OPTIMISING REAGENT USE IN CLAY HOSTED RARE EARTH EXTRACTION

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ABSTRACT

Understanding what makes a project profitable in the design phase is crucial. We usually rely on existing data for benchmarking, but in this case, due to limitations on data availability, WGA supported an extensive bench and pilot test work campaign with Australian Rare Earths (AR3) to create cost estimates and designs. As a result of this approach, our focus in flowsheet development is to find ways to reduce operating costs, particularly by recycling reagents. This approach involved using a data science approach to quickly test different scenarios and pinpoint what most drives profitability.

Project Background

AR3's Koppamurra project is a large clay hosted rare earths prospect in Southeast South Australia. The mineral resource is 186 Mt at 712 ppm TREO and contains valuable magnet elements Nd, Pr, Dy, and Tb which are essential in high strength permanent magnets used in wind turbines and electric vehicles. WGA have been supporting AR3 for three years, starting with drilling data management, then metallurgical test work program management, and now through to cost estimation and preliminary engineering. To make sense of the flowsheet economics, we need to understand what drives profitability. We needed to define what are the big levers that will make a project profitable over the life of operations.

Methodology

Typically, we rely on existing plant design and operating costs to do preliminary 'back of the envelope' cost estimates. But, as most of the historical work has been done in China, a lot of that information isn't available in Australia. So given we need a flowsheet to evaluate project profitability, and we have limited or no access to benchmarking data, WGA supported AR3 in conducting a comprehensive test work campaign, with over 300 bench scale tests and pilot operations at ANSTO, SGS Lakefield, Bureau Veritas, and University of Toronto, to understand the process set points. From this a flowsheet and cost estimate were developed based on the met test work and pilot results.

There are several moving parts to the profitability calculation, but to focus our efforts to get the most impact during flowsheet design, a multi scenario analysis was developed to rapidly assess several scenarios to identify the big levers. WGA automatically ran thousands of cases to identify the most profitable scenarios with the support of the WGA data science team. Multiple scenarios were run to increase profitability using these levers, but operating costs remain the biggest lever, so the focus is on minimising and recycling leach and impurity removal reagents in flowsheet development through WGA's ongoing support of the AR3 Koppamurra project.

Outcome

Our integrated team of process engineers and data scientists were able to collaborate with AR3 to develop a comprehensive mass balance model and profitability analysis to focus flowsheet development, with the objective of reducing time to commercialisation.

Keywords: clay hosted rare earths, profitability, economic analysis, pilot operations

INTRODUCTION

Australian Rare Earths' Koppamurra project is a large clay hosted rare earths prospect in Southeast South Australia (Figure 1). The mineral resource is 186 Mt at 712 ppm TREO and contains the valuable magnet elements Nd, Pr, Dy, and Tb which are essential in high strength permanent magnets used in wind turbines and electric vehicles. Australian Rare Earths vision is to become Australia's first clay hosted rare earths producer, and to support this drive to commercialisation, we needed to identify key drivers and major factors that will influence the project's profitability throughout its operations. Typically, we rely on existing plant design and operating costs to do preliminary 'back of the envelope' cost estimates, but the availability of that information is limited. As a result, Australian Rare Earths conducted a comprehensive test work campaign, with over 300 bench scale tests and a pilot operation to understand the process set points for flowsheet and cost estimate. As a result of our approach, our focus in flowsheet development is finding ways to reduce operating costs, particularly by recycling reagents. This approach involved using a data science approach to quickly test different scenarios and pinpoint what drives profits the most.

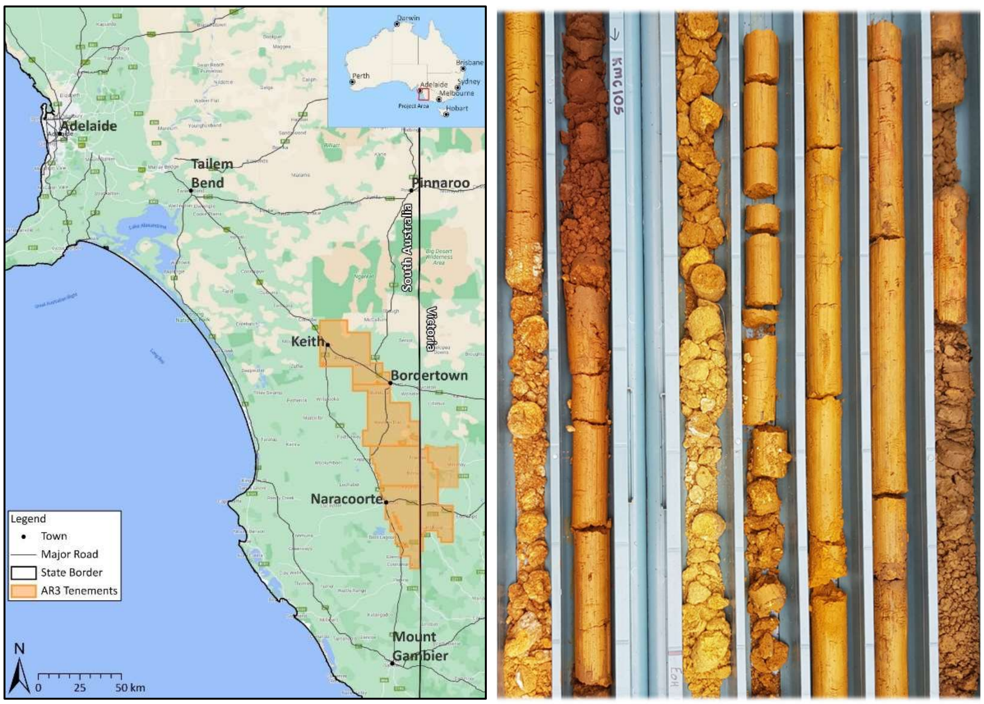

Figure 1: The Koppamurra project is located in the southeast of south Australia, around the Naracoorte region. The latest resource estimate of the deposit is a 186 Mt at 712 ppm Total rare earth oxides.

PROJECT BACKGROUND

Rare earths are essential in high strength permanent magnets, which increase the efficiency of electric motors, including those used for wind turbines, and electric vehicles. Therefore, the magnet rare earths, Nd, Pr, Dy, and Tb, have an important role to play in a sustainable future. China has historically dominated the global production and supply of rare earths, accounting for a significant share of the market. Efforts have been made in recent years to diversify the supply chain and reduce dependency on China. Australian Rare Earths Koppamurra project will play an important role in Australia's supply of these critical minerals.

The location of Koppamurra is favourable for access to utilities and local labour, and Australian Rare Earths has already engaged the community in several initiatives including open days and high school career events. The Australian Rare Earths exploration team have progressed significant drilling campaigns to derive the resource estimate and produced several representative composites and bulk samples for the metallurgical program, including a trial pit. Importantly, the Koppamurra deposit contains valuable magnet elements Nd, Pr, Dy, and Tb. These rare earths are concentrated with the fine clays and distributed to the lanthanite minerals, which means that these rare earths can be extracted 'easily' as compared to other rare earth minerals that require energy intensive cracking and roasting.

COST ESTIMATE AND PROFITABILITY APPROACH

The cost estimate was developed to guide understanding what drives profitability of the project, that is, identification of the big levers that will make a project profitable over the life of operations. Through this analysis it was identified that operating costs are driven by reagent use, while capital costs in a slurry leach flowsheet are driven by dewatering equipment size, and revenue is driven by magnet rare earth production.

envelope' cost estimates. However, a lot of that information isn't available in Australia. So given a flowsheet is required to evaluate project profitability, and there is limited or no access to whole of plant benchmarking data, AR3 conducted a comprehensive test work campaign, with over 300 bench scale tests and a pilot operation at ANSTO, SGS Lakefield, Bureau Veritas, and University of Toronto, to understand the process set points. From this work a flowsheet and a cost estimate were developed, based on the metallurgical test work and pilot results.

The following approach was used to produce a cost estimate, to assess profitability and identify levers, and then pull these levers from the earliest stages of the project to maximise potential:

- Flowsheet development for the Mixed Rare Earth Carbonate (MREC) process shown in Figure 2. Typically, existing plant design and operating costs are used to do preliminary 'back of the
- Process set points were derived from test work for input to the mass balance to estimate capital, operating costs, and revenue.
- Capital costs were built off major mechanical equipment, with factored costs, and benchmarking.
- Operating costs from consumables and utilities use.
- Revenue from rare earth production rates.

Using these costs, profitability was measured by net present value (NPV). NPV compares present value of cash inflows to cash outflows for the life of the project. There are other ways to measure profitability, but this is a widely used way that's easy to interpret, so it's been applied to this project.

The cost analysis is built on the mass balance and robust models for rare earth extraction and acid consumption. The predictive models in the mass balance are based on over 200 leach tests that have been ingested into the metallurgical database. The acid consumption model is relatively simple, driven by acidity, calcium content and leach duration. The extraction models are accurate, shown in Figure 3, and are aiding understanding what the secondary factors driving extraction might be, through a machine learning approach to identify key features of the extraction.

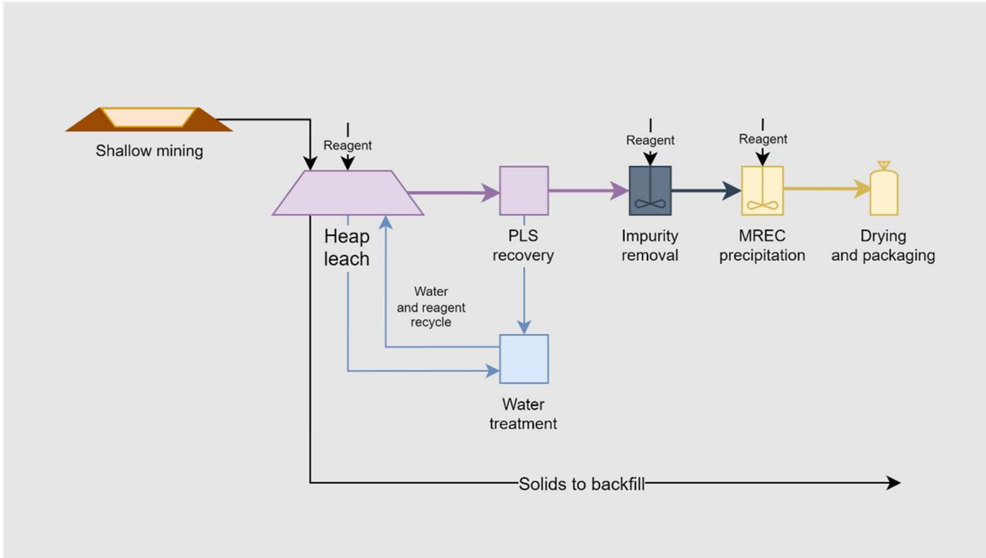

Figure 2: The cost estimate was built off the flowsheet mass balance for Mixed Rare Earth Carbonate (MREC) production

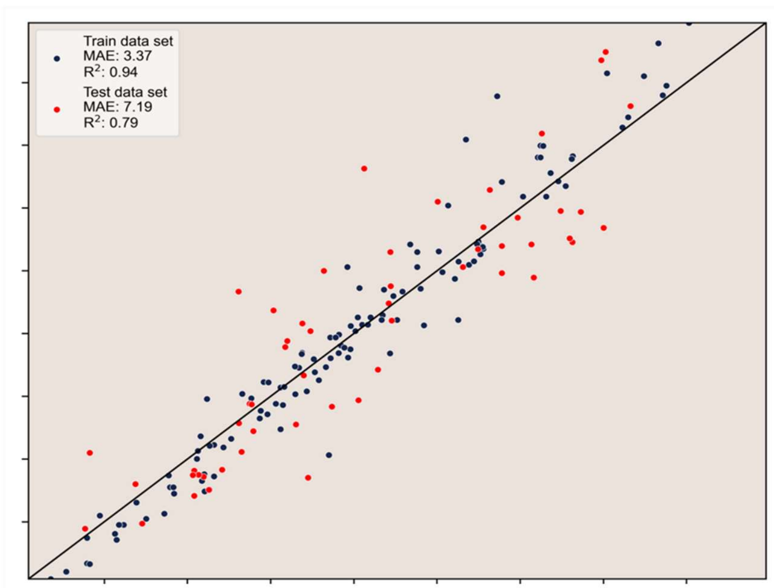

Figure 3: The models used in the mass balance for acid consumption, rare earth extraction and gangue dissolution had high accuracy as shown in this plot of actual versus predicted. These predictive models, including machine learning models, were built using over 200 Koppamurra leach tests.

CAPITAL COSTS

Since capital costs were built of major mechanical equipment benchmarking, the costly items are quickly identified. In terms of capital costs, the dewatering equipment size in a slurry leach has a large impact and was a key factor in investigating the applicability of heap leach. In the slurry leach flowsheet option, there are two key areas where clay is separated from liquor:

- After leach, the rare earth rich leach liquor is separated from the clay waste.
- After neutralising of the slurry leach residue, the neutralised clay waste is separated from water. These solids to are used as backfill, to rehabilitate and return the land to the landholders.

Filtering a clay presented challenges in practice, but evaluation of several techniques, led to either a centrifuge or screw press at a commercial scale being proposed.

Through this evaluation of slurry leach and dewatering, WGA saw an opportunity to reduce technical risk and capital costs through application of heap leach in place of slurry leach for rare earth extraction, in the Koppamurra flowsheet. Using a heap leach rather than slurry leach means that the dewatering steps are eliminated:

- Separating of the rare earth rich liquor from the clay waste is achieved through normal operation of the heap leach.

- Neutralisation of the material before backfilling could be achieved in the heap rather than in a stirred tank. This potentially means that the neutralised heaped material is ready for immediate backfill, supporting rapid rehabilitation of the land.

The heap has both capital and operating cost advantages over a slurry leach. Capital cost of a heap leach is lower than slurry leach tanks due to reduction in dewatering equipment. There are also benefits to reduction in operating cost through reduction in flocculant, water, and power consumption that were required for dewatering. Based on this evaluation, AR3 has initiated heap leach test work at ANSTO. The material has been successfully agglomerated and percolated on a small scale in column heap leach. Several column leaches have been conducted at 2-4m height with ore variability to represent the deposit. The preliminary column leach results conducted at ANSTO have shown rare earth recoveries that are comparable to slurry leach.

Figure 4: Capital cost of a heap is lower than slurry leach tanks, plus there are benefits to reduction in operating cost through reduction in flocculant and power consumption from dewatering. The material has been successfully agglomerated and percolated on a small scale at ANSTO

OPERATING COSTS

Operating costs remain the biggest lever to increase profitability, so in current test work there is a focus on minimising and recycling reagents in the flowsheet. For this project, mining costs are comparatively low due to the shallow nature of the deposit (Figure 7), and they are not explored further in this paper.

Reagent operating costs are highly connected to extraction reagent use and how it impacts downstream reagent use in the impurity removal step in the following ways:

- In REE recovery, increase in acid use increases rare earth recovery, (positive), but also increases dissolution of impurities (negative). The main impurities that impact MREC quality are Al and Fe.

- In impurity removal, any increase in impurities extracted in REE extraction step, increases the reagent use in the impurity removal step.

Therefore, there are two operating cost penalties for increasing the acidity, so the trade-off for the increased extraction and revenue needs to be positive.

The approaches being investigated to minimise operating costs are pH optimisation, leach duration, and reagent recycle:

- **pH optimisation**: By increasing the pH, we can get a 50% reduction in acid consumption, and a reduction in iron and aluminium dissolution (Figure 5). This reduces operating costs in the impurity removal step and can produce higher quality product with less effort and cost. Previous work has shown that high REE recoveries can be achieved at pH 2 at ambient conditions, with sulphuric acid and magnesium sulphate. This was recently proven for heap leach column test work at ANSTO which showed that at lower acidity, of pH 2.2, the acid consumption halved compared to pH 1.5, the ratio of REE to aluminium increased (Figure 6) The heap leach test work indicated that the heap leach Pregnant Liquor Solution (PLS) may have a lower impurity profile with higher rare earth concentration.

- **Leach duration**: Another lever to consider in operating costs is leach duration, given that for a lower acidity, a longer leach may yield similar recoveries, and potential have a positive impact on REE to impurity rations. The trade-off between acidity and leach duration is being investigated. The trade-off is a decrease in operating costs, for an increase in plant capital costs, that is, trading acid costs for either slurry leach tank install or heap leach setup costs, which has a positive impact on NPV.

- **Reagent recycle:** There are opportunities to recycle up to 98% of reagents by regenerating chemicals onsite. The trade-off is again between operating and capital costs, that is, trading cost of purchasing reagents for cost of capital for water treatment. Recovery of water and reagents is being assessed at a desktop level and will be tested through application of nanofiltration (NF) and ultrafiltration (UF) in an upcoming test work program. Potentially acid and salt used in REE extraction can be recycled. Impurity removal precipitation reagents could also be recycled.

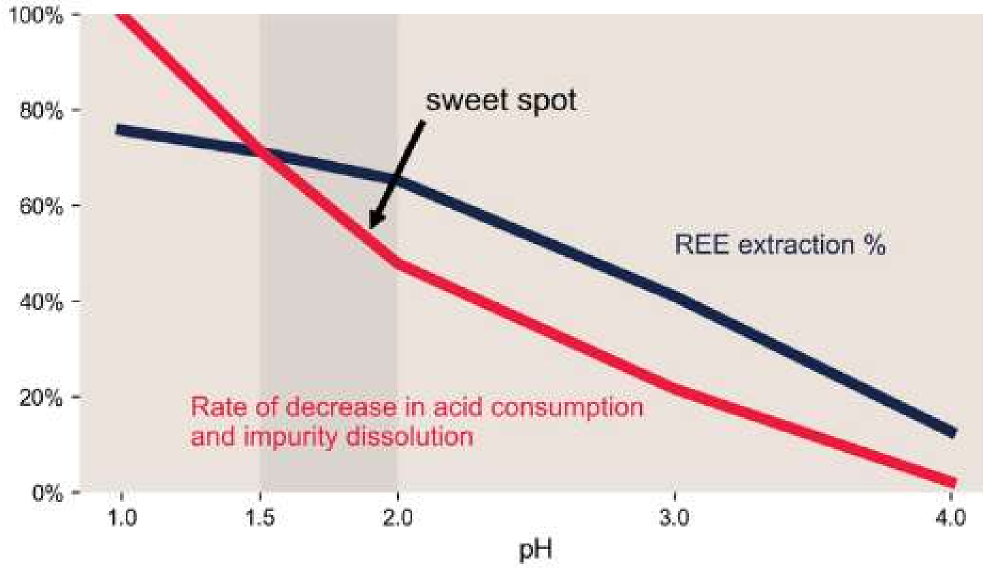

Figure 5: By increasing the pH, we can get a 50% reduction in acid consumption, and a reduction in impurity dissolution.

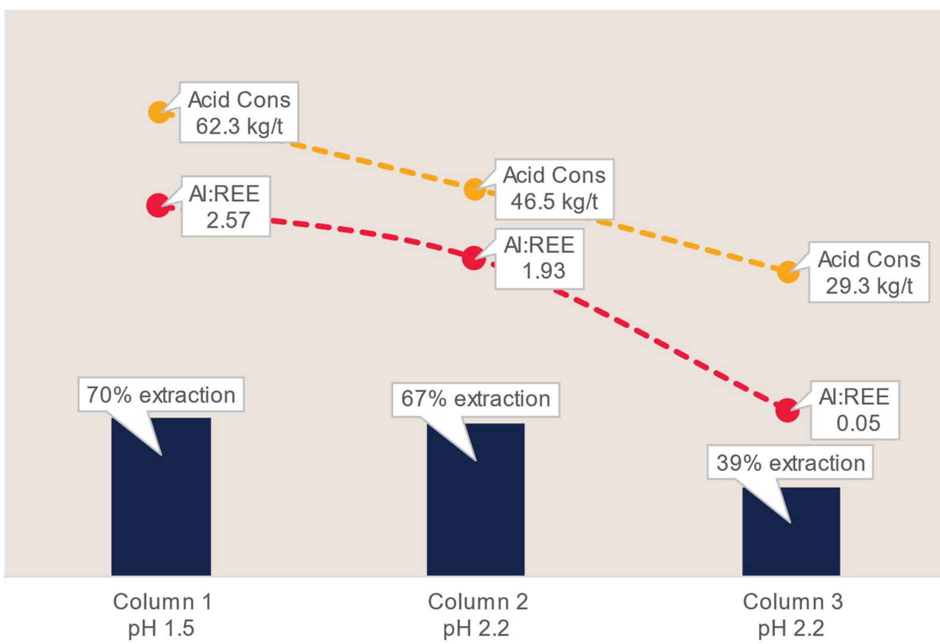

Figure 6: Heap leach column test work at ANSTO showed that at pH 2.2, the acid consumption reduced by up to 50% compared to pH 1.5, and the ratio of aluminium to REE decreased.

Figure 7: The Koppamurra deposit is within the first 10m, which means that surface mining costs are relatively low compared to other key operating costs such as reagent consumption. This image shows a trial pit excavated at Koppamurra in 2022.

REVENUE

Revenue is driven by magnet rare earth production, which in simple terms, is derived from ore grade, and recovery.

In the clay hosted ionic clays at Koppamurra, the rare earth grade of the clay is not enough to inform the recovery. Up to 77% recovery of the four magnet rare earths can be achieved from the Koppamurra ore, but the test work at varying pH, with over 200 tests at ANSTO and University of Toronto, has shown that there are likely three phases of rare earths. This understanding could not have been inferred from the rare earth grade and mineralogy alone – the metallurgical test work program was required. Those three phases, present in all clay hosted rare earths, are:

- Rare earths that are ionically adsorbed, that are removed to solution at mild acidity.
- Secondly, rare earths that are more tightly bound and require higher acidity.
- And thirdly, a small amount of mineralised rare earths that require either roasting or cracking.

Another factor to consider that impacts revenue, is the distribution of the four magnet rare earths in the ore and product. This impacts the value of the mixed rare earth carbonate product.

In the test work program, the focus is on pH to drive revenue and profitability, but there may be opportunities to target high grade areas to increase production. This especially makes sense at the beginning to pay off the project. Application of temporary or progressive heap leaching may maximise revenue in the early stages of Koppamurra. Recent resource modelling has identified high-grade rare earth subsets that would support this approach. Therefore, high grade satellite mine sites with temporary heap pads to target these high-grade areas may increase profitability. Another advantage to this progressive heap leach is rapid and progressive rehabilitation of the land. The extracted topsoils and overburden could be temporarily set aside, ready to be placed back on top of the washed clay. There is also an opportunity to expand and scale up production over time across the region.

CONCLUSIONS

WGA’s integrated team of process engineers and data scientists collaborated with Australian Rare Earths to develop a comprehensive mass balance model and profitability analysis to focus flowsheet development, with the objective of reducing time to commercialisation. There are several moving parts to the profitability calculation that can be pursued, but to focus effort, and ensure efficient use of time and resources, WGA developed a multi scenario analysis to rapidly assess several scenarios to identify the big levers. Through this analysis it was identified that operating costs are driven by reagent use, capital costs are driven by dewatering equipment size, and revenue is driven by magnet rare earth production. Through this analysis we identified an opportunity to reduce technical risk and capital costs through the application of heap leach in place of slurry leach to eliminate dewatering costs. Australian Rare Earths are now focusing on reducing operating costs through water and reagent recycle, and progressive heap leach approach to target high grade areas to increase profitability.