The Road to a New Bauxite – Mine and Refinery Optimisation

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Abstract

The Rusal Aughinish Alumina (AAL) refinery is located on Aughinish Island on the shore of the Shannon Estuary 33 kilometres west of Limerick city in the South West of Ireland. The plant, commenced operation in 1983 and has a current production capability of 1.99 million tons per annum. It sources bauxite predominantly from Guinea, Brazil and Guyana and uses the Bayer process to produce Alumina. Since 2010, Rusal Aughinish has been preparing to move to a new bauxite Dian-Dian located in Guinea from a bauxite reserve owned by Rusal. This was an opportunity and a challenge for the company to deliver optimum production and costs for both the mine and the refinery without impacting adversely on product quality. It is well established that any change to the chemical composition of the bauxite requires careful assessment in a refinery operation. The detailed study carried out over a few years was used to determine the overall project scope for the mine and the refinery. The key objectives of the project have been to optimize bauxite quality and production while managing operational challenges such as equipment erosion in the digestion chain, mud throughput increase and impurities control. A state-of-the-art mining strategy, installation of dryers at the mine and a second bauxite unloader at the refinery capable of handling additional throughput, the implementation of an automated deep cone thickener in the mud circuit and capacity upgrade of the oxalate removal unit have played key parts in the successful transition to the new bauxite. This paper outlines how the transition to the new Dian-Dian (DD) was achieved.

Keywords: Alumina refinery, Dian-Dian bauxite, mine, deep cone thickener, impurities balance.

1. Introduction

Aughinish was commissioned in 1983 with a design capacity of 800 000 tonnes per annum. The refinery design was based on high quality dry CBG (62 %) and dry MRN (38 %) bauxites. Both bauxites had very high extractable alumina, well above 50 %, and a low level of organics, in particular MRN with Total Organic Carbon (TOC) three times lower than CBG. The refinery was designed using the best available technology at the time: a Kaiser digestion design, an Alcan precipitation design and Alcoa calciners were installed. A single chain was built originally and today the refinery is still operating on that single chain, but the production capability has been increased to approximately 1 990 000 tonnes per annum.

These design choices have introduced some operational constraints:

- The precipitation circuit only operates optimally if the circuit is oxalate-free.
- The organic and inorganic impurities removal units have a relatively small removal capacity and require low level of impurities input.
- The mud circuit and its equipment were designed for relatively low mud factor.

The selection of plant design and technology for an alumina refinery is generally based on the physical and chemical composition of bauxite supply. Bauxite handling, method of extraction of the alumina content, mud circuit requirement and control of bauxite impurities are just a few critical aspects that have to be considered in the plant design. For a chosen plant design and technology, production, costs and quality are optimised within constraints specific to the refinery.

Since mid-2018, a new bauxite is being supplied to the Rusal Aughinish refinery. This new bauxite is coming from Rusal's own "Dian-Dian" bauxite reserve. Since March 2019, Dian-Dian accounted for 60 % of the bauxite mix processed in the refinery. This achievement came through a thorough process of integration of the new bauxite for both the mine and refinery. Close collaboration between Rusal Management, the mine project and refinery teams was critical for the success of this transition.

The Dian-Dian project arguably started nearly 3 decades ago when exploration drilling and sampling was carried out in 1991. Feasibility studies were also carried out at various times in 1991, 2007 and more recently in 2013 by the Russian National Aluminium-Magnesium Institute (VAMI) or now called Rusal Engineering Technical Centre [1]. Conceptual studies were carried out by that AAL Research and Development department starting in 2010 to assess impacts on the refinery.

Since Rusal acquired Aughinish in 2007, one of the long-term objectives has been to increase Rusal's own bauxite to be supplied to its refineries. Over a period of 8 years, through close collaboration between various stakeholders (Rusal personnel on the mine project and at Rusal Aughinish) all design details were assessed, engineered and constructed at the mine and the refinery. This effort delivered a custom designed project fulfilling the requirements of all stakeholders at the mine and refinery while optimising the overall capital expenditure and operating costs. Figure 1 illustrates the process followed to deliver the transition to Dian-Dian.

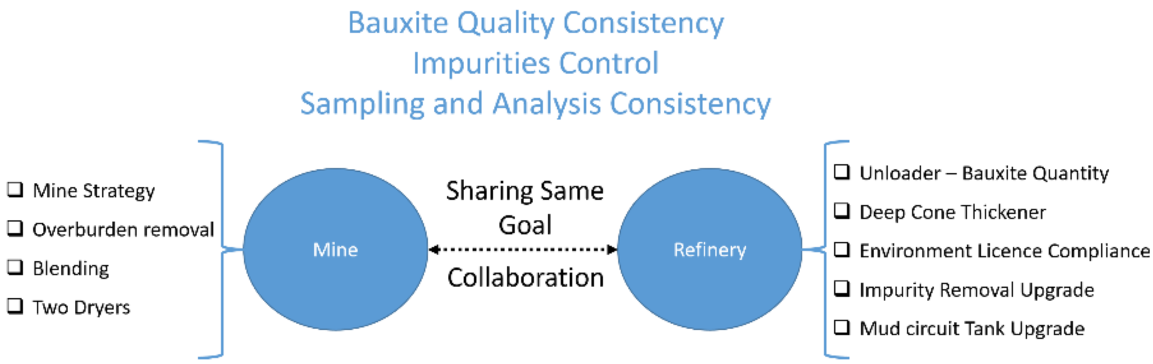

Figure 1. Process used to deliver transition to Dian-Dian Bauxite.

The result was a smooth transition with stable and consistent supply of bauxite quality with minimum disruption to normal operation at the refinery and more importantly, no production loss incurred at the refinery during the transition process.

Those milestones achieved in delivering the transition to new DD bauxite are listed in Table 1.

Table 1. Milestone during transition to Dian-Dian.

Year	Milestone
Pre - 2007	Exploration, Sampling and Reserve Estimation
2010	Bauxite supply concept studies initiated
2010 – 2013	Conceptual studies in progress
2015	Mine construction initiated
Q3 2017	Mine starts operation
Q4 2017	Second Unloader in operation in refinery
Q2 2018	Deep Cone Thickener in operation in refinery
Q2 2018	1st shipment leaving Dian-Dian
Q3 2018	1st shipment trial at the refinery
Q4 2018	Oxalate Upgrade Phase I in refinery
Q3 2019	Two dryers in operation in mine
2019-2022	Mud circuit Tank Upgrade in refinery

The following sections provide details on the important design and construction aspects of the project to accomodate the processability of Dian-Dian bauxite at AAL refinery:

- Bauxite quality optimisation at the mine and refinery.
- Refinery capability and limitations assessment.
- Bauxite handling – Installation of second unloader at the refinery and dryers at the mine.
- Impurities control – Control of bauxite mix, TOC and oxalate unit upgrade.
- Mud throughput increase and its impacts - Deep cone thickener and mud circuit tank upgrade.

2. Mine - Bauxite Quality Optimisation

The production capability and operational stability at the refinery depends directly on a consistent and optimised bauxite quality from the mine. In other words, the performance at the mine to deliver optimised bauxite quality parameters with little variability has a major impact on the performance at the refinery in terms of production, product quality and costs [5].

The most critical operational aspects at the mine are (Figure 2) [2]:

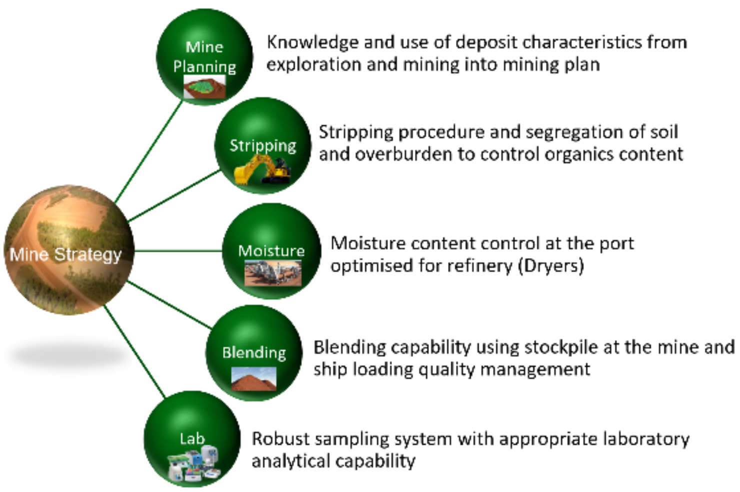

Figure 2. Mine strategy explained.

- Knowledge and use of deposit characteristics from exploration and mining into mining plan.
- Stripping procedure and segregation of soil, overburden and low quality layers (Figure 3) [4].
- Blending capability using stockpile at the mine and at the port for ship loading.
- Moisture content control at the port optimised for refinery – This meant installation of dryers.
- Robust sampling system with appropriate laboratory analytical capability.

Figure 3. Stripping and Segregation of Top Soil, Overburden and high TOC bauxite.

2.1. Deposit Characterisation and Mining Strategy

A mining plan including deposit characterisation was developed to ensure that the bauxite quality shipped to the refinery would be optimised and variability kept to a minimum. The integration of the deposit characterisation from the exploration stage and blending approach made the mining plan model more robust and accurate to moderate the natural variability from the deposit (Figure 4) [2]. Figure 5 shows some important quality parameters for Dian-Dian bauxite delivered to the refinery since its introduction.

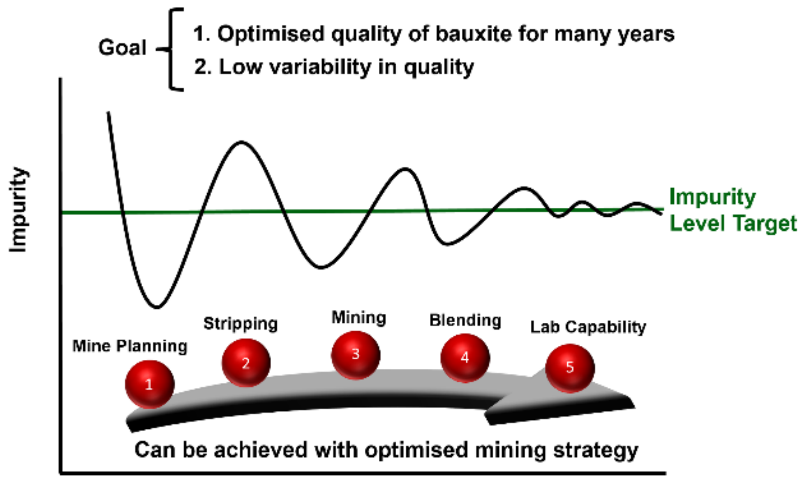

Figure 4. Optimisation of bauxite quality.

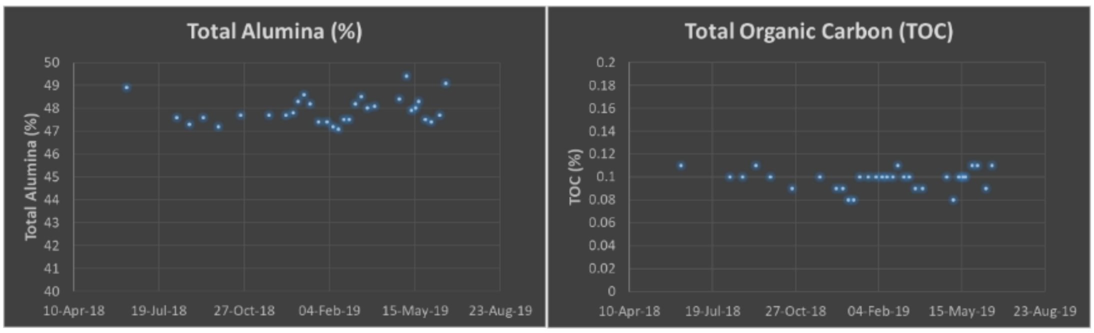

Figure 5. Consistency in delivering Alumina and TOC since first shipment.

2.2. Laboratory Analytical Capability

A modern laboratory equipped with best available instrumentation was installed at the mine using the same standard equipment and staff competence that would be required to supply bauxite to third parties. The key aspects in developing the laboratory were:

1. Competent laboratory personnel in place with specific bauxite quality responsibilities.
2. Established and approved methods in place with quality control and reference to standards.
3. Adequately equipped laboratories with purpose-designed equipment and instruments.
4. Laboratory lay out separating the sample preparation and analytical instrument areas.
5. Port capability to produce a representative sample during the loading process using recognised international standard (Figure 6).

Figure 6. Automating Sampling system during ship loading was installed.

Figure 7 provides images of the laboratory and TOC analyser which has become a critical instrument in delivering consistent TOC for each ship to Rusal Aughinish and other refineries.

Figure 7. Dian-Dian Laboratory and TOC analyser.

2.3 Plant Trial to Assess Bauxite Handling and Processability at the Refinery

Good collaboration between the mine project and refinery teams allowed the prioritisation in implementing the project so that the operation of the mine could start as early as possible at low bauxite volume while construction was still in progress. This strategy made possible an early plant trial at Rusal Aughinish so that all the systems could be tested and assessed both at the mine and refinery. From the refinery point of view, this approach ensured that the bauxite handling systems such as hoppers, belts, chutes, crushers, bins and mills, as well as the processability in the plant were tested 1 year in advance of mine construction completion. The trial was repeated in September 2018. These two trials enabled final optimisation of the strategy for processing the new bauxite in the refinery with some important points identified such as moisture control and TOC consistency to allow better refinery production stability and to avoid production disruption.

Extensive sampling was carried out during the trials (June / July 2018) at the bauxite loading and unloading stage to ensure corroboration of results between laboratories at the mine and the refinery. This proved to be useful as a relationship between both labs' personnel was established, in addition to sampling and analysis methods being validated.

2.4. Bauxite Quality Delivered since Commissioning

The Dian-Dian mine has been in operation since June 2018 with most of the infrastructure complete at this stage, Figure 8 and 9 show some of the infrastructures installed at the mine and the port.

31 ships have been delivered to the Aughinish refinery and every ship has been delivered in line with the design criteria with excellent bauxite quality stability.

Figure 8. Mining at Dian-Dian using surface mining equipment.

Figure 9. Taressa Port Infrastructures.

3. Refinery Capability and Limitations

The continuous assessment of refinery bottlenecks or limitations is monitored on an on-going basis at Rusal Aughinish [8]. This combined with existing system for monitoring of production lost opportunities [9] provided a good foundation for the capability assessment ahead of the migration to Dian-Dian bauxite. From this assessment, it was clear that some plant systems had to be reviewed in more detail and debottlenecked:

- Threat to Industrial Emissions Licence in terms of final pH of the residue on the bauxite residue disposal area due to increase in mud throughput. This limitation was treated as a priority and eliminated.
- Bauxite unloading and handling capability with a lower level of bauxite alumina.
- Digestion wear management with increased coarse bauxite particles and greater solids load from higher bauxite throughput. This meant reviewing comminution system capability, operation and maintenance practices.
- Mud circuit equipment reliability and production stability with increased mud throughput. The main equipment concerned were the mud thickeners and improving mud filtration performance.
- Impurities balance for both oxalate and inorganics such as carbonate and sulphate.

It is worth mentioning that a detailed review was carried by Rusal Aughinish with the support of external specialists to assess the option of integrating the capability of processing wet bauxite at the refinery. This assessment included the review of bauxite handling and comminution systems and the impact on energy efficiency and water balance management at the refinery. Energy efficiency was an important consideration to avoid an increase in both energy consumption and greenhouse gas emissions which is legislated by the European Emission Trading System (EU-ETS).

Optimisation of the project, by considering all the various elements that are included in the entire chain of operation from the mine to the refinery, has made the implementation leaner and more robust, resulting in no production loss at the refinery.

4. Bauxite Handling Systems

It became evident at an early stage of the project that bauxite handling capacity would be a production limitation for the refinery unless tackled.

4.1. Bauxite Unloading Capacity – Installation of a Second Unloader at the AAL Port

The lower alumina content in Dian-Dian was going to lead to a higher unloading rate and higher jetty occupancy which was already in excess of 90 % with the single original unloader. The original unloader was also in need of major repairs after 35 years of operation, and which requires extended periods of time out of service, which would not have been possible with only one unloader. Rusal took the early decision to move ahead with the installation of a second unloader. The three year project was initiated in 2015 with successful commissioning in Q4 2017 increasing the unloading rate and allowing major maintenance time to be carried out on the original unloader.

This proved to be an important decision in subsequent years as the CBG alumina content reduced progressively over a few years to similar level to Dian-Dian alumina content. Maintenance on the original unloader was deferred short term until the installation of the second unloader was complete. Figure 10 show photographs of second unloader before being shipped to refinery from Germany and both unloaders at the refinery port.

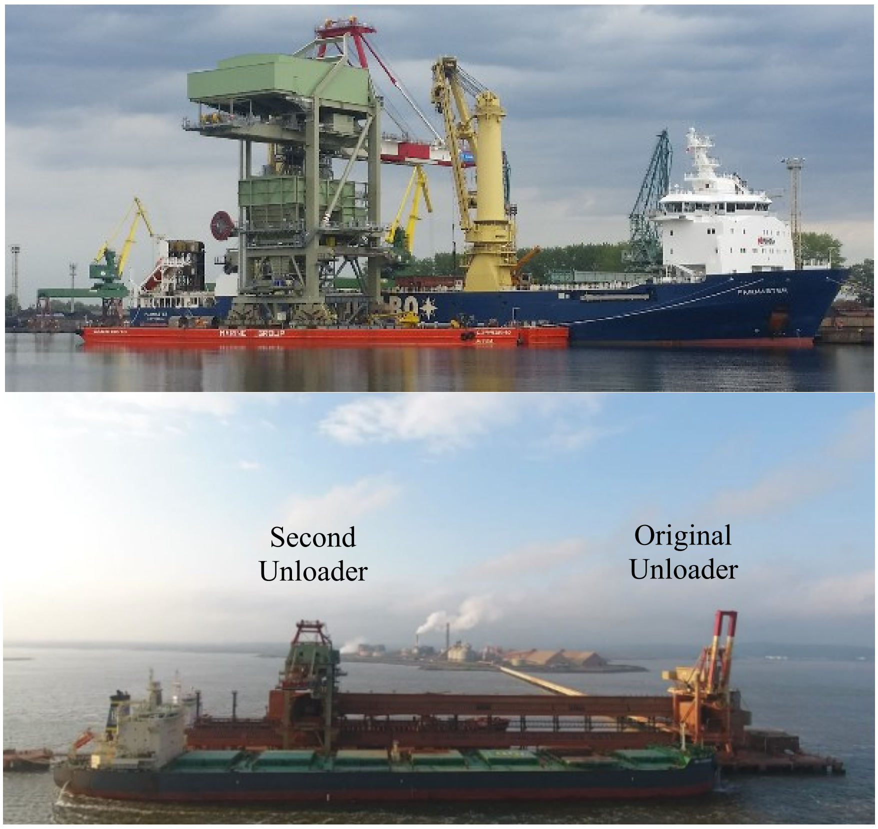

Figure 10. Second unloader before shipping and after installation completion.

4.2. Bauxite Moisture – Installation of Two Dryers at Dian-Dian Mine

As mentioned in the introduction, Aughinish bauxite handling was designed for low moisture content (between 6 and 7 %) using dried bauxite. Additionally, the bauxite wet grinding mills are fed from three original bins designed for dry bauxite.

For moisture content control, the road map was not straight forward as many options were considered and many iterations completed before a final decision was made to install two new dryers at the mine.

The retrofitting of wet bauxite handling at the refinery would have been very complex, more expensive and would have caused significant disruption to production. As mentioned above, a detailed review was carried out to determine requirement and costs (capital and operation costs) to convert the refinery from dry to wet bauxite. This scenario would have resulted in major investment to convert the entire bauxite handling system from dry to wet bauxite with significant operational and production disruption. The additional water input with wet bauxite in the refinery would have necessitated the installation of a big evaporator. Energy efficiency in digestion would have deteriorated significantly with associated direct gas costs and indirect costs due to additional greenhouse gas emissions which are subject to heavy carbon tax in Europe and will only increase in the future from the current rate.

The lowest overall costs option was to manage bauxite moisture control at the mine with the addition of two dryers. Figure 11 shows both dryers. The dryers commissioning was finalised in June with both dryers in full operation in July 2019 without any issue.

Figure 11. Dry bauxite storage and two dryers at the Dian-Dian mine.

Optimisation testing has been carried out to minimise energy consumption in the dryers: dust extinction moisture (DEM) was determined by University of Greenwich using the Australian Standard AS-4156.6 and equipment shown in Figure 12. DEM is the moisture content at which a bauxite is deemed to emit no dust: DEM for Dian-Dian bauxite is 7 to 7.5 % as shown in Figure 13. This will allow to optimising moisture control for the refinery while minimising energy consumption.

Figure 12. DEM testing rig.

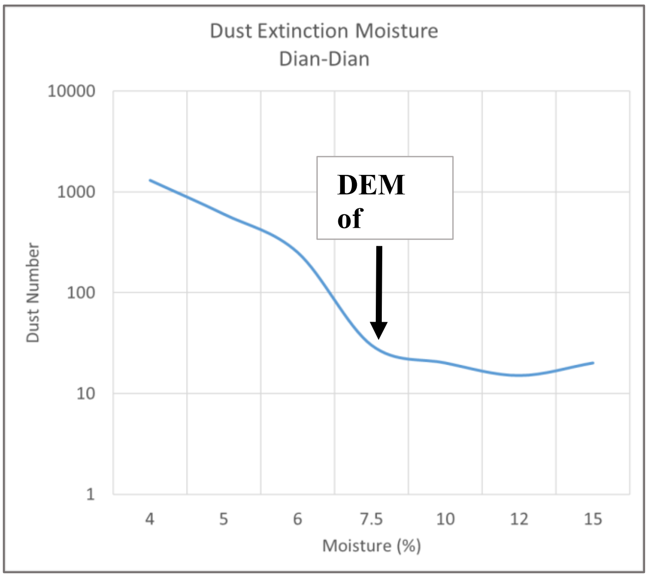

Figure 13. Dust measurement results.

5. Impurity Control

5.1. Organic Impurities Control – Mine and Refinery Optimisation of Resources

Organics contained in bauxite are a mix of plant and animal materials in various stages of decomposition. The organics content in bauxite is very much dependent on the bauxite origin but also on the mine strategy regarding timing and quality of stripping of the overburden and the blending of the top layer, which is richest in organics. The organics are chemically modified in the refinery at high temperature digestion and impact significantly on liquor productivity in many ways such as boiling point elevation, specific gravity or viscosity. The critical impurity for AAL to monitor and control is sodium oxalate ($Na_2C_2O_4$) or simply “oxalate”, which builds up in the refinery’s recirculating liquor.

Aughinish refinery is designed to operate an oxalate-free precipitation circuit. This means that oxalate must always be maintained in solution below its critical saturation point. This is achieved by ensuring that the oxalate input and oxalate output are in balance. If oxalate is not maintained below this critical concentration in solution, oxalate co-precipitates with alumina trihydrate (gibbsite) in all areas of the precipitation circuit. Oxalate crystals tend to be needle-like and cause various problems in a precipitation circuit:

- Increased nucleation of gibbsite fines leading to weak product, high in fines.
- Increased scaling rates in pipework, tanks, overflow launders and on filter cloths.
- Production limitation from loss of operational stability and adverse impact on product quality.

To maintain an oxalate balance in the process liquor, oxalate is removed from the liquor through a side-stream process called “organics and impurities removal unit” where oxalate and other impurities are removed from the liquor.

Close collaboration between the Rusal project and Aughinish refinery teams produced optimum control of organics (TOC). A robust bauxite mining strategy with clear quality deliverable guidelines has resulted in TOC being delivered to a challenging target. Figure 14 shows the level of Total Organic Content (TOC) in Dian-Dian delivered to the refinery since June 2018.

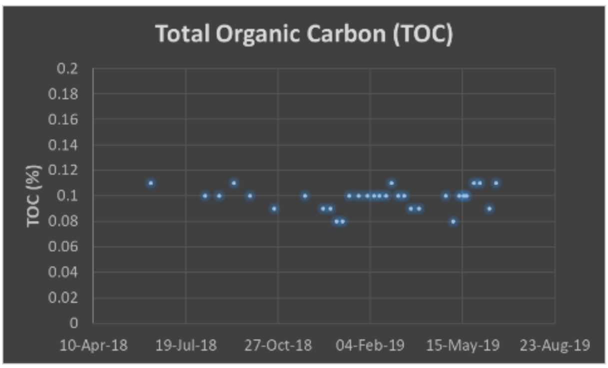

Figure 14. TOC for each shipment since June 2018 with average of 0.100 %.

Additionally, the capacity of the oxalate removal unit at the refinery had to be upgraded to sustain production in future years and allow flexibility in bauxite quality and bauxite mix. A two-phase project is being implemented with the first phase completed to increase oxalate crystallisation productivity by recycling the seed and increasing solids concentration as shown in Figure 15.

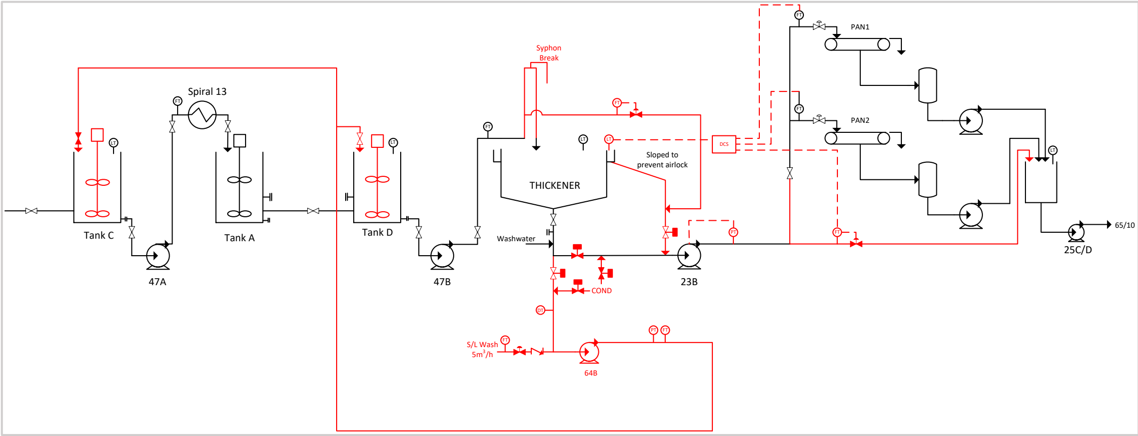

Figure 15. Oxalate seed recycle schematic.

5.2 Inorganic Impurities – Bauxite Mix Control

Aughinish refinery relies on two process routes to control inorganic impurities: internal causticisation using milk of lime occurring at high digestion temperature and desilication reactions occurring at low and high temperature:

Internal Causticisation Process

Milk of lime reacts in the digester at optimised conditions with the sodium carbonate present in the liquor. This reaction produces calcium carbonate and sodium hydroxide (Equation 1). The calcium carbonate reacts further with the anatase (TiO_2) in the bauxite to improve boehmite extraction at high temperature and form calcium titanate or perovskite ($CaTiO_3$) (Equation 2). Lime addition can be optimised for both alumina extraction and carbonate removal depending on the process requirement and bauxite mix composition.

$$Ca(OH)_2 + Na_2CO_3 \rightarrow CaCO_3 + NaOH \quad (1)$$

$$CaCO_3 + \text{Anatase } (TiO_2) \rightarrow \text{Perovskite } (CaTiO_3) \quad (2)$$

Desilication Process

Kaolin in the bauxite (the majority of reactive silica) reacts with sulphates, carbonates and chlorides via the desilication process (see Figure 16). The kaolin reacts to form sodalite at low temperature and cancrinite at high temperature. The amount of impurities removed is proportional to the percentage of reactive silica in the bauxite as shown by the model developed by Peter Smith from CSIRO (Figure 17) [7].

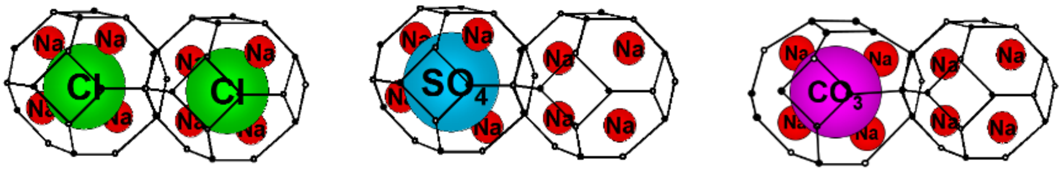

Figure 16. Carbonate, sulphate and chlorides trapped in cage structure.

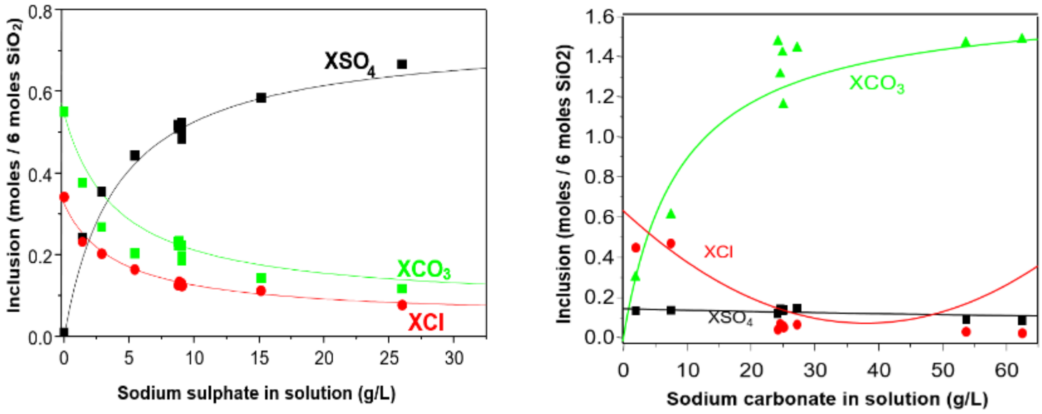

Figure 17. Impact of silica on impurities removal through desilication.

In summary, a minimum amount of reactive silica in the bauxite mix is required to maintain these impurities (mainly carbonate and sulphate) in balance, normally via an active and predictable bauxite mix management.

The option to sustain production capability with 100 % Dian-Dian bauxite would require a major investment programme with installation of external causticisation (shown in Figure 18) [2]. Milk of lime is added to heated liquor stream from mud washing circuit in a reactor where lime reacts with carbonate in the liquor to form calcium carbonate and regenerate caustic (Equation 1). High lime consumption up to 45 tons per day would be required. This would require a major programme of investment including challenging planning permission and a licence review.

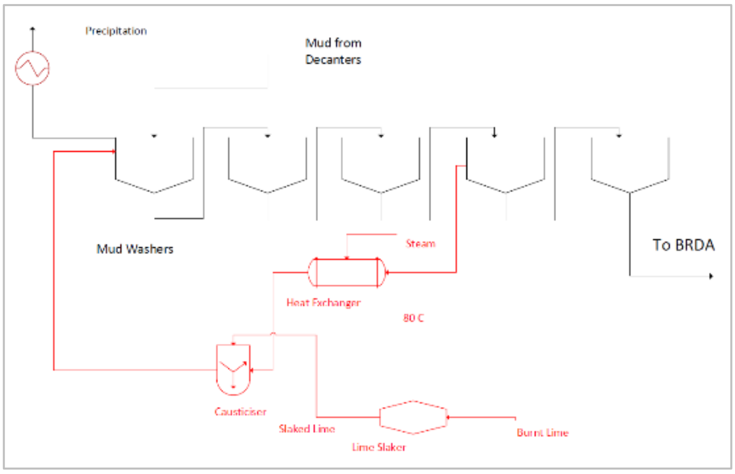

Figure 18. External causticisation.

6. Deep Cone Thickener Installation and Mud Circuit Upgrade

Moving to Dian-Dian meant that a higher mud throughput would feed the mud circuit and the BRDA. The mud throughput limit was well established (before DCT) beyond which point the thickeners and mud filters become overloaded and would compromise production stability. Thickener feedwell performance would also be compromised at higher mud flux.

More importantly, the additional mud tonnage would have resulted in Industrial Emissions Licence (IEL) concerns on the BRDA with residue soda exceeding the limit after residue farming. This was prioritised and led to an early decision to install a Deep Cone Thickener (DCT) as one additional stage of washing ahead of the transition with Dian-Dian to mitigate this threat. The operation of the DCT resulted in significant improvement and reduction in soda to BRDA ensuring the sustainability of residue farming and compliance with the Licence.

The existing mud thickeners will require to be upgraded to handle higher mud flux (Figure 19) and now that the DCT is in operation for more than 1 year, the upgrade of existing tanks can be done without compromising production stability. This upgrade has started with the first tank to be completed in 2019 and the full project should be completed in 2022.

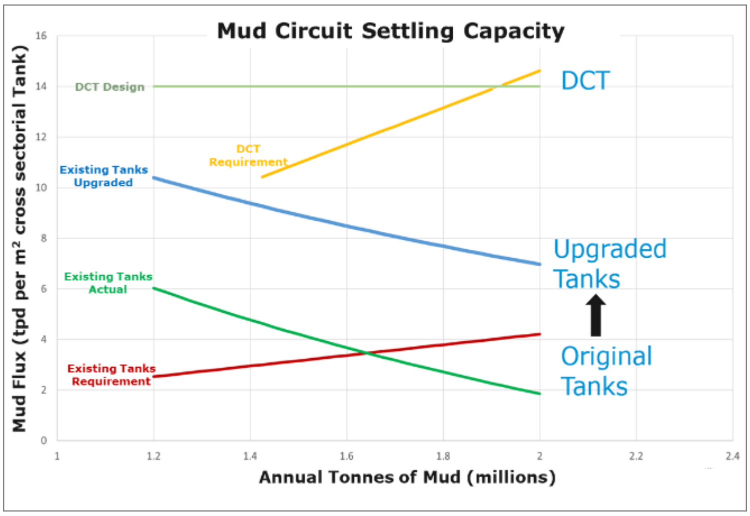

Figure 19. Mud Flux and its impact on mud circuit capacity.

6.1 Deep Cone Thickener and its Operation

The DCT is in operation since May 2018 after a short commissioning period. Its performance has been excellent since commissioning and has reduced soda losses with residue very significantly and eliminated the IEL concern. The additional stage of washing with the DCT will also reduce the scaling rate in the final mud filtration stage and improve its overall performance. Figure 12 shows 3D drawings used for training and image of the DCT after completion [6].

Figure 20. DCT 3D drawing and photo of completion.

The DCT operation is fully automated and integrated in the mud circuit control scheme (Figure 21 and 22) [6]. Mud inventory, mud interface, flocculent addition, feed and outlet flow are all controlled automatically.

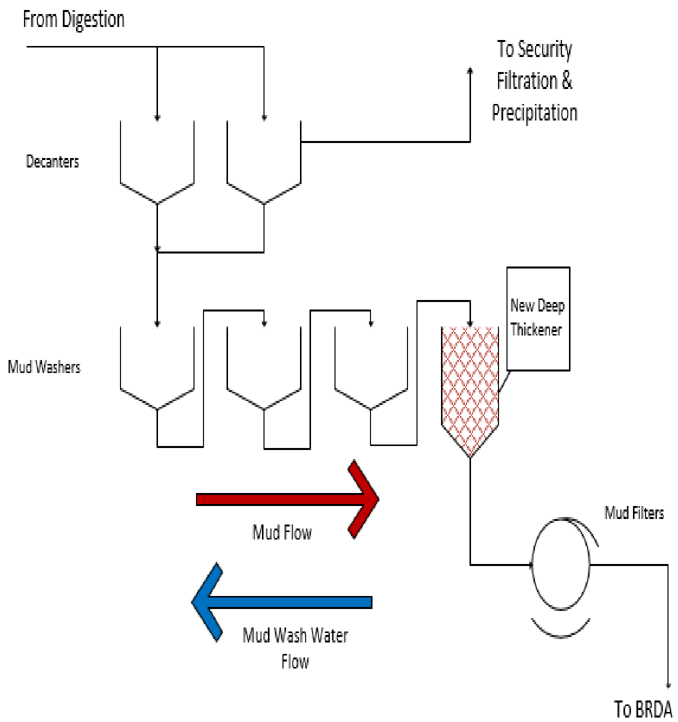

Figure 21. Integration of DCT within mud circuit.

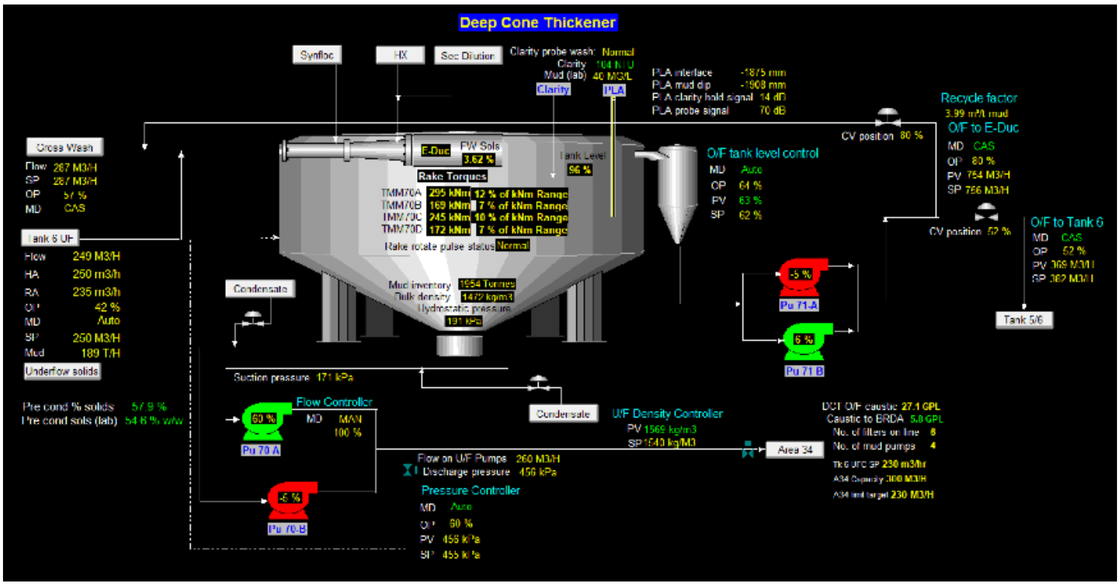

Figure 22. Fully automated control scheme.

The main advantages with DCT versus older technology thickeners are well known and documented [3]:

- Smaller footprint on site.
- Lower flocculent consumption and improved mud inventory (storage and control).
- Higher underflow density: ~55 % versus current washers at 45 % with better consistency.

- Longer turnaround times (3 - 5 years) and reduced maintenance.
- Significant savings on caustic recovery.

Additional advantages to Rusal Aughinish is that it enables upgrade of all other mud circuit tanks without compromising production stability.

7. Conclusions

Since 2010, Rusal Aughinish has been preparing to move to a new bauxite from the Dian-Dian mine located in Guinea from a bauxite reserve owned by Rusal. This was an opportunity and a challenge for the company to deliver optimum production and costs for both the mine and the refinery without impacting adversely on product quality.

The transition to Dian-Dian was successfully achieved by optimising the entire chain of operation from the mine to the refinery. This was delivered by having close collaboration between the mine project team, refinery personnel and Rusal Management.

The mine operation plays a key role in controlling the overall bauxite quality and level of impurities, particularly its organics content. Optimised alumina, silica and TOC content with low variability in bauxite quality was critical to the refinery requirements.

Rusal Aughinish upgraded specific production systems to improve the level of optimisation and a smooth transition was achieved while maintaining production, minimising operational disruption and avoiding any impact on product quality while optimising costs for the mine to refinery operation.

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