

Utilisation of a Modern Scale Management Technique for Precipitation Tanks

Pradeep Mudgala¹, Suresh Yadav², Ahlam AlMajrafi³ and Ahmed AlBreiki⁴

1, 2. Senior Process Engineer

3. Process Engineer I

4. General Superintendent

Al Taweelah alumina refinery – Emirates Global Aluminium, Abu Dhabi, UAE

Corresponding author: aalmagrefi@ega.ae

<https://doi.org/10.71659/icsoba2024-aa022>

Abstract

Scale management in Precipitation circuits is of vital importance in an alumina refinery to ensure adequate availability of equipment for meeting the production targets. A common problem in alumina refineries is scale formation in precipitation tanks which, if not managed properly, could lead to heavy scaling in the tanks, requiring lot of time and efforts to resolve the problem and a significant production loss. At Al Taweelah alumina refinery, which is set up with an oxalate co-precipitation circuit, enhanced gibbsite and oxalate scaling was observed in the precipitation tanks during the first 2 years of operation with an impact to the precipitation yield and a potential loss of control on availability of tanks. Enhanced scaling led to longer outage of tanks, as well as frequent flow drops and availability issues of Interstage Coolers (ISCs), requiring multiple Caustic Cleaning Liquor (CCL) washes to clear scales. This paper presents how Al Taweelah alumina employed modern thermal imaging techniques, combined with heat transfer concepts, to develop an in-house estimation of the scale quantity in tanks. Through better estimation of scale formation, tank turnaround schedules were optimised and tanks exhibiting increased scaling could be identified in advance. Additionally, the paper discusses in-house solutions aimed at reducing ‘gravel’ scale impacts on ISCs, including the concept of ‘milking’ tanks (small quantity of slurry taken out from tank and passed through a trommel screen to remove some of the suspended scales from the tank), modifications to ISC scale trap design and operation. These have resulted in a significant reduction in the scale quantity in precipitators, increased availability and utilisation rate of equipment, hence leading to an improvement in yield and reduction in caustic consumption.

Keywords: Gibbsite scaling, Oxalate co-precipitation, Oxalate scaling, Precipitation yield, Thermal imaging.

1. Introduction

In March 2019, Al Taweelah alumina refinery commenced operations. Overcoming initial start-up challenges, it swiftly reached its design capacity of 2.0 Mt/a. Through continuous focus and numerous enhancements, the refinery has substantially crept production to an impressive 20 % above its original nameplate capacity.

At Al Taweelah alumina, there are five common agglomeration tanks, that serve two trains of sixteen (16) growth tanks to the Precipitation circuit. Al Taweelah alumina has co-precipitation of sodium oxalate with hydrate in the growth trains. Eight ISCs are installed in each train to help improve productivity [2].

In the precipitation facility, hydrate is precipitated from the liquor solution. Precipitation of hydrate is maximised by cooling of the hydrate slurry. Maximising yield must be balanced against the requirement to maintain the quality specifications of particle size, strength, and impurity

content. These competing requirements of yield and quality influence the cooling profile, the caustic concentration, and how mass distribution is controlled in the facility.

During startup, all precipitation tanks were initially clean. A staggered approach was employed to commence the cleaning of tanks, aiming to prevent simultaneous cleaning of multiple tanks. However, as we progressed with caustic cleaning based on the design residual life, significant scaling was observed on the tank walls and dip tubes.

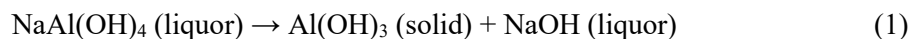
Frequent changes in temperature profiles, alumina/caustic (A/C) ratio, and other parameters (particularly following oxalate precipitation) were necessary to control particle sizing. These variations in operating parameters led to a substantial increase in scaling across all tanks. Tanks equipped with ISCs were notably affected due to the temperature drops. The heavy buildup of scale significantly extended the tank cleaning duration, disrupting the management and turnaround time of precipitation tanks. This resulted in the need for a more effective scale management strategy.

This paper presents the implementation of a modern scale management technique for precipitation tanks, aiming to enhance yield and reduce tank turnaround time.

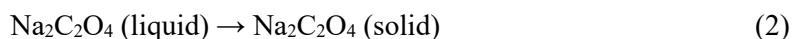
2. Scale Management.

Scale formation around the walls of precipitators has led to considerable financial expenses for the refinery. In the Bayer process, precipitation of alumina trihydrate ($\text{Al}(\text{OH})_3$), also known as hydrate, frequently leads to significant build-up of gibbsite and oxalate scales on the internal surfaces of the precipitation tanks.

The hydrate precipitation reaction is represented by Equation (1):



Sodium oxalate precipitation chemical relationship is represented by Equation (2):



Precipitation tanks installed with interstage coolers, located mid-growth train, have had their residual life reduced significantly due to excessive scale formation; this is indicative of a difference in scaling mechanism as compared to the front of precipitation tanks.

Gibbsite growth rates are much higher at the front of precipitation tanks and scaling at the front of the precipitation tanks is considered to be particulate fouling that shows strong inter-particle growth (crystallisation scaling), with surface coverage of very fine gibbsite particles resulting from oxalate crystallisation that has driven gibbsite nucleation [1]. Scale rate in precipitation tanks can be calculated using Equation (3).

The root cause for excessive scaling is attributed to an accumulation of organics in the process that stabilise oxalate and influence the oxalate precipitation behaviour. It is considered that the recycled oxalate and the freshly precipitated oxalate at the front of precipitation have their surface poisoned by organics in the liquor that stabilise the oxalate. These stabilising organics are likely to come in the form of humics (from the bauxite) and potentially from additives to the process, such as Crystal Growth Modifier (CGM). This causes the oxalate to precipitate once the oxalate Supersaturation (SSAT) has breached a particular threshold [3].

Scaling rate in each precipitator is defined as follows:

$$\text{Tank scaling rate} = \text{solid flux} \times \text{scale surface area} \times \text{fraction contributing to scale} \quad (3)$$

where:

Solids flux (t/h)	Solids concentration (t/m ³) × flow through tank (m ³ /h)
Scale surface area (m ²)	Tank wall surface area (m ²) × roughness factor.
Fraction contributing to scale	(gibbsite yield (g) × (oxalate yield (g)) ^x) / K(constant)

The images below are taken from scale samples collected from the trommel, where scale has been collected from precipitation tank ‘milking’. Two scales that appeared physically different were collected, first one is a smooth scale, the other one relatively rough scale. Both scale samples were found to be gibbsite from X-Ray diffraction analysis (XRD) analysis with no other significant phase detected. A Scanning electron microscopy (SEM) image of the two scales is shown in Figure 1. Based on lab test, it has been anticipated that, rough scale is formed in mid-train tanks where ICSs were installed. However, smooth scale is formed in front tanks which have no ICSs installed. Plant data shows that scales from ISC tanks required more duration to be dissolved even with lower Residual life compared to non -ISCs tanks.

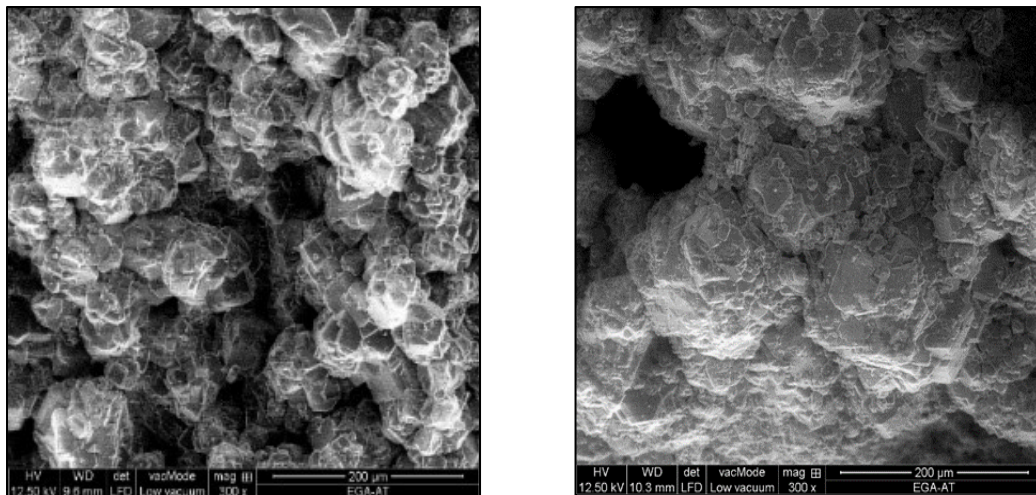


Figure 1. SEMs of trommel scales. Left: rough scale sample, Right: smooth scale sample.

The main objective of scale management is to optimise the residual life of the tanks by defining the required controls and establishing effective monitoring tool to be used for estimating the amount of scale accumulated in the tanks. This will significantly improve availability of precipitation tanks, reduce blockage issues in the ICSs, reduce cost by optimising the frequency of tanks caustic cleaning and reduce downtime involved with the de-scaling procedure.

2.1 Original Philosophy

Precipitation tanks were not adhering to their defined cleaning schedule 100 % of the time since startup. The tank turnaround time was averaging 31 days (vs 20 days target) with a variation of 11 days. Failure to comply to a strict cleaning schedule and tank turnaround duration led to production losses.

Initially, each tank’s residual life was set based on the design process parameters (Supersaturation (SSAT), Temperature, etc), and caustic cleaning was scheduled accordingly. The quantity of scale accumulated in the tank was not determinable and only visible when the tank was taken out of service. Tanks were requiring multiple CCL washes to clear the scale and this extended the tank

outage duration. Figure 2 shows a comparison of a clean draft tube vs heavily scaled draft tube after 175 days of tank operation.

CCL is used to dissolve hydrate scale from equipment surfaces in Precipitation. The rate of hydrate dissolution is maximised by high CCL caustic concentration (470 g/L) and low A/C. Temperature is limited to 85 °C to prevent stress corrosion cracking of mild steel.



Figure 2. Tank draft tube. Left: Tank online for 175 days (vs expected residual life 230 days), Right: Clean draft tube.

The residual life of the precipitators was originally set up such that it increased down the growth train, as may be expected as a function of gibbsite growth rate. In early 2021, it was observed that the precipitation tanks installed with interstage coolers located mid-growth train were scaling at a much higher rate than design. The scale was analysed as predominantly hydrate and oxalate. Due to present of ISCs in mid train tanks, slurry temperature reduces and caustic concentration increase. This change in temperature and caustic concentration reduce the oxalate equilibrium which enhance precipitation of oxalate in the tanks. And as a result, mid train tanks had to have their residual life reduced significantly as shown in Table 1.

Table 1. Precipitator design vs new Residual life.

Tank #	Design Residual Life (2019–2021), days	Residual Life (2021–2023), days	New Residual Life (2023–present), days
1/2	90	120	140
3/4	140	140	140
5/6	175	160	160
7/8	217	140	140
9/10	245	140	140
11/12/13	280	140	140
14/15/16	364	364	182

2.2 New Philosophy

To develop an in-house estimation of the scaling in tanks at Al Taweelah alumina, a thermal imaging method was established. Initially, thermal images across the precipitation trains were visually checked to identify tanks with higher scale content. This was later improved further by developing an excel based calculation set up for each tank combining visual data from images with heat transfer concepts thereby quantifying the amount of scale in each tank. Figure 3 B–C demonstrates examples of heavily scaled tank, and clear tank respectively.

2.2.1 Thermal Scanning

Thermal scanning using a Forward Looking Infrared (FLIRE75 24° model, from FLIR systems AB Sweden) camera has been used to monitor scale accumulation in the tanks on a weekly basis. Procedure and guidelines have been created for consistent positioning refer to Figure 3A, and scan configurations (temperature range 45–75 °C, Rainbow high contrast colour mode, etc.) while taking the photos. Field operator will take one picture per tank from a designated location to capture an image for the entire tank. All images are stored chronologically to monitor scale evolution and build a database. A thermal scan is also done before and after CCLW (CCLW) of each tank. The CCLW duration is extended for a day in case residual scale is observed.

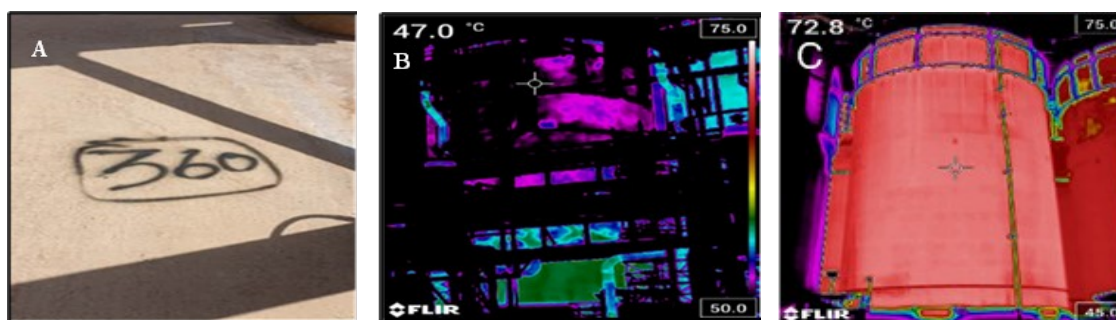


Figure 3. Thermal image examples. A) marked spot; B) heavily scaled tank; C) clean tank.

2.2.2 Scaling Estimation

Heat transfer fundamentals were utilised to get to the best possible estimation for scale thickness. This generated a database that, together with thermal imaging comparison, would help define the optimum residual life for each tank. Excel calculations were developed to better estimate the scale accumulation in the tanks, with the following methodology in Figure 4.



Figure 4. Scale calculation methodology.

Excel sheet generation:

- Date & Time Reporting: Date and time was recorded for each photo to align with online data for tank temperature and status, ensuring accurate estimation.

Tank temperature measurement:

- For tanks with a temperature indicator, data is collected directly from the tank's online temperature reading.
- For tanks without a temperature indicator, but with an ISC (Interstage cooler), the temperature can be obtained from the ISC inlet temperature indicator representing tank temperature.
- For tanks without an indicator or ISC, temperature is calculated based on the heat of reaction, considering 0.3–0.4 °C temperature increase.

Steps to read the thermal images:

- Only consider online tank thermal images for scale estimation. Out of service or CCL tanks are excluded.

- Each tank is divided into a matrix of 4 columns by 32 rows, used to estimate scale growth in each matrix. Each row is named as A, B, C, and D.
- Reference legend of camera image compared with actual tank image. Refer to Figure 5.
- Temperature difference between slurry and tank shell temperature is used to calculate scale thickness.
- Scale thickness is calculated as the average scale of the overall tanks across each column, A, B, C and D. Also, estimating maximum scale and minimum scale over the tank shell to identify patches and its growth over the time.
- The colour in the thermal image is checked in the adjacent reference table to assign a temperature for each section. Each section corresponds to about 1 m of the tank height.

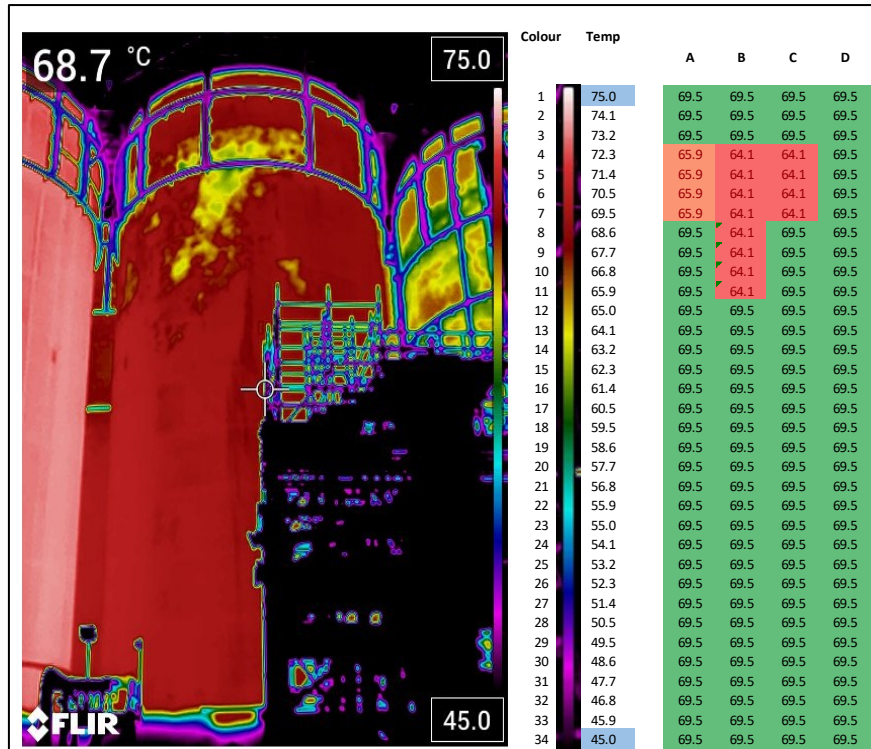


Figure 5. Screen shot of scale estimation based on tank temperature using temperature scale configuration.

Heat transfer and scale calculation:

To calculate scale thickness in each tank, we need to consider the thermal resistance from the scale in the tank. Fourier's law of heat conduction, which is given in Equation (4), is used to calculate heat transfer across the tank [4].

$$q_x = kA \frac{dT}{dx} = kA \frac{T_2 - T_1}{dx} \quad (4)$$

where:

- q_x Heat flux, W
- k Material conductivity, W/m-K
- A Tank area, m²
- dT Temperature difference, °C or K
- dx Thickness, m

The combined heat transfer coefficient in each tank is calculated considering resistance of slurry, scale, steel and ambient using following Equation (5):

$$UA = \frac{1}{R_{slurry} + R_{scale} + R_{steel} + R_{ambient}} \quad (5)$$

where:

- U Overall heat transfer coefficient, W/m²·K
- A Area, m²
- R Resistance between the first and second layers, K/W

The contact resistance will depend on the material. Equation (6) is used to calculate resistance for each surface:

$$R_i = \frac{1}{k_i A} \quad (6)$$

where:

- k_i Thermal contact conductance W/m²·K

Considering:

- Scale thermal conductivity = 2.0 W/m·K
- Steel thermal conductivity = 67.4 W/m·K
- Slurry heat transfer coefficient = 500 W/m²·K
- Convective heat transfer for moderate wind factor = 5 W/m²·K

- Scale thickness in all sections (A, B, C and D) is back calculated using above Equation (4).
- By using the average scale thickness, scale density and tank area, the weight of scale on the wall is calculated.
- A similar approach is used to calculate the draft tube scales considering the area of each draft tube in the precipitator tanks.
- As scanning is performed from front of tank due to accessibility and safety issue, assumption is made to consider similar scale accumulation in back side of the tank.
- Total scale tonnage is determined by adding both tank wall and draft tube scales.
- Table 2, is generated after the calculations for better evaluation:

Table 2. Example of generated data for scale: thickness and tonnes in precipitation tanks.

Tank	Status	Avg Scale Thickness (mm)	Max Scale Thickness (mm)	Min Scale Thickness (mm)	Total Scale tonnes (Wall + DT)
Tk-1	Duty	8	9	8	19
Tk-3	Duty	13	14	13	31
Tk-4	Duty	67	350	1	158
Tk-9	Duty	0	1	0	1
Tk-10	OOS	-	-	-	-
Tk-13	Duty	26	27	26	56
Tk-14	CCLW	-	-	-	-

Generated data in Figures 6 and 7 below is used to monitor scaling behaviour in each tank to identify abnormal scale growth. Addition to that, tanks residual life is reviewed on a frequent basis and changed to improve tank availability and performance. Based on Residual life, tanks

are taken off for CCLW. In special cases, if growth rate is identified to be high in specific tank, a decision is made to prioritise the tank for CCLW based on quantity of scale accumulation.

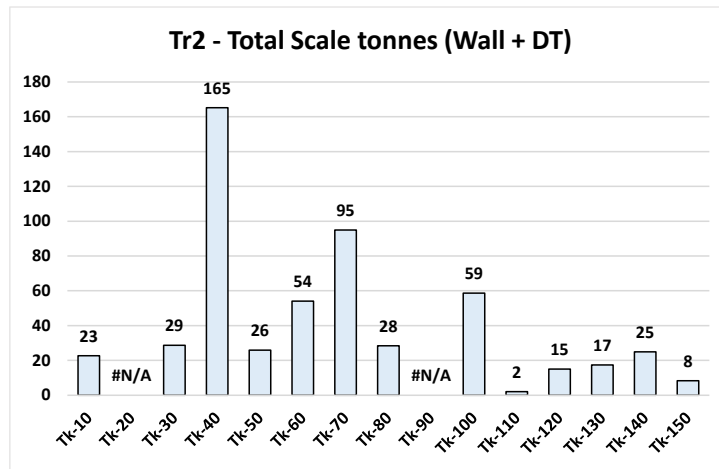


Figure 6. Calculated total scale mass.

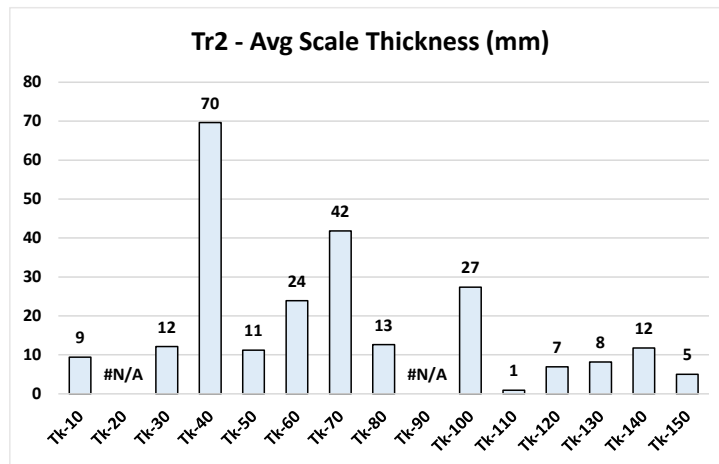


Figure 7. Calculated average scale thickness.

2.2.3 Precipitation Residual Life Application

As part of Al Taweelah alumina technology, cutting-edge Industry 4.0 solutions were utilised to visualise and analyse data effectively to enable us to construct Business Intelligence (BI) dashboards. These dashboards empower process engineers to make required decisions. The technology has been developed in-house by Al Taweelah alumina team, facilitating frequent change management and allowing for modifications as needed. Al Taweelah alumina utilises Honeywell Advanced Formula Manager (AFM) software to create bespoke calculations for determining residual life down to a minute-by-minute basis, which are subsequently integrated with thermal images. The captured thermal images are synced to cloud for generating appropriate analytics. Historical data is available and stored for continuous improvement. Figure 8 below shows a screenshot of the dashboard established in Al Taweelah alumina to enhance the visualisation of tank condition.



Figure 8. Screen shot of precipitation residual life dashboard.

2.3 Further Process Enhancements

Al Taweelah alumina established further improvements/ modifications to manage the scale accumulation in the precipitation tanks. These include, but are not limited to dip tube modification, rim cleaning of tanks, trommel operation, and ISC scale trap modification.

2.3.1 Dip Tube Modification

Precipitation tanks have a dip tube arrangement to feed slurry into the launder. Due to the design of the dip tubes, there is a large dead zone in front of the first and third launder gates preventing closure of the gates at times. Dip tube hard scales obstruct the launder gate closing, and hence hinder necessary turnaround activities. To improve and ease launder gate operation, the dip tubes have been modified by cutting windows as shown in Figure 9, which have helped in reducing scale build-up in the gate.

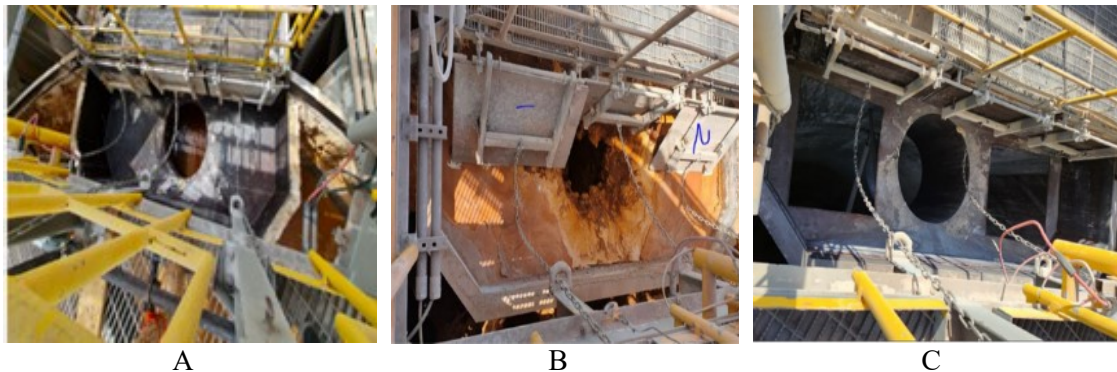


Figure 9. Dip tube arrangement: A) original design; B) scale build-up; C) after the modification.

2.3.2 Rim Cleaning

As per the original CCLW strategy of each tank, caustic was filled up to the launder gate bottom, resulting in the formation of a scale ring at the rim of the tank. To overcome this issue, the strategy was modified to get a positive isolation of all inlets and outlets and increase the CCL level close to the rim of the tank. This also keeps the gate, frames, and incoming launder clear.

2.3.3 Trommel Operation

Scales in suspension continuously enter ISC pumps suction line and block the strainer which affects ISC performance and requires ISCs to be taken offline for strainer cleaning. The ISC residual life was averaging 3–4 days versus a target of 10 days, requiring frequent washing to remove the scales restrictions. To remove suspended scales from the tanks, a ‘milking’ concept was implemented, whereby part of the slurry from a scaling tank is pumped to the last precipitator in the train, and the slurry is then processed through a trommel screen to remove scales from the slurry and the lean slurry is then returned to the process (refer to Figure 10). The operations team implemented ‘milking’ of tanks as a routine operation, rotating tanks each week, and this resulted in an improvement in sustaining flow targets and an availability increase to 14 days.

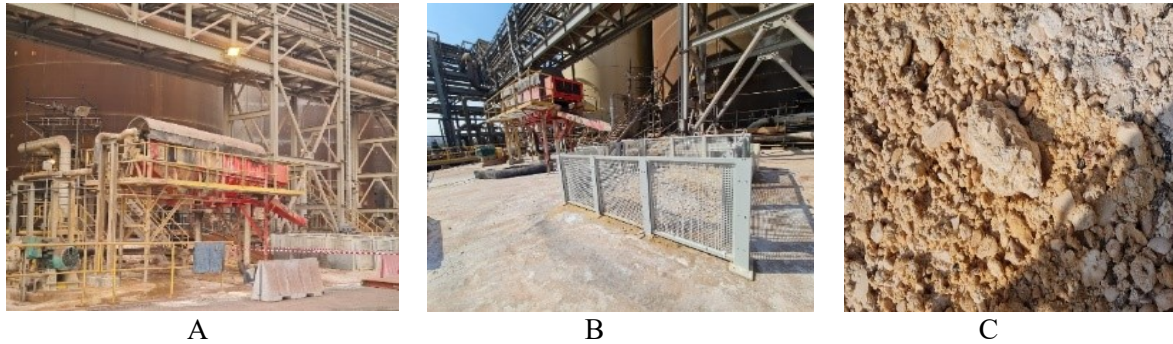


Figure 10. Trommel Operation: A) trommel arrangement; B) trommel screen; C) scale accumulated in a trommel.

2.3.4 ISC Scale Trap Modification

High levels of scales were restricting the scale baskets on ISC pump suctions very frequently. This resulted in the slurry flow through the ISCs to be reduced and being unable to pump and hence cool the slurry. As an immediate action, built-up scale in the scale baskets required manual intervention for scale basket removal and cleaning to clear the restrictions. After trials, the design was changed from a cylindrical basket to an inverted conical scale basket which utilises the impact of slurry on the basket, reducing the likelihood of blockages and extending its lifespan. This resulted in the ISCs to sustain flows for about 14 days (vs 3–4 days earlier).

3. Implementation and Results

With quantification of scales in precipitators and implementation of the other modifications a reduction has been observed in scale tonnage from average of 3000 t/train in 2021 to an average of 500 t/train in 2024 achieving Al Taweelah’s internal scale target. Figure 11 shows the reduction of scale build up over the time. Figures 12-13 are an indicting comparison in total scale and average scale thickness in growth train 2 between 2021 and 2024.

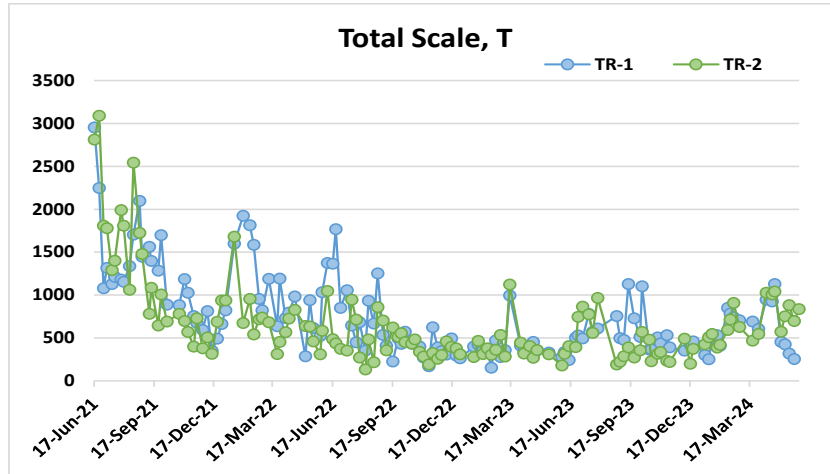


Figure 11. Scale mass (T = tonnes) in precipitation tanks since June 2021 to March 2024.

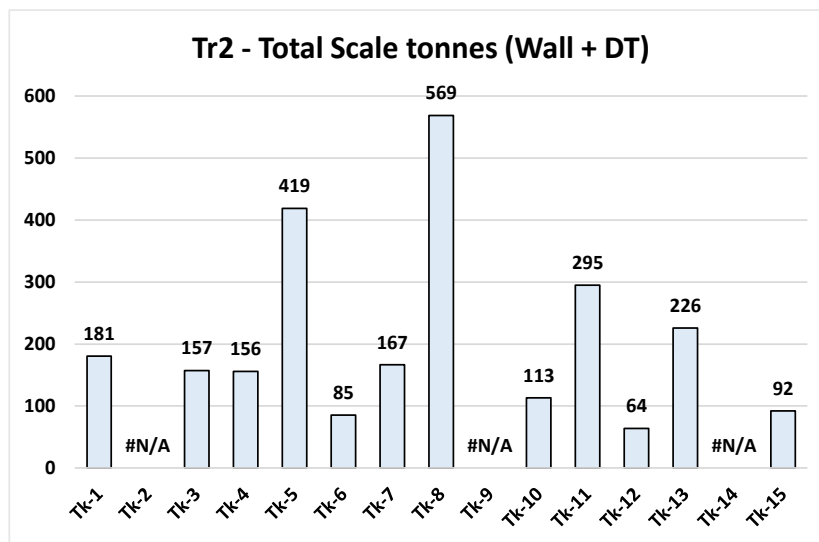


Figure 12. Calculated scale mass in 2021.

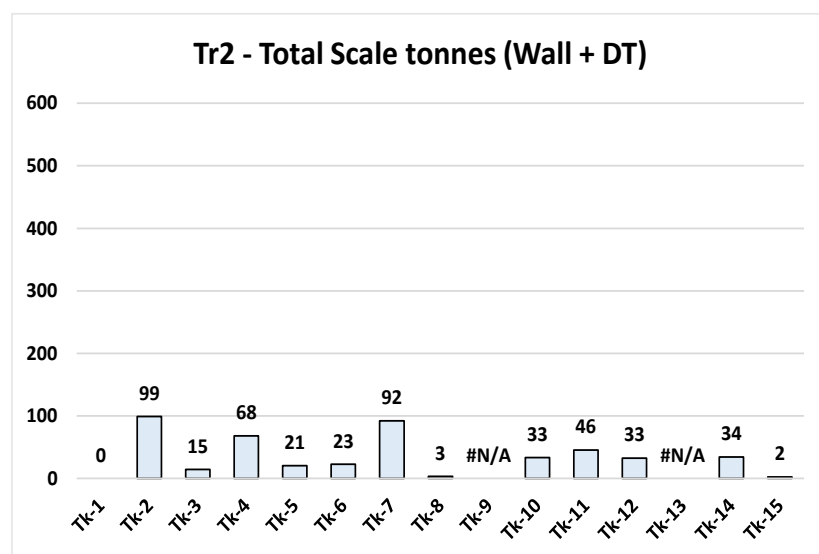


Figure 13. Calculated scale mass in 2024.

By establishing the new philosophy of scale management, notable enhancements achieved including:

- Improvement in hydrate yield, as accumulation of 10 cm of scale in each tank represents an estimated 0.2 g/L Yield, equivalent to ~5 830 t/a.
- Improvement in ISC performance. ISC flow issues directly impact the cooling capacity in the precipitation trains. Every 1 °C temperature higher across both precipitation trains represents an estimated 0.5 g/L Yield, equivalent to ~14 600 t/a.
- Increasing the frequency of ISC tanks CCLW which reduced the overall scaling rates.
- No overcleaning of the non-scaled tanks.
- Maintaining residual life of the tanks in control.
- Improvement in tank availability. Precipitation tanks turnaround cycle reduced from 30 days to 10 days subsequently number of offline tanks in day reduced from average of 6.3 to 3.2 tanks/day. Availability of 1 tank extra, increases the production by 36 t/day.
- Cost consumption reduced as requirement of caustic cleaning brew reduced. Before each tank required 2 brews to clear off the scales. Currently at times, 2 tanks could be cleaned with 1 brew.
- There are also intangible gains associated to operational costs with strainers cleaning, hydro blasting for scaling removal, valve cleaning, gate cleaning, etc.

3.1 Future Opportunities

With great outcomes achieved using the scale management thermal scanning method, future opportunities are being explored, such as:

- Utilisation of drone-mounted cameras equipped with thermal imaging technology which can cover the entire circumference of the tanks for an even better visualisation and estimation.
- Development of an artificial intelligence application to automate the process of generating the temperature information from the image directly in to the excel utility. This will be automating scale calculation.
- A reliable predictive scale formation relationship to eliminate the need for thermal imaging.

4. Conclusions

In conclusion, scale management in precipitation circuits is crucial in alumina refineries to ensure equipment availability and meet production targets. At Al Taweelah alumina refinery, enhanced gibbsite and oxalate scaling posed challenges during the initial operational years, impacting precipitation yield and potentially escalating loss of control on tank availability. Utilising modern thermal imaging techniques, Al Taweelah's in-house estimation method for scale quantity in tanks helped optimise tank turnaround schedules with proactive identification of tanks susceptible to an increase in scaling level. Aided with a good quantification of scales, additional in-house solutions implemented to mitigate scale impacts on Interstage Coolers (ISCs), including tank 'milking' via trommel screens, modifications to ISC scale trap design, Dip-tube modification and rim cleaning significantly improved the scale condition in precipitators, thereby, enhancing equipment availability and utilisation, yield, and reducing caustic consumption.

5. References

1. Alistair Gillespie et al., Scale Predominance Diagrams for Bayer Precipitation Tanks, *Proceedings of the 9th International Alumina Quality Workshop*, 18-22 March 2012, Perth, Australia, 237-244.
2. Sami Albastaki et al., Application of Split Growth in a Greenfield Alumina Refinery, *Proceedings of Alumina 2024, the 12th International Alumina Quality Workshop*, 22-25 April 2024, Dubai, UAE.

3. R.T. Chester and J.D. Kildea, Management and Control of Sodium Oxalate Precipitation in the Bayer Process, *Proceedings of Alumina 2018, the 11th International Alumina Quality Workshop*, 9-14 September 2018, Gladstone, Queensland, Australia, 60-68.
4. C.P. Kothandaraman, *Fundamentals of Heat and Mass Transfer*, 3rd Edition, New Age International, 2006, pages 30-40.