

Washer Overflow Liquor Chemistry Prediction by Using Mud Level Instrumentation

Rodrigo Neves¹, Diego Silva², Mohammed Miharaj³, Sourav Biswas⁴,
Abdullah Al-Otaibi⁵ and Akram Khan⁶

1. Lead Process Engineer – Red Side
2. Senior Engineer – Advanced Process Control
3. Lead Process Engineer – Alumina Refinery
4. Technical Manager – Alumina Refinery
5. Technical Director – Alumina Refinery
6. Process Control Superintendent – Alumina Refinery

Ma'aden Bauxite and Alumina, Ras Al Khair, Saudi Arabia

Corresponding author: nevesr@maaden.com.sa

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Abstract

Maaden alumina refinery digestion alumina to caustic ratio (A/C) control is a feedback control with a lag time of 40 minutes to determine the equilibrium ratio inside digesters that adjusts the bauxite slurry required to achieve the target ratio with a margin set point (SP). Margin SP is the difference between digester equilibrium ratio and target ratio inside digesters. Digester equilibrium condition is estimated from online measurement of blow-off liquor chemistry, lab results of lead washer overflow liquor chemistry at periodic intervals and flash tanks evaporation rate. In Bayer process, clarification area uses different technologies available in the market for online measurement of interfaces and mud level in settlers and washers. Maaden uses mud level instrumentation for such purpose. Lead washer overflow (dilution) is injected to last flash tank outlet to control blow-off caustic and temperature. Lab team analyses lead washer overflow liquor chemistry at periodic intervals, and this causes multiple step changes leading to highly variable digestion target ratio control affecting digestion alumina production. This paper presents a novel approach where the online mud level instrument raw conductivity values are newly introduced to predict the liquor chemistry (alumina and caustic) in lead washer overflow using statistical method and the online values were connected to the digestion ratio control as part of digitalization projects. As a result, this improved the digestion ratio control and reduced alumina production losses by 34 000 tonnes per year (1.89 % loss avoidance yearly).

Keywords: Bayer process, Digestion ratio control, Process control and digitalization.

1. Introduction to Maaden Alumina Refinery Digestion Process

The Saudi Arabian Mining Company (Maaden) owned Maaden Aluminium complex is a largest fully integrated aluminium complex located in the minerals industrial city of Ras Al Khair on the east coast of Kingdom of Saudi Arabia. The complex consists of a bauxite mine and an alumina refinery, an aluminium smelter and a rolling mill. Maaden Alumina Refinery has been designed to produce 1.8 Mtpa alumina from bauxite and in turn will be smelted to produce 0.74 Mtpa of aluminium. Bauxite mine located at Al Baitha in north- eastern Saudi Arabia approximately 600 km north-west of Ras Al Khair supplies bauxite to alumina refinery by rail and has a production capacity of 5 Mtpa of bauxite. Key infrastructure for Maaden aluminium complex includes the port, power plant and desalination plant as well.

Maaden alumina refinery commenced operation on November 2014 with 2 digestion units and is currently operating with a capacity of 1.87 Mtpa of smelter grade alumina (SGA) (FY-2024 actual SGA Production). Bauxite handled at Maaden complex has a high boehmitic content of 32 %

approx. and so the digestion process – which extracts alumina from bauxite by contact with strong caustic liquor at high temperature and pressure – is applied with a temperature of 273 °C and a pressure of 5 200 kPa.

The digestion area receives bauxite slurry from pre-desilication tanks and strong liquor from digestion test tanks which is blended and pumped through jacketed pipe heaters to preheat the slurry to 200 °C using flash steam from digestion flash tanks. Preheated bauxite slurry is introduced into the digester vessels where it is heated to 273 °C using high pressure steam direct injection to achieve required extraction of alumina from bauxite and with required residence time.

The slurry is then cooled in a series of flash tanks, reduced to atmospheric pressure in the blow-off tank before being fed to clarifiers for solid-liquid separation. The flash vapours are used to preheat the incoming bauxite slurry in jacketed pipe heaters. Blow-off alumina to caustic ratio (A/C) and total causticity (TC) of the slurry feeding the mud settlers are in the range of 0.695–0.700 and 248–252 g/L respectively. Mud washing circuit recovers liquor rich in alumina and caustic from the mud settler underflow mud in counter current decantation method. Dilution liquor (lead washer overflow) has an alumina to caustic ratio (A/C) in the range of 0.60–0.64, total causticity (TC) at 120–135 g/L and total alkalinity (TA) 130–150 g/L respectively, and is injected into the slurry stream prior to the blow-off tank to cool down the slurry and to increase the super saturation.

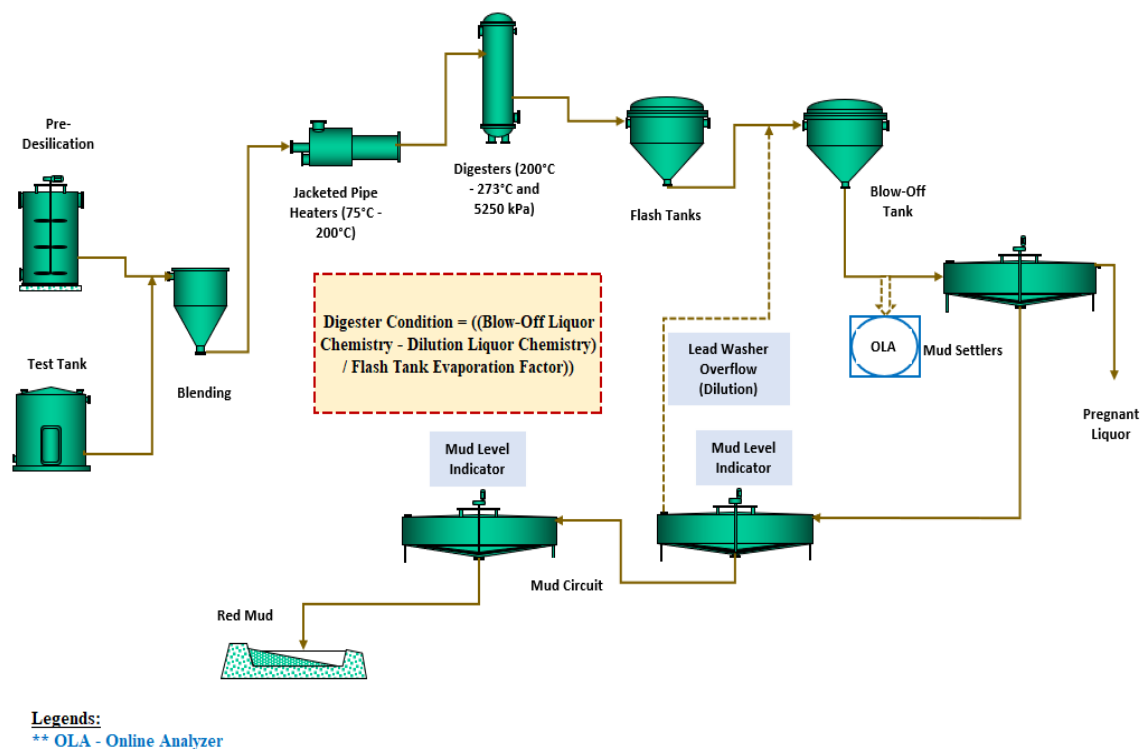


Figure 1. Maaden alumina refinery digestion process

The equilibrium ratio inside digesters is estimated from a blow-off analyser for alumina to caustic ratio (A/C) and total causticity (TC) together with laboratory analysed dilution liquor (lead washer overflow) alumina to caustic ratio (A/C) and total causticity (TC) values and evaporation factor across the flash tanks. Digester target ratio is controlled with margin SP between equilibrium ratio and actual ratio inside digesters, defined by the digestion engineer to minimize the error in the equilibrium calculation and to avoid the risk of auto precipitation. Bauxite slurry is charged accordingly to achieve digester ratio target and thereby production target with a lag time of ~40

minutes. Blow-off online analysers are corrected using CUSUM biasing model with lab analysed data at periodic intervals for alumina to caustic ratio (A/C) and total causticity (TC).

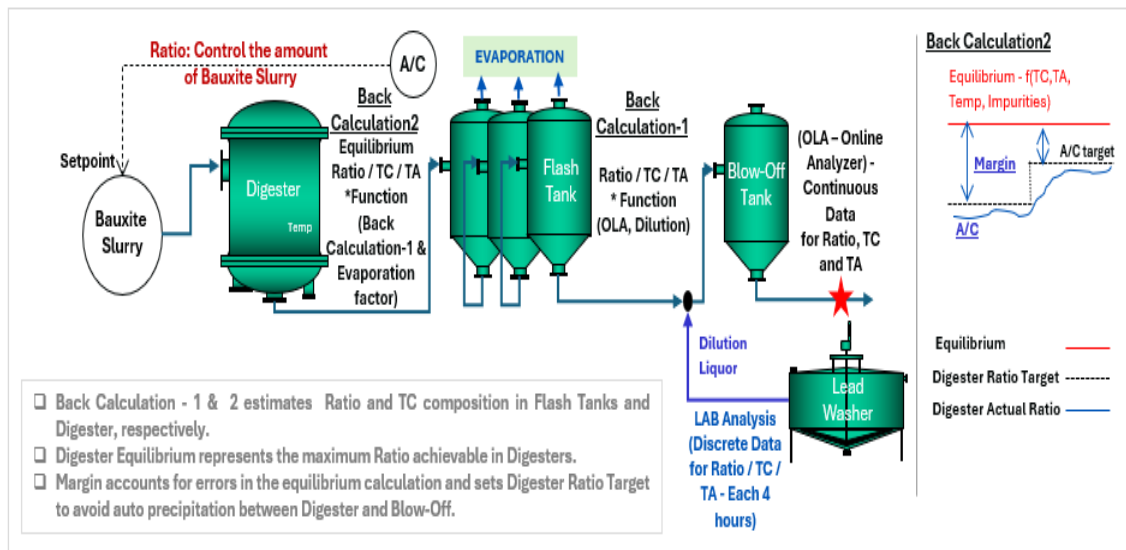


Figure 2. Digestion ratio process control.

Hereafter abbreviations will be used to mention the following parameters.

- Lead washer overflow liquor - “**Dilution liquor**”
- Alumina to caustic ratio (A/C) - “**Ratio**”
- Total causticity - “**TC**”
- Total alkalinity – “**TA**”
- Alumina – “**Al**”

2. Digestion Ratio Control Challenges with Dilution Liquor Chemistry Data

Dilution liquor chemistry for ratio and caustic is analysed in Maaden Laboratory once in 4 hours and the results are updated in LIMS (Lab Information Management System). Digestion ratio control system uses this data to calculate the caustic and ratio inside the digesters as explained in section-1. Dilution liquor chemistry for ratio and TC remains the same for 4 hours till updated with next result after 4 hours. Any sudden step change in dilution liquor ratio due to either actual drop / increase (or) due to wrong sampling / wrong results outside the range mentioned in section-1 affects digester equilibrium ratio. Step change with increase in dilution liquor ratio leads to opportunity production losses and step change with drop in dilution liquor ratio leads to overcharging events, consequently, allows alumina to precipitate in blow-off mud reporting high bauxite consumption to achieve blow-off target ratio and alumina production.

Next Figure 3 shows an example of such upset event with dilution liquor ratio fluctuations.

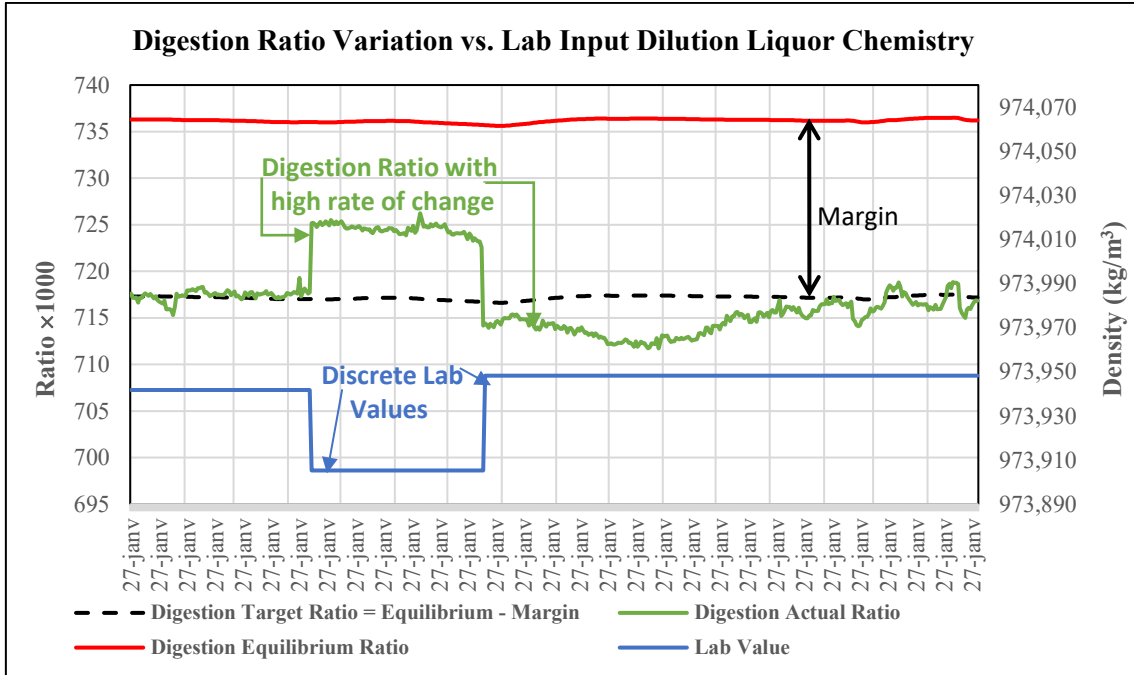


Figure 3. Digestion ratio variation with lab input dilution liquor chemistry.

3. Improvement Action – Phase by Phase

Digestion ratio control back calculation has been improved by implementing two actions in phases.

- **Phase-1** action is to use “lead washer mud level instrumentation raw conductivity values to predict the dilution liquor chemistry using a regression equation”.
- **Phase-2** is to use “an algorithm to judge dilution liquor discrete lab values outliers and to minimize high rate of change and to avoid big step change in digester ratio back calculation when lead washers online mud level instrumentation goes fault (low confidence) and needs maintenance.

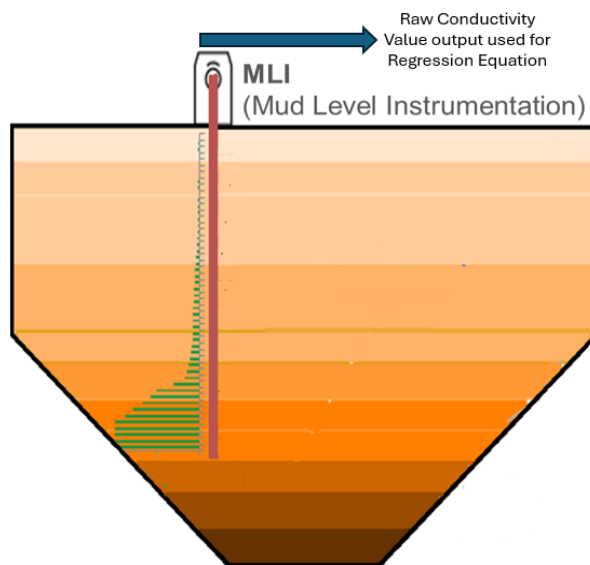


Figure 4. Lead washer (clarifier) showing mud level instrumentation

3.1 Phase-1: Conductivity-Based Prediction of Dilution Liquor Chemistry

A correlation algorithm has been developed which will predict dilution liquor chemistry (Al, TA and TC) using raw conductivity values read from online mud level instrumentation on a continuous basis against 4 hours once discrete values from lab. The online programmed dilution liquor chemistry values are synchronized for Digester back calculation as a continuous feed.

The statistical regression results R^2 , P-value and F-statistic between the conductivity vs Lab (Alumina, Total Alkalinity and Total Causticity) confirms that the regression equation is a valid predictor of the lab results based on online conductivity measurements.

Table 1. Regression statistics.

Regression Statistics			
LAB	R Square	P-value	F
Al	0.756	1.69E-18	170.65
TC	0.844	7.53E-24	297.54
TA	0.764	3.40E-19	181.13

The scatter plot below shows the relation between conductivity and lab.

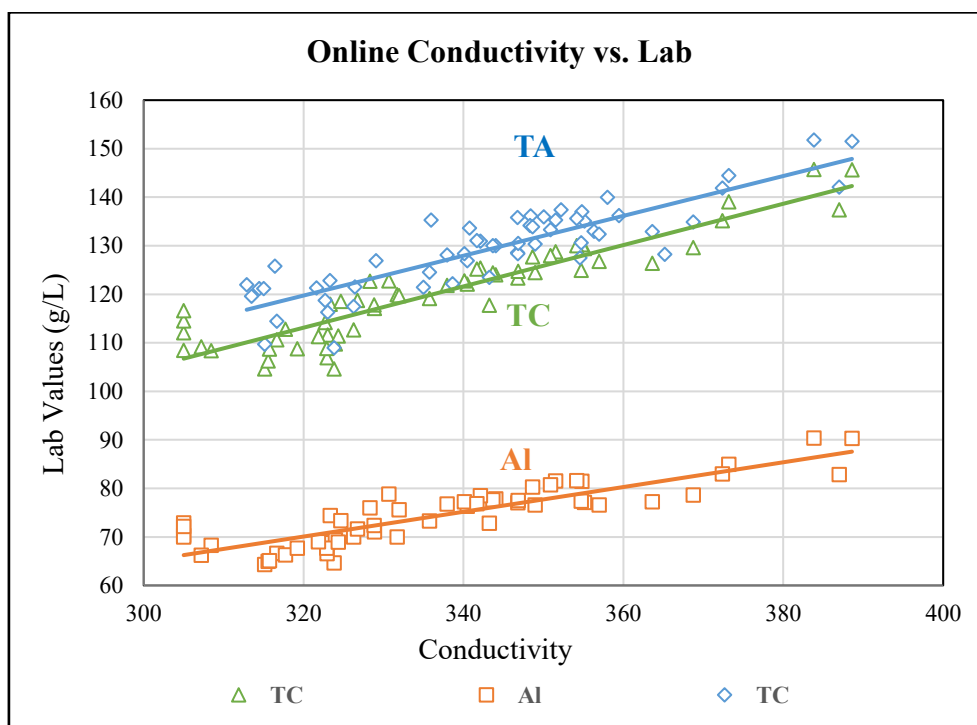


Figure 5. Dilution liquor TA / TC / Al correlation – lab vs. online conductivity values.

Accurate data monitoring is essential in industrial process. Though laboratory (lab) measurements provide reliable results, the data are discrete and can delay the continuous digestion ratio calculation. Online sensors provide continuous monitoring but can be distorted due to sensor drift or calibration issues. As demonstrated in R^2 , the regression can be explained by 75.6 %, 84.4 % and 76.4 % for Al, TC and TA respectively. To use this correlation for dilution liquor chemistry as an input for the digester back calculation, it was also necessary to implement a lambda-based statistical correction to minimize the drift over time between the predictor versus lab results.

The lambda method calculates the error (difference) between the lab and the predictor (online regression) at the same timestamp (t) by applying a bias correction factor in 30 % of the error to adjust future predictions.

So, Lambda-Bias correction will follow this equation:

$$Bias(t) = \lambda \times (Y_{Lab(t)} - Y_{Corrected(t)}) \tag{1}$$

$$Y_{Corrected(t)} = Y_{Corrected(t)} + Bias(t) \tag{2}$$

$$Y_{Corrected(t=0)} = Y_{Online(t)} \tag{3}$$

where:

- λ 0.3
- $Y_{Lab(t)}$ Lab results in the specific timestamp
- $Y_{Corrected(t)}$ Online regression in the same lab timestamp with the bias
- $Y_{Corrected(t=0)}$ Online regression without bias
- $Y_{Online(t)}$ Online regression.

Bias changes will act with low-pass filter to adapt the changes in the bias gradually while minimizing the error. The trend line in the graphic shows how the bias correction adds dynamic adaptability to minimize the deviation over time which will support the predictor to be more reliable to use in digester back calculation, representing the dilution liquor chemistry. It also shows the correlation behavior between the predictor and the Lab in real time value.

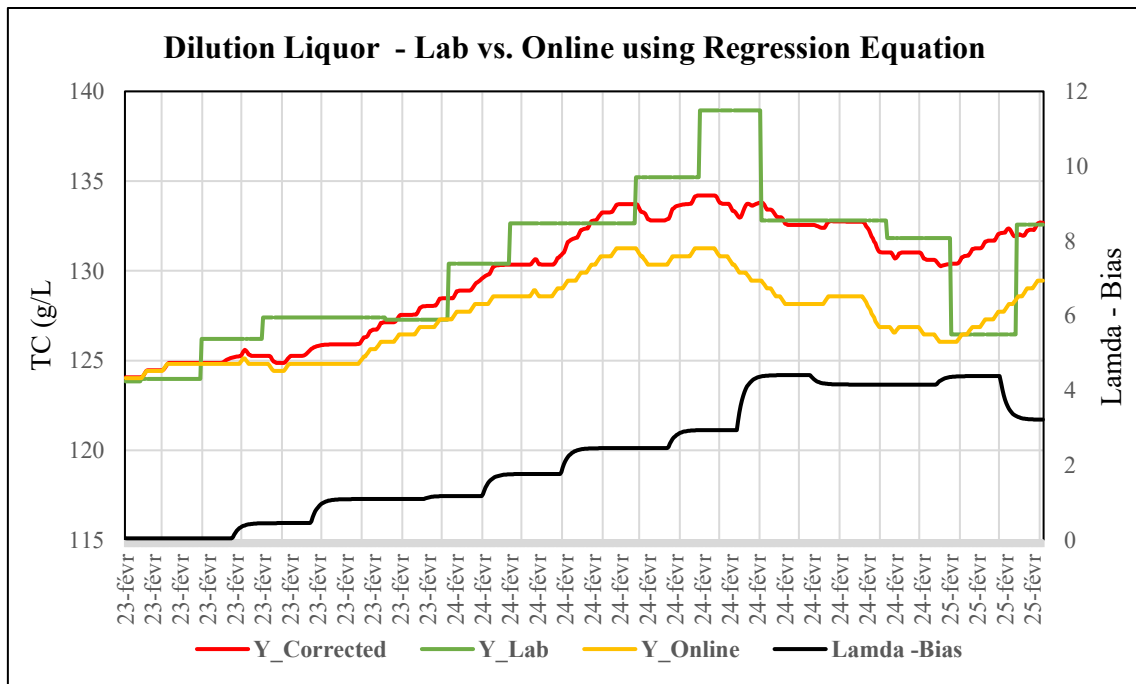


Figure 6. Dilution liquor TC – discrete lab value vs. predicted online regression value.

3.2 Phase-2: Algorithm Application to Adjust Outlying Lab-values

A program has been developed to switch automatically the “regression equation calculated dilution liquor chemistry parameters” to “lab values” when the mud level instrumentation goes bad with low confidence output and to switch back when the instrument gains back its confidence.

An instrument configuration has been set to identify its 100 % confidence. When the lab values are updated in LIMS once in 4 hours, the algorithm will judge if there are any outliers to minimize the high rate of change in lab values which will contribute to do a big change in digester ratio back calculation.

The objective of this algorithm is to eliminate outliers without suppressing actual measurement values. The newly developed algorithm interrogates 4-hour once Maaden Lab values against a specification limit calculated from selected source data, either from an instrument or recent lab data history. If the lab sample value falls within the specified limits, it is accepted; otherwise, it undergoes with statistical adjustments based on predefined parameters.

The algorithm calculation triggered upon the appearance of a new lab result. Depending on the mode of specification limit calculation (instrument-based or lab-based), the value is first validated and then checked to determine if it is in the initialization or calibration phase. The phase is defined by the pre-specified size of the data set used in the specification limit calculations.

Once the process exits the initialization phase, it begins to calibrate the output based on the lab input and the calculated specification limits. If the lab value violates the calculated specification limits, it is adjusted using predefined adjustment factors. Conversely, if the lab value falls within the specification limits, it is relayed to the output without adjustments.

This algorithm effectively removes outliers from process parameters by applying statistically calculated specification limits that represent the process variability range. It interrogates new lab values accordingly and determines the degree of reliance on the new lab results.

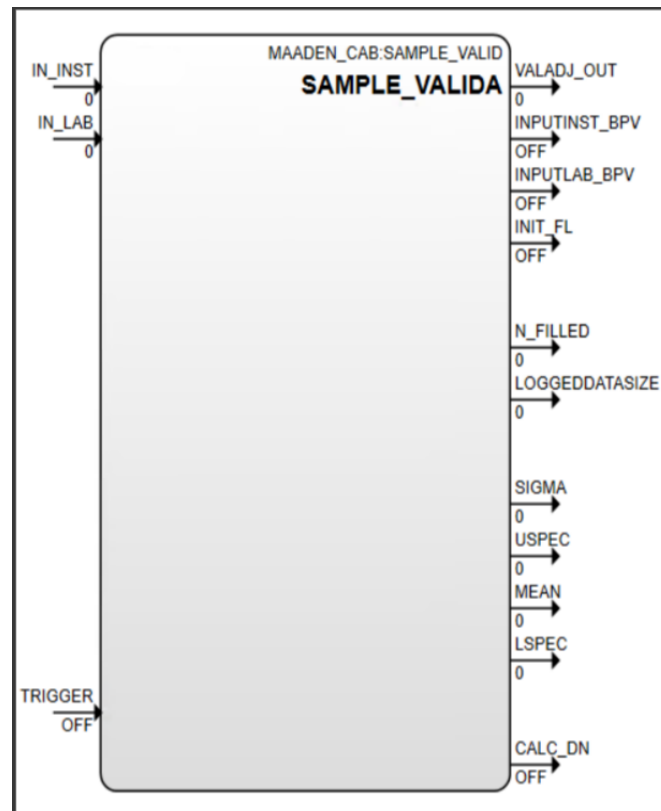


Figure 7. Developed custom algorithm block (CAB).

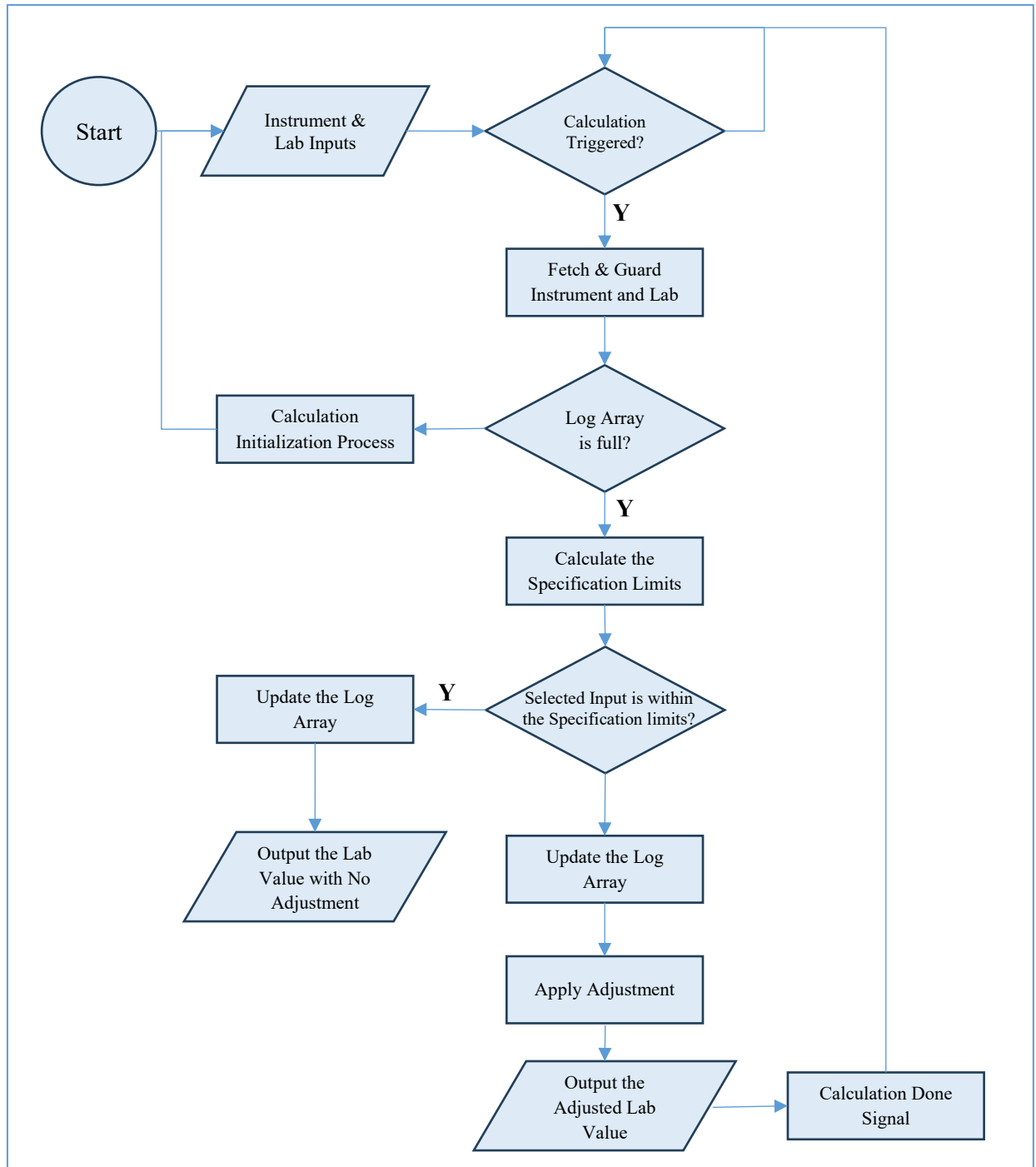


Figure 8. Algorithm explaining phase-2 improvement action.

4. Conclusion – Improvement with Digestion Ratio

Phase-1 and phase-2 improvement actions detailed in sections 3.1 and 3.2 have enhanced Maaden alumina refinery’s digestion ratio control program, reducing standard deviation by 33 % in Digester TC and 77 % in Digester A/C and leading to improved process stability comparing financial year 2021 and 2024. Financial year 2022 and 2023 are considered as the action implementation and fine-tuning years for the implemented actions. This improvement prevented an alumina production loss of 34 000 tonnes, which constitutes to 1.89 % of Maaden alumina refinery’s annual production capacity.

The improvement in Digester TC and Digester A/C, before and after, is shown in the graph below.

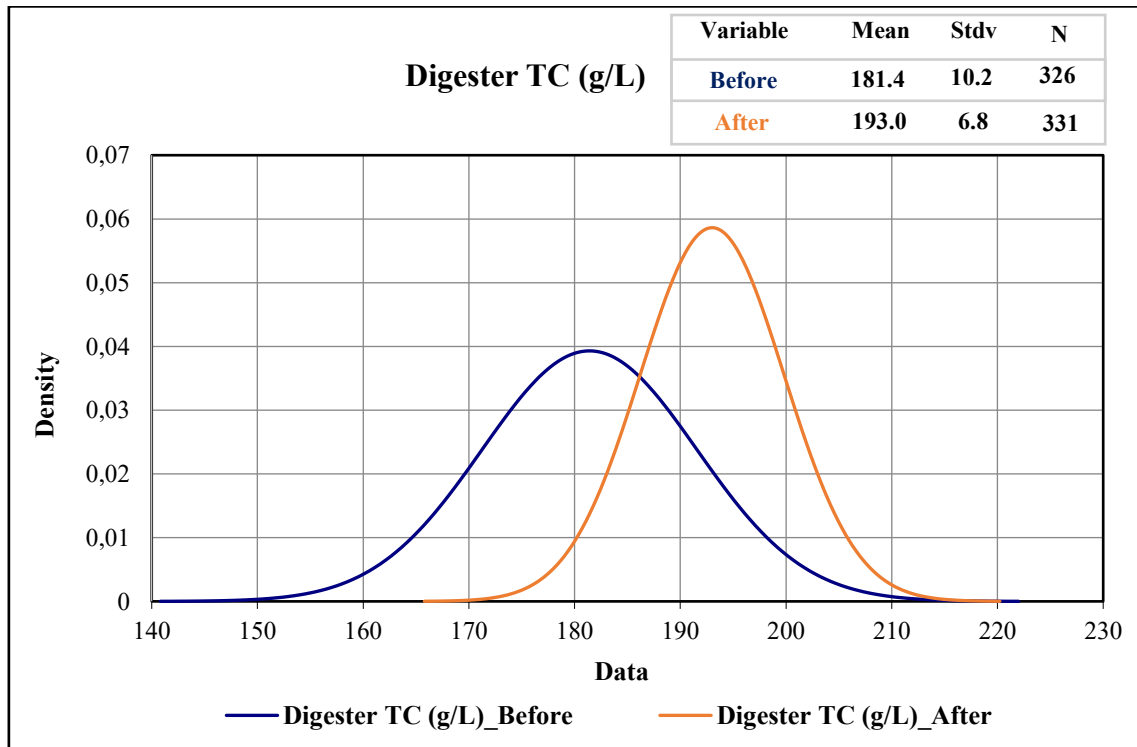


Figure 9. Improvement in Digestion TC control.

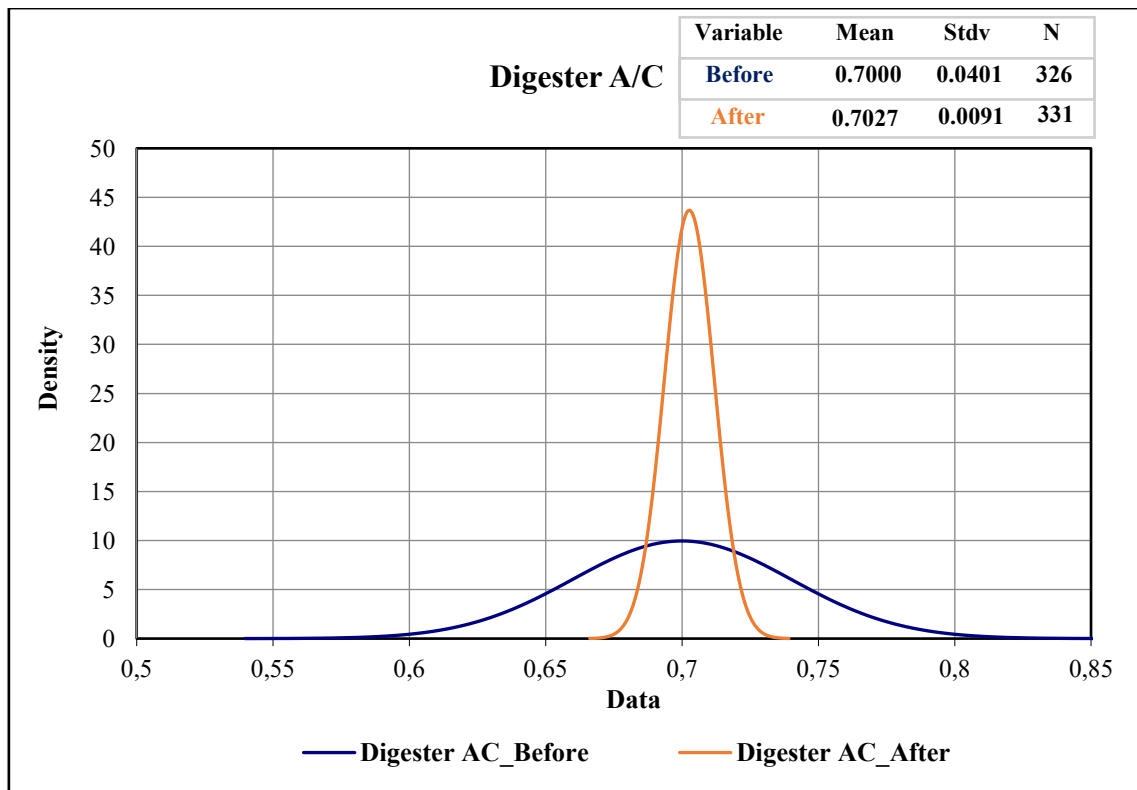


Figure 10. Improvement in Digestion A/C control.

Production gain calculation is explained in detail in Table 2.

Table 2. Production Gain Calculation.

Process Parameters	Unit	Year - 2021	Year -2024
Digestion Flow	m ³ /h	2520	2494
Digester TC	g/L	181	193
Digester A/C	-	0.700	0.703
SPL A/C	-	0.331	0.323
Digester Yield (2021 Spent Liquor A/C basis)	g/L	66.9	71.7
Increase in Yield	g/L	4.8	
Overall Operation Factor Considered	-	0.926	
% Contribution Considered (More Conservative)	%	35	
Production Gain	tonnes	34 189	
Production Gain (Rounded Off)	tonnes	34 000	

Production gain is calculated based on an increase in digester yield as all actions implemented are to improve digester condition in terms of TC and A/C. Digester yield increased from 66.9 g/L to 71.7 g/L with digester TC increase from 181 g/L to 193 g/L and digester A/C increase from 0.700 to 0.703. This corresponds to 4.8 g/L increase in digestion yield.

$$\text{Digester yield (g/L)} = \text{Digester TC (g/L)} \times (\text{Digester A/C} - \text{Spent Liquor A/C}) \quad (4)$$

$$\begin{aligned} \text{Production gain (t/year)} = & [\text{Digestion Flow (m}^3\text{/h)} \times \text{Digester Yield (g/L = kg/m}^3\text{)} \\ & \times 24 \text{ (h/day)} \times 365 \text{ (day/year)} \times \text{Plant Overall Operation Factor} \times \\ & \text{\% Contribution assumed on a more conservative basis}] / 1000 \text{ (kg/t)} \quad (5) \end{aligned}$$

5. Path Forward Plan

The subjected development, “developing regression equation from online instrument continuous raw values to predict Bayer liquor chemistries using periodically analyzed lab values of the same process stream” is under transformation to other areas of refinery wherever applicable in Maaden. Currently the work is progressing to predict PGL (pregnant liquor) liquor chemistry using new installation of conductivity meters to develop a regression equation from lab values analyzed at periodic intervals to help with better process control in precipitation circuits.

These improvements will pay way more for the digitalization of process across Alumina industries as well as other industries wherever it is applicable to do.

6. References

1. Montgomery, D. C., & Runger, G. C. Applied Statistics and Probability for Engineers, *John Wiley & Sons, Inc.*, 2014, 790 p.