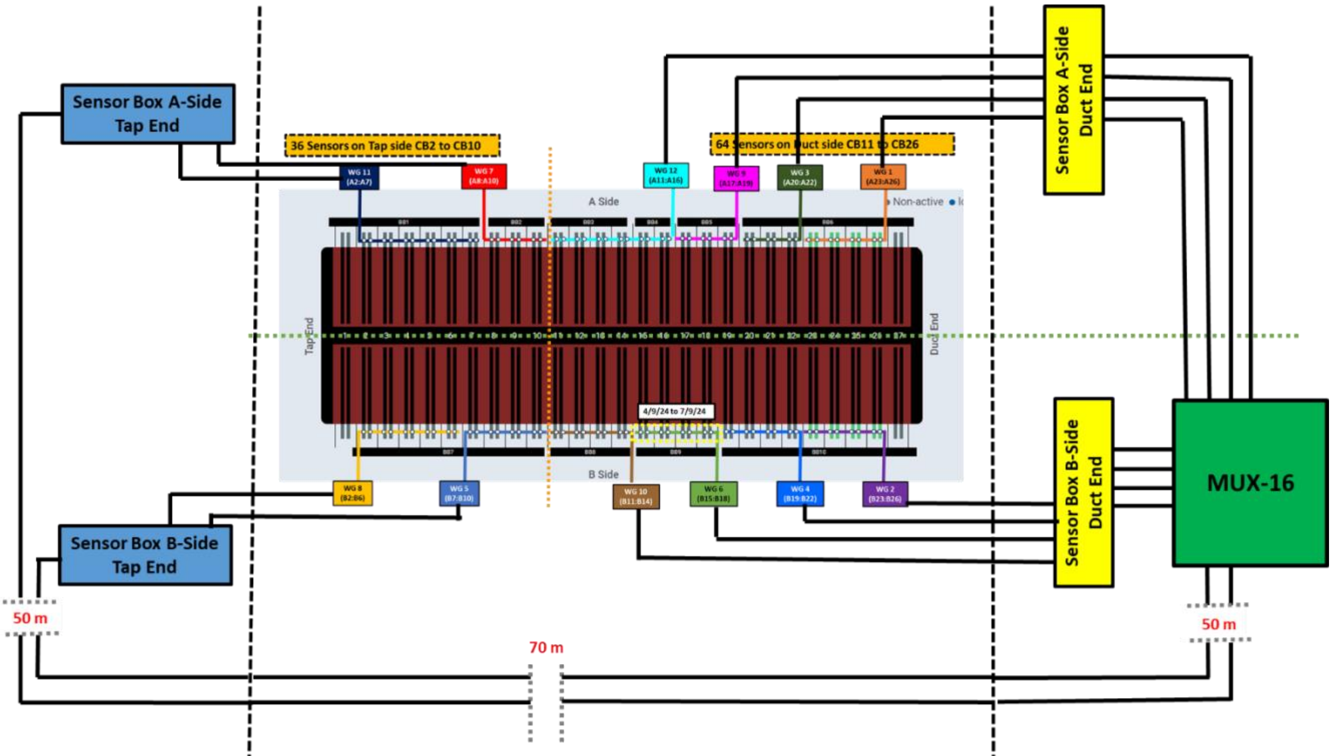


Figure 17: I-IoT Cloud Based Communication Protocol Schematic

2.6. Final Installation

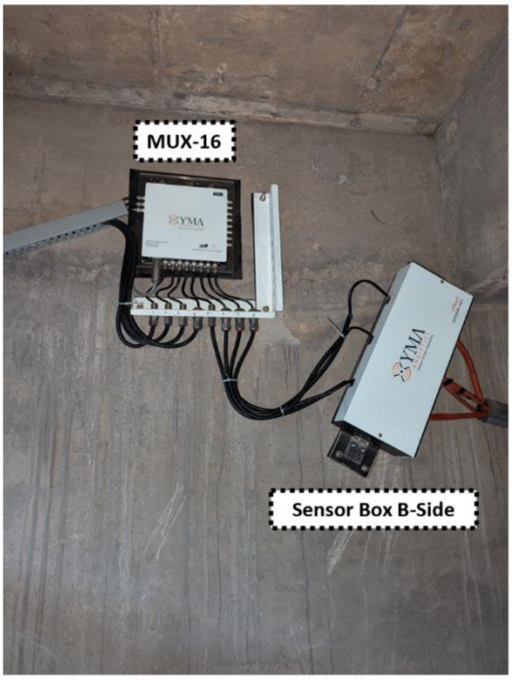


Total no. of waveguide installed = 12

Total no. of collector Bars covered = 100

Figure 18: 100 Collector Bar Installation Schematic of 1606 pot

Figure19: 100 Collector Bar – Waveguide Assembly of 1606 pot



Installation B Side of Duct End:

Installation A Side of Duct End:

Installation A Side of Tap End:

Installation B Side of Tap End:

Figure 20: Sensor Unit Assembly Zero Level 1606 pot

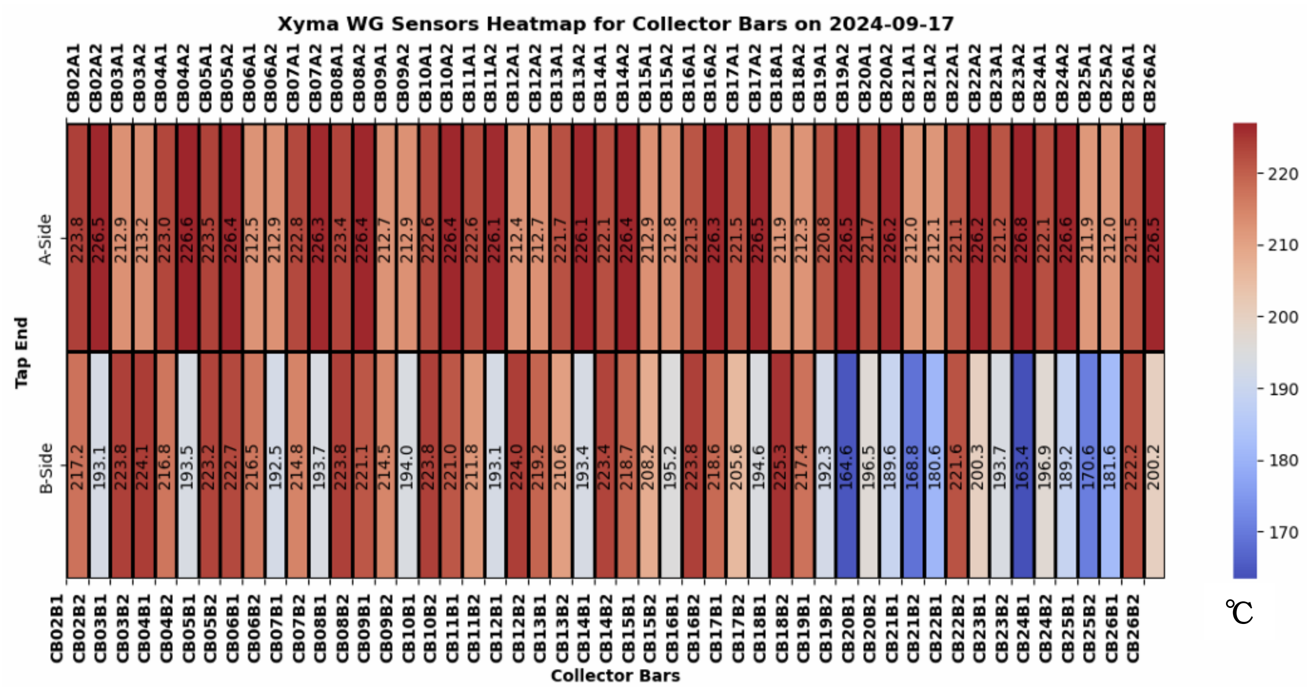


Figure 21: Waveguide Sensor Temperature map of all 100 Collector Bar of 1606 pot

<u>100 Collector Bar WG temperature recording datasheet of 1606 pot:</u>

[A-Side_cb2_to_cb26.xlsx]
[B_side_cb2_to_cb26.xlsx]

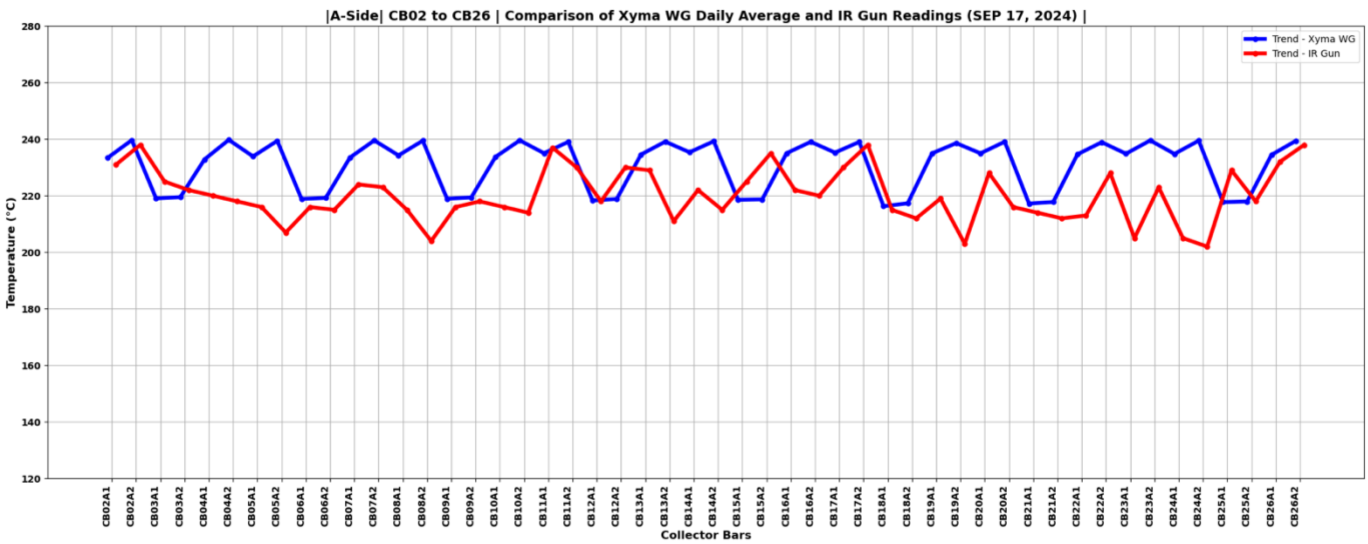


Figure 22: IR Gun – Waveguide Sensor Temperature Comparison of 1606 pot

2.7. Observations on Installation

- **Enhanced Insulation for the Waveguide Sensor Collector Bar Assembly:** As the collector bar serves as the cathode terminal in the pot, implementing multi-layered insulation ensures optimal performance and longevity for the waveguide sensor collector bar assembly.
- **Optimized Clamping Method:** Upgraded clamping solutions facilitate seamless operator access to the collector bar at the Zero Level of the pot, enabling efficient and secure integration of the Waveguide & Collector Bar assembly.
- **Robust Electronics & Sensor Unit Assembly:** The advanced design of the Electronics unit is tailored to withstand the challenging conditions of a smelter plant, including dust, vibrations, magnetic fields, and chemical exposure, ensuring reliable and uninterrupted operations.
- **Adaptable Smelter Operation in High Temperatures:** Innovative installation and maintenance strategies enable efficient handling of extreme temperatures in the smelting process, ensuring smooth and safe operations.

2.8. Conclusion

This report underscores XYMA Analytics' dedication to advancing industrial process monitoring. Rooted in IIT Madras' pioneering research, XYMA continues to bring innovative, high-impact solutions to the industry. The deployment at Vedanta-BALCO stands as a testament to the value of continuous, real-time temperature monitoring in ensuring operational efficiency, safety, and process optimization. Notable significant observations were made during the deployment, and to standardize our product to Aluminium Smelter standards, we have gathered valuable feedback from our plant visits & Operation team of BALCO. The real time CBT data shows the insights on the different activities in the potline like anode change, metal tapping, beam raising etc. This feedback has been instrumental in enhancing our process, ensuring that we meet the highest client satisfaction standards. As an industry leader, XYMA is committed to setting new benchmarks in Aluminium Smelting technology, offering solutions that empower smelters to achieve greater performance and resilience.

3. Phase-2: Real time monitoring of Side shell temperature in Pot Shell at NALCO, Angul, Odisha

3.1. Introduction

XYMA's advanced ultrasonic waveguide sensor technology has been successfully deployed at National Aluminium Company Limited (NALCO), a Navratna Public Sector Undertaking (PSU) under the Ministry of Mines, Government of India. This deployment focuses on enhancing the temperature management of the side shell in NALCO's aluminium smelting process—an area critical to maintaining the structural and thermal integrity of the smelting pots.

The side shell is vital for effective thermal insulation and structural stability within the electrolytic cell. Precise temperature control in this zone is essential for extending pot life, preventing failures, and ensuring consistent smelting performance. XYMA's waveguide-based sensing solution delivers continuous, accurate, and multi-point temperature monitoring, ensuring the smelter operates within optimal temperature thresholds. This directly supports improvements in energy efficiency, equipment reliability, and process stability.

By integrating XYMA's I-IoT-enabled sensors with real-time data visualization and analytics, NALCO gains deep operational insight, allowing for informed, data-driven decisions. This real-time visibility enhances predictive maintenance, improves worker safety, and supports consistent production quality.

The resulting energy savings and operational efficiencies from real-time thermal control contribute to reduced costs and a lower environmental footprint. This initiative underlines NALCO's commitment to sustainability and innovation, showcasing how advanced monitoring technologies can drive long-term operational excellence and global competitiveness in the aluminium sector.

3.2. Problem Statement

The Current temperature monitoring methods in aluminium smelting operations face significant limitations that impact process efficiency, safety, and overall reliability. The prevailing approach—manual infrared (IR) gun measurements taken at periodic intervals—offers only a limited snapshot of surface temperatures within a narrow operating range of 220°C to 250°C, with a typical inaccuracy margin of 5–10°C. Such methods are not only labour-intensive but also prone to human error, compromising the consistency and accuracy of data required for effective process control.

These infrequent, surface-only measurements fail to capture vital internal temperature gradients and dynamic changes, resulting in incomplete thermal profiles. This gap in monitoring leads to inefficient energy usage, suboptimal metal quality, and increases the likelihood of critical equipment failures, particularly in the side shell (SS) areas of the pot.

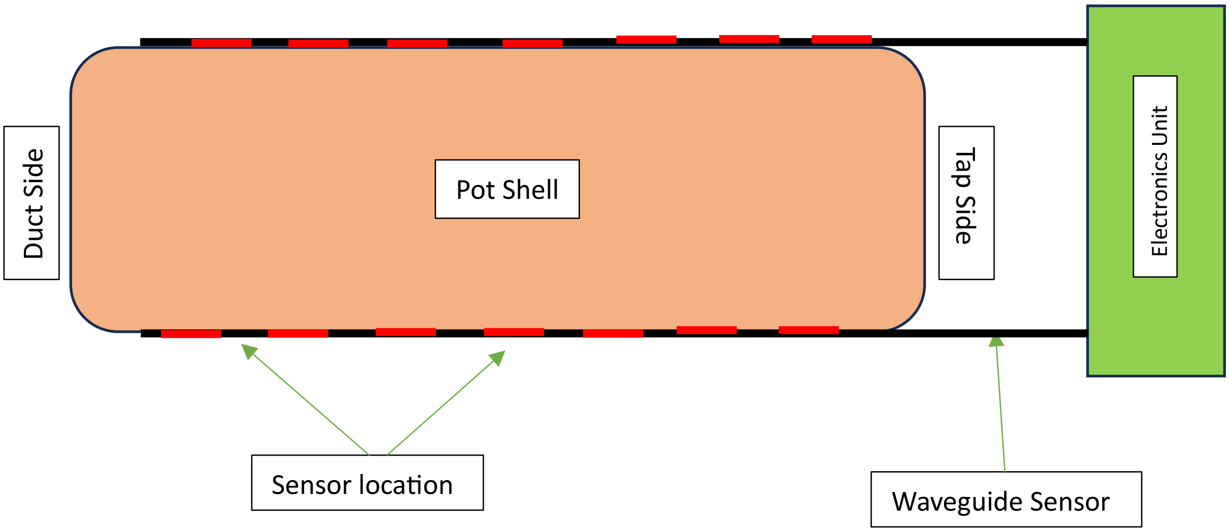
One of the most severe consequences of inadequate temperature monitoring is cell leakage, a common issue in aging aluminium smelters. A leakage event is one of the most hazardous operational failures, often requiring personnel to work in close proximity to disconnect the affected cell from the main potline. This action disrupts operations and typically necessitates a 50% reduction in potline power. In extreme cases, complete power shutdown may be required to address the leak, leading to production losses, process instability, and increased emissions. Despite best efforts, no smelter has fully eliminated cell leakage, which continues to occur 2–3 times per month, resulting in significant maintenance costs, safety hazards, and operational downtime.

Given these challenges, there is a critical need for an automated, continuous temperature monitoring system. A real-time solution would enable:

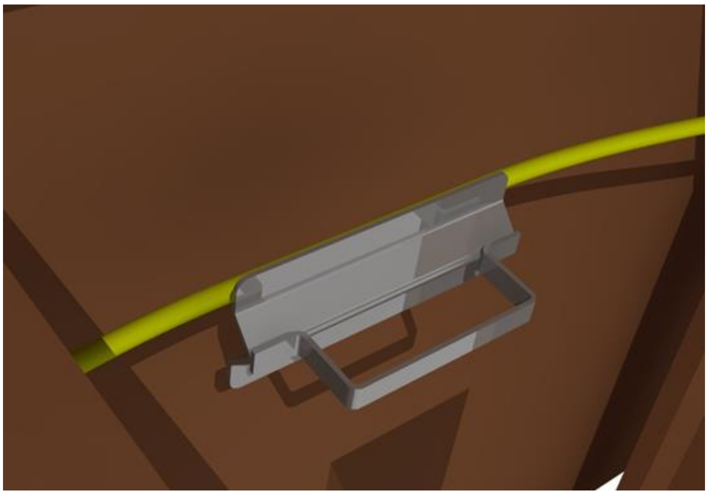
- Accurate multi-point temperature readings across both surface and internal zones
- Early detection of thermal deviations that may indicate pot health issues
- Proactive leak detection and predictive maintenance
- Reduction in manual intervention and enhanced worker safety
- Improved energy efficiency and smelting consistency

By replacing outdated manual methods with automated, high-resolution monitoring, smelters can shift from reactive maintenance to proactive decision-making, reduce risks, and optimize performance across the entire operation. This transformation is essential for modern aluminium production to achieve higher safety standards, lower environmental impact, and greater operational resilience.

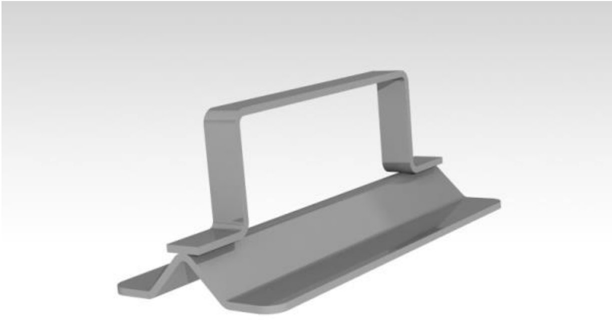
3.3. Proposed solution



- No. of side shell- 24
- No. of waveguide- 2
- No. of sensors locations- 24



Exploded View of waveguide and clamp assembly



Clamp

3.4. Installation Procedure:

The following procedure outlines the comprehensive steps for installing XYMA's ultrasonic waveguide temperature sensors at NALCO smelter facilities. The goal is to ensure safe, accurate, and efficient deployment with minimal disruption to existing operations.

1. Material Supply and Logistics

Prior to commencing field work, ensure the **complete shipment and receipt** of all XYMA components, including:
Waveguide sensor assemblies
Electronics processing units
Cable assemblies and conduit
Mounting hardware
Calibration tools and safety accessories
Perform an inventory check at the NALCO site to **verify all parts against the packing list** and ensure no damage has occurred during transit.
Coordinate logistics to store the equipment securely and near the installation area for ease of access.

2. Technology Brainstorming and Scope Finalization
Conduct an **on-site joint technical meeting** between XYMA and NALCO engineering and operations teams.
Application requirements
Sensor placement strategy
Communication interface with NALCO's existing systems
Key roles and responsibilities for execution
Finalize the **detailed installation scope, timeline**, and **safety compliance plan** based on site conditions.

3. Pot Selection for Sensor Installation
Work closely with the NALCO operations and maintenance teams to:

Identify the target **pot(s)** based on operational accessibility, pot health condition, and safety zoning.
Align the installation window with the **production schedule** to minimize disruptions.
Secure work permits and access clearances in accordance with NALCO's safety procedures.

4. Power Supply Setup
Confirm the **availability of power supply (typically 230V AC)** at or near the sensor installation point.
If not readily available, assist in laying temporary or permanent lines and installing protective enclosures and power panels as needed.
Verify **earthing and surge protection mechanisms** to ensure reliable operation of the electronics unit.

5. Cradle Hole Making
Mark the waveguide insertion points accurately on the **pot cradle structure**, referring to site-specific engineering drawings and XYMA's technical specifications.
Drill and machine the cradle holes using **high-temperature-rated tools and safety gear**, ensuring:
No damage to pot integrity
Compliance with dust and fume management protocols
Clean and prepare the area for waveguide mounting.

6. Catwalk/Slab Removal (for Side Shell Waveguide Access)
For side shell monitoring, dismantle the **catwalk or slab section** obstructing access to the side shell.
Use mechanical lifting aids or cutting tools as needed, following NALCO's work-at-height and hot work safety standards.
Ensure **barriers, safety nets, and fire-retardant coverings** are in place to protect personnel and equipment.

7. Waveguide Installation at Side Shell
Insert and anchor the waveguide sensor precisely into the prepared side shell location.
Use high-temperature mounting compounds or fasteners to ensure **stable, vibration-resistant installation**.
Route cables through **conduits or protective sleeves** to the nearest junction box or electronics unit location.

8. Sensor and Electronics Unit Installation
Mount the **main sensor body** on the installed waveguide.
Position the **electronics processing unit** in its designated location, preferably away from high-temperature zones and with adequate shielding.
Establish all electrical and signal connections using **certified industrial-grade connectors**.
Verify cable integrity and secure strain reliefs to avoid tension or disconnection under operating conditions.

9. Sensor Activation and Data Transmission to IIoT Dashboard
Power up the sensor and electronics unit.
Check:
Sensor initialization
Ultrasonic signal quality
Internal diagnostics
Establish **network connectivity** (wired or wireless) to XYMA's IIoT server.
Begin **real-time data streaming** to the XYMA dashboard.

Validate temperature readings through preliminary tests and calibration checks to ensure **data accuracy and reliability**.

10. Report Generation and Work Completion Letter

Document the complete installation process, including:

Site layout and sensor locations

Photographs of installation steps

Connection diagrams and test logs

Initial data validation results

Submit a **comprehensive installation report** to NALCO's project authority.

Issue a formal **Work Completion Letter**, jointly signed by XYMA and NALCO representatives, confirming the successful execution of the installation phase.

3.5.Results:

After successful deployment of waveguide sensor in side shells of aluminium pot at Nalco, Angul. The following are the results for the period of 1 week

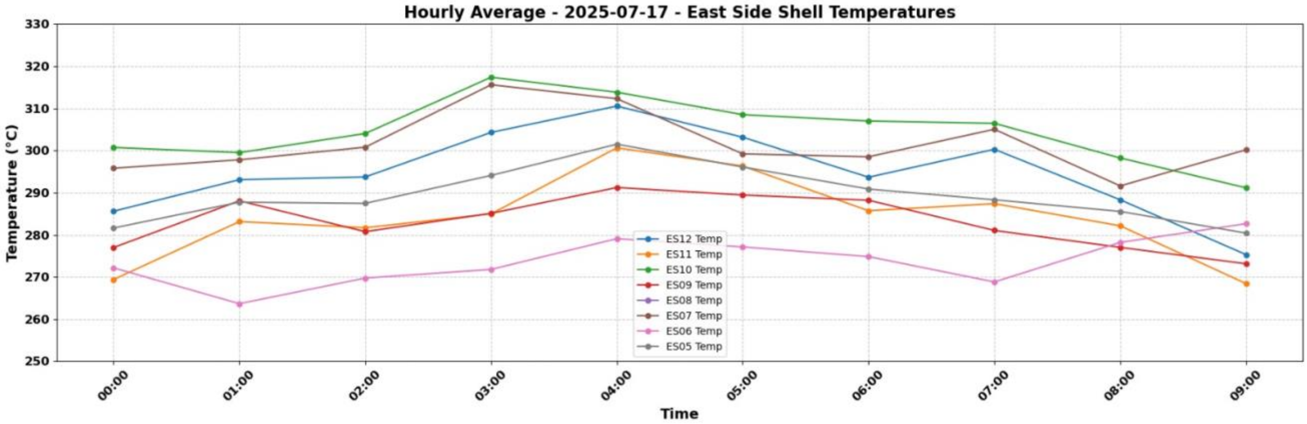


Figure 23 : Side Shell Temperature data of east side of potshell

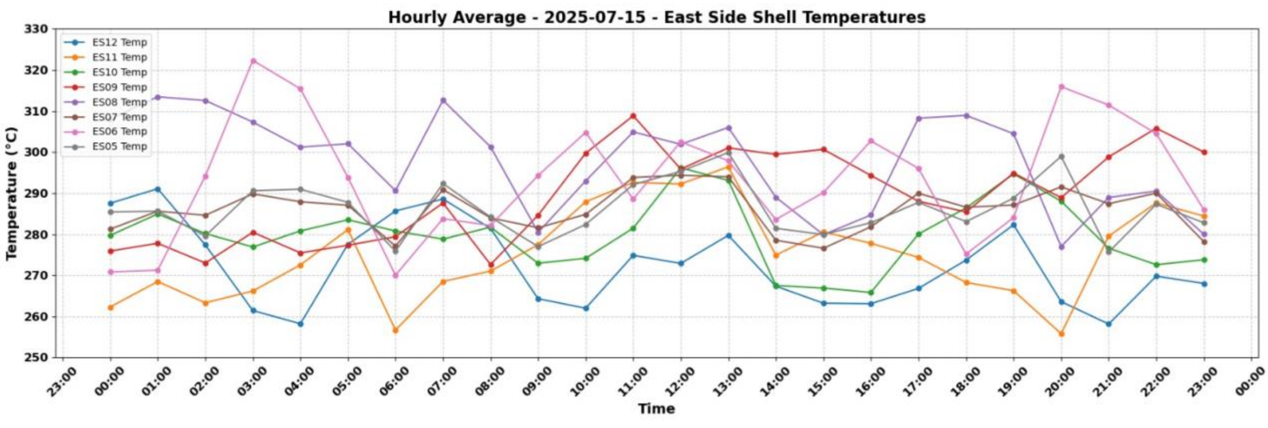


Figure 24 : Side Shell Temperature data of east side of potshell

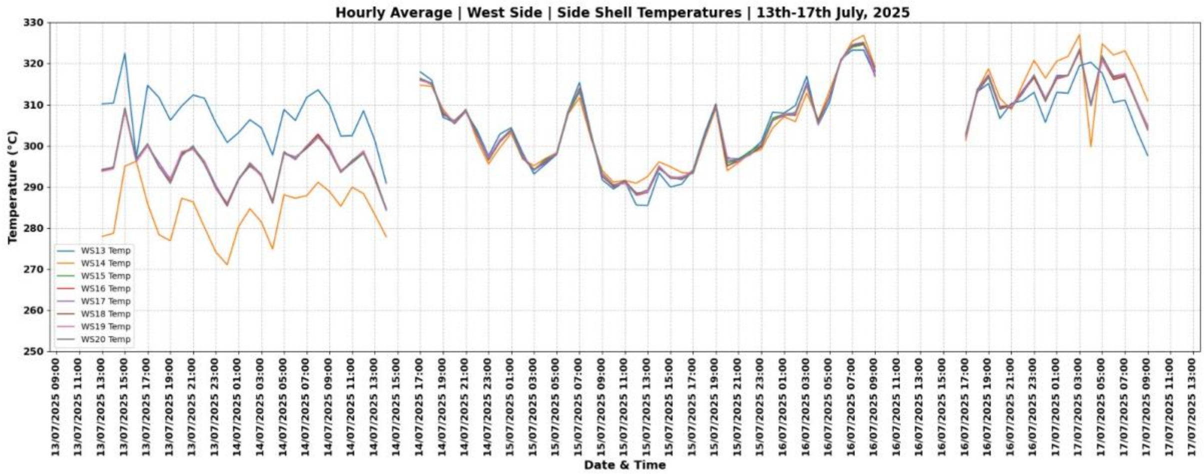


Figure 25 : Side Shell Temperature data of West side of potshell

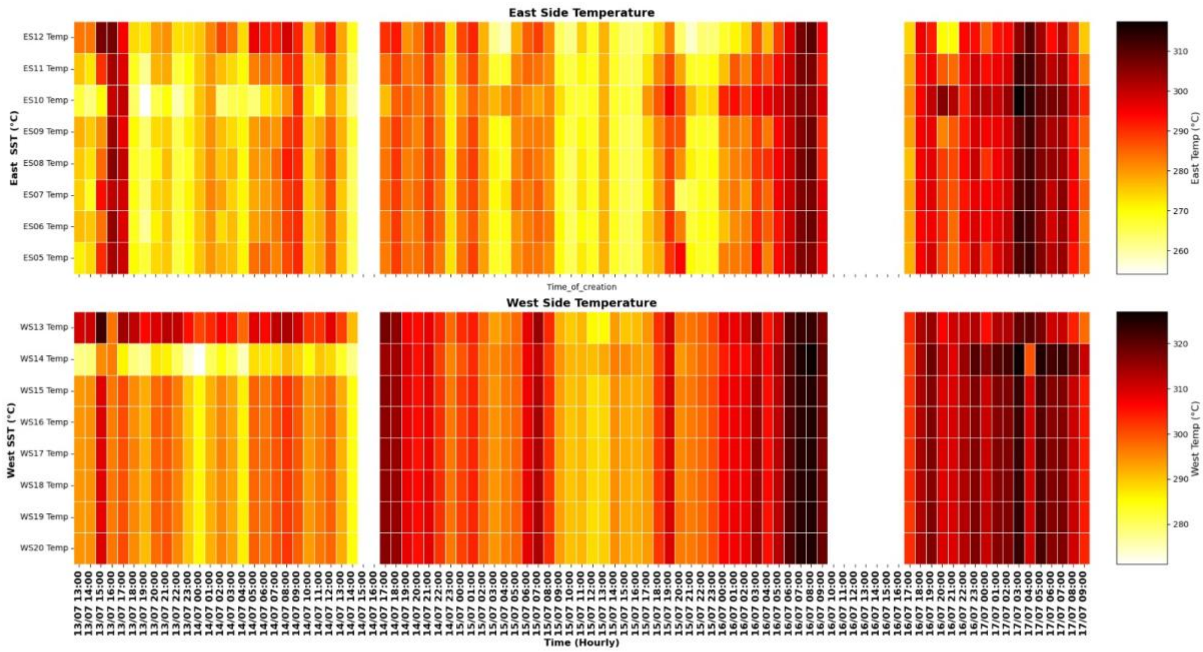
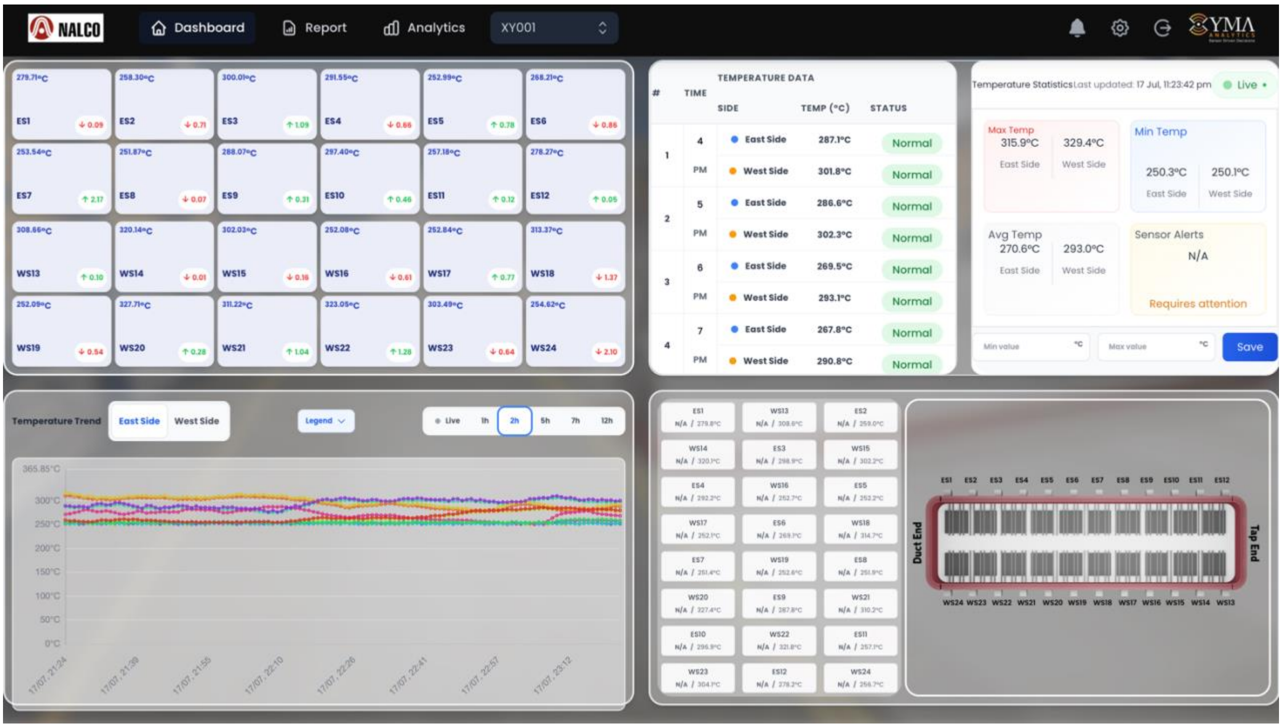


Figure 26 : Heat map of side shell temperature in potshell

Online Dashboard



Installation Photos:

3.6. Conclusion:

In conclusion, the installation phase was meticulously carried out in line with established protocols, prioritizing technical precision and operational safety. Thorough documentation, including connection diagrams and test logs, has been completed to support future reference and maintenance. Initial data validation confirmed the system's effectiveness and readiness for continued use, while the successful collection and analysis of side shell temperature data demonstrated reliable system performance. The integration with an online dashboard now enables real-time monitoring, empowering users to detect thermal anomalies early, support preventive maintenance, and ensure optimal operational health.

The issuance of a formal Work Completion Letter, jointly signed by representatives from both XYMA and NALCO, marks the official and successful completion of this installation phase. These achievements reflect a strong commitment to quality, compliance, and the realization of project goals by all stakeholders, paving the way for a smooth transition to subsequent operational stages.