Overcoming the Challenges of Extraction Lithium from Hard Rock

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The sulphation route for the extraction of lithium from hard rock is a mature technology but the three plants currently in stages of being constructed, commissioned or ramped up to full capacity are experiencing challenges both in terms of cost growth as well as meeting the design performance. This paper described the lessons that Talison can learn from these pioneering plants in the design and eventually constructing of a plant in Western Australia.

Lithium extraction from spodumene hard rock, using sulphuric acid, was patented by Ellestad and Leute in July 1950[i]. In 1951 Hader published a full description of the sulphation technology in use at Lithium Corp of America's St Louis Park plant[ii]. The basic process is shown in the block diagram in Figure 1.

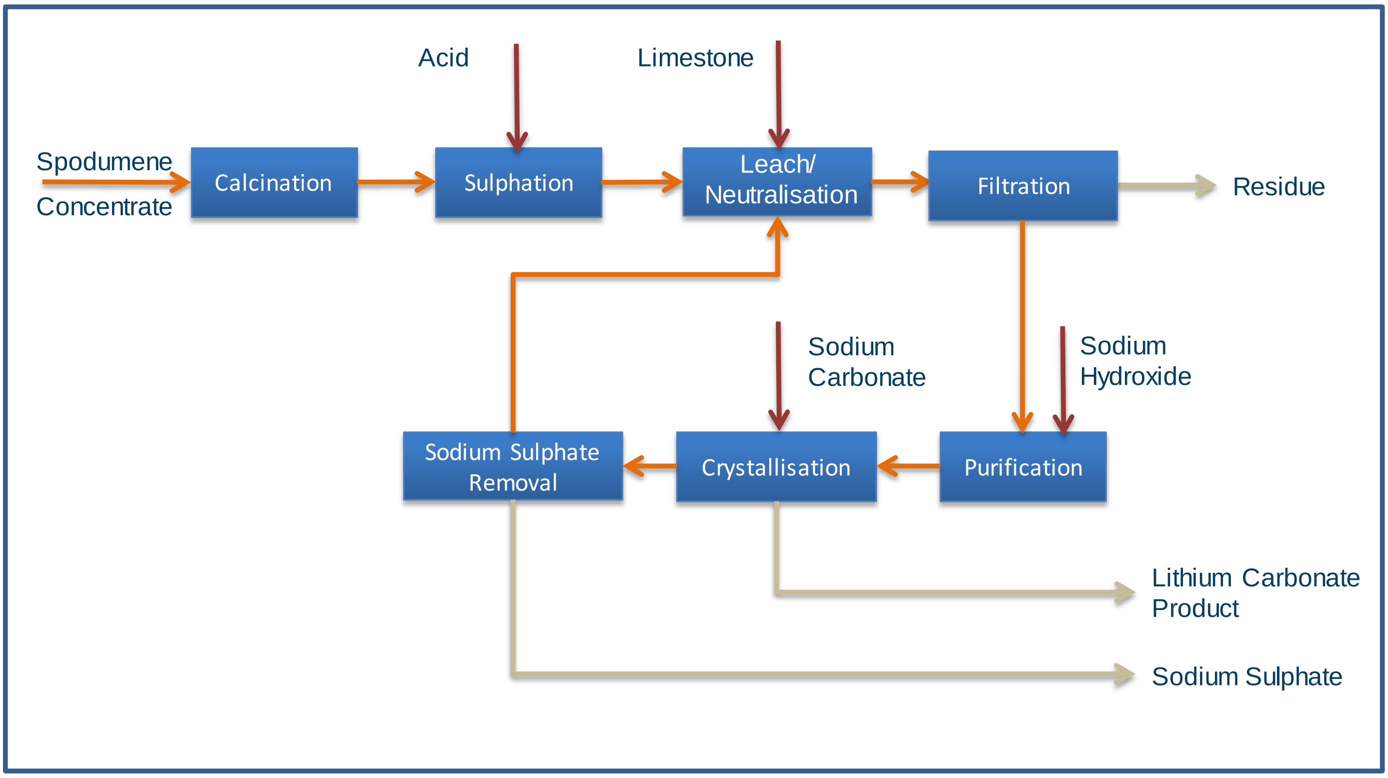

Figure 1: Basic Sulphation Technology for the extraction of Lithium from Spodumene

In the sulphation process the spodumene concentrate is calcined to transform the α- spodumene into β-spodumene**,** which makes it amenable to reaction with sulphuric acid to form lithium sulphate in Sulphation Step. The product from the Roaster is water leached followed by neutralisation and impurity removal. The purified liquor of lithium sulphate is then mixed with sodium carbonate to form lithium carbonate product. The barren liquor from the lithium carbonate crystallisation contains an appreciable amount of sodium sulphate which is removed in a crystalliser prior to the remaining barren liquor being recycled back to Leach.

Over 60 years on, Galaxy, Canada Lithium and Tianqi are in the process of commissioning hard rock plants essentially based on the same approach. However, there has probably not been a hard rock plant built since the 1970's. Thus these companies can be considered pioneers in trying to reengineer the process using 21st century equipment. Hence it is not surprising that these companies are experiencing varying levels of issues in commissioning and starting up of the plants. The purpose of this article is to review the current plants**,** and specifically**,** the reasons for cost growth and lower plant performance.

Prior to discussing the common problem themes the throughput ramp up of the Galaxy Jiangsu project is superimposed on a set of typical ramp up profiles after McNulty[iii] to compare the progress made to date, with the different scenarios McNulty considered. In his paper McNulty analysed plant start-up data for 41 plants classified under four scenarios:

Type 1 plants were based on mature technology, with well proven designs and have little innovation, such as gold or electrowinning plants.

Type 2 plants are similar to type 1 but had some novel equipment, full pilot plant trial were not fully completed and process conditions were severe, abrasive and/ or corrosive.

Type 3 plants were constructed with limited pilot testing, the product or ore quality was not explored or understood and there were design flaws that required plant modifications. Fast track projects would fall into this type**,** especially if the consequence of fast tracking were not mitigated through adequate planning.

Type 4 plants typically exhibited less mature technology, novel design and or limited testwork and tended to take considerably longer to ramp up. McNulty pointed out that there was a real risk that Type 4 plants will never achieve the design throughput. As a result companies with Type 4 could end up going bankrupt as a result of the monthly spend and financing costs, typically many millions of dollars per month**,** but with less sales revenue than expected.

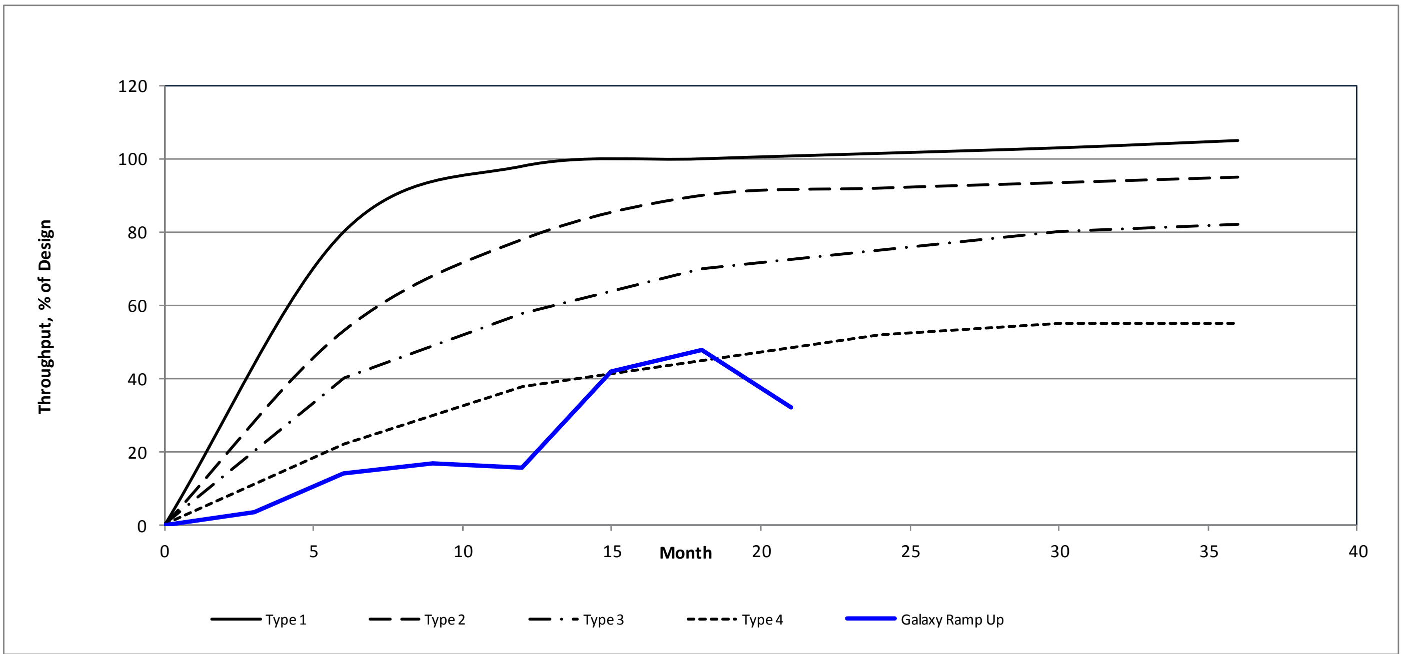

Figure 2: Galaxy Jiangsu Ramp up superimposed on the McNulty Ramp up Curves

Figure 2 shows Galaxy's reported quarterly production of lithium carbonate as a percentage of nameplate design throughput versus time after commissioning, superimposed on McNulty's curves for the four different plant categories. The Figure shows that at 15 months the Galaxy production performance was similar to what might have been predicted for a Type 4 plant. If the Galaxy production data had been plotted in terms of battery grade product it would paint a less promising picture. The current price of battery grade lithium carbonate is around US$ 6,500 compared with a price around US$ 5,800 for technical grade. Fortunately the difference is relatively small compared with other industrial chemicals.

In 1981 Merrow et al.[iv] analysed the start-up data from 44 chemical process plants which had an elemental of novelty or technical change compared with similar plants. They developed two equations for predicting cost growth and plant performance, especially for pioneer plants which historically had major cost growth and under-performed. Although the data was collected in the period 1978 through to 1981, the equations, appear to be as relevant today as they were then. The two equations are presented in this article and used as the basis to discuss the themes as to why the current hard rock lithium plants are experiencing problems.

Cost Growth

Merrow et al.[iv] suggested that Cost Growth as a percentage of the final capital cost compared with the original estimated cost could be explained by the following equation:

Cost Growth = 1.122 – ([NEW] *0.003 + [IMPURITY] * 0.021 + [COMPLEXITY] *0.011 + [DEFINITION] * 0.04 + [DEVELOPMENT] *0.024) + [INCLUSIVE] *0.0011

The Cost Growth Equation contains three technical variables and three project variables. These are explained in Table 1. Of the 6 variables listed in Table 1, the % New or Novel Equipment, Impurity Problems and Project Definition accounted for 70% of the cost growth variance, and in the text below the role of these variables in the project execution of the current hard rock sulphation plants is reviewed.

Importantly the external variables which are commonly cited as the reasons for cost growth, such as labour unrest, limited labour resources, weather and force majeure event, were not shown to be statistically significant.

	Variable	Comments
Technical	% New or Novel Equipment [NEW]	Cost of new or novel equipment purchased as a percentage of the overall cost of equipment purchased. The greater this percentage the greater is the expected cost growth.
	Impurity problems [IMPURITY]	Lithium plants with closed recycle/s and issues of impurity build-up and the challenge to produce battery grade lithium carbonate would rate as a significant issue.
	Process Complexity [COMPLEXITY]	The sulphation route with many process steps (greater than 11) would be considered complex.
Project	Project Definition [DEFINITION]	This is based on firming up the site for the proposed plant and the level of engineering design completed.
	Process Development [DEVELOPMENT]	A score reflecting if the process is reasonably understood compared with there still being issues to be addressed.
	Inclusiveness [INCLUSIVE]	Essentially the percentage of items priced versus factored in the estimate.

Table 1: Cost Growth Variables

In the writer's opinion, two of the three current companies building plants are pioneers in the sense they had limited or no information of similar plants, let alone of plant producing roughly 20,000 t/y lithium carbonate. It is fair to assume that these plants had a considerable proportion of new equipment, which would not be the case for another company building a lithium carbonate plant and learning from the successes and failures of the plants currently being commissioned and ramped up.

In addition two of the plants have changed from water cooled calcine coolers, opting for air coolers. The combination of limited or no testing of these units on calcine, the impact of clinker (sintered lumps) and the calcine material properties are likely to pose a number of issues for these units in commissioning. The novelty variable also affects the predicted performance of the plant and is discussed for the Performance Equation below.

A common design failure, usually under the instruction of the owner, is to limit the capital cost and provide no allowance in the event that the novel technology does not work or the performance is well below that required. In the case of the current plants where some or all of the equipment such as the calcine mill, the acid mixer, calcine water cooler and roaster have been removed from the conventional flowsheet, the author would highly recommend that space and infrastructure be provided that will allow for modifications that may be required, in order for the plant to achieve its rated capacity and product quality.

Project definition is critical and progressing through the normal steps of conducting studies at increasing accuracy levels. Although the names of the various stages may be different, the steps usually would be as set out in Table 2.

Study Phase	Typical Study accuracy
Scoping Study	+/- 50 %
Preliminary Feasibility Study	+/- 25%
Definitive Feasibility Study	+/- 15%

Table 2: Typical Phases in a project Development

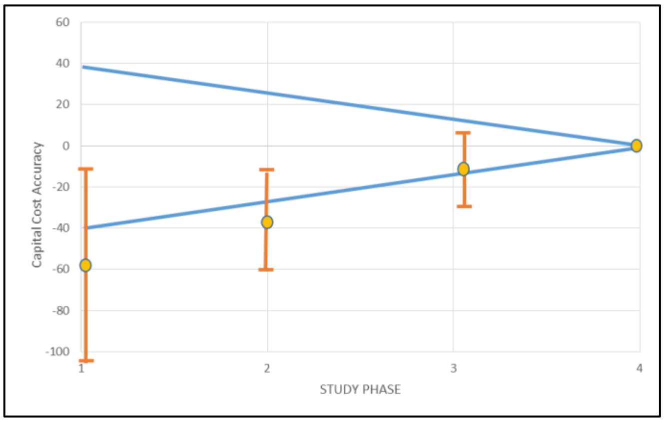

Figure 3: Possible Capital Cost Progression at Subsequent Study Phases

This can be shown diagrammatically as in Figure 3 as funnel with lower accuracy in the initial phases converging to the actual project price when the plant is built, study phase 4. The critical point to note in the figure is that with pioneer plants, it is common that the initial cost estimates are lower than the final cost, as a result of the limited knowledge available. As the design develops there is a better understanding of the infrastructure and equipment required, which results in the estimated cost increasing as shown by the orange bar lines in figure 3. In addition during the design development, a number of changes to the flowsheet are typically made which explains why the initial capital costs can be outside the accuracy.

It is not uncommon that the initial cost estimate can be too low by a factor of 2 - 3. As an example Reed Resources[iv] published a summary of their pre-feasibility study for a 17,000 tons per annum lithium carbonate plant in Kwinana with an estimated cost of US$ 125 million. Talison has stated that the 20,000 tons per annum lithium carbonate, proposed for Kwinana has an estimated cost of around AU$ 250 million based on completion of an engineering study with an accuracy of +/- 15%.

In the case of the Galaxy project the feasibility stage was skipped and detailed design started after the scoping study with the strategy of fixing any problems that arose on site. This may in part explain the ramp up type shown in Figure 1 and the increase in capital cost.

The lessons that Talison has learnt from the current projects is:

- The importance of completing the pilot plant work,
- The pilot plant work and modelling must include the build-up of impurities in the recycled streams,
- Not to skip a skip a stage in engineering development of the plant design,
- Limiting the amount of novel or new equipment and unit operation introduced into the design, and
- Realizing that external factors such as such as labour unrest, limited labour resources, weather and force majeure event can probably be mitigated through planning and competent management.

Performance Formula

The Performance Equation contains four technical variables which are listed in the table below.

	Variable	Comments
Technical	Number of new steps [NEWSTEP]	This refers not only to novel processes but also if there are changes in temperature, tenor or ……
	Proven Mass Balance Reactions in Model [MASS BAL]	The degree to which reactions have been derived from, test work data.
	Waste Handling Problems [WASTE]	Design difficulty in handling waste in meeting regulatory requirements.
	Solids processing [SOLIDS]	In the case of hard rock processing this is valid, adding performance challenges.

Table 3: Performance Variables

Merrow et al.[v] suggested that actual Plant Performance as a percentage of expected production to the actual production achieved could be explained by the following equation:

Plant Performance = 85.8 – ([NEWSTEP] * 9.69 + [WASTE] * 4.12 + [SOLIDS] * 17.9) + [MASS BAL] * 0.33

Based on the published flowsheet for the Canada Lithium Project, the changes to the flowsheet from the original flowsheet described are:

1. The feed is from a flotation plant, i.e. much finer and could pose dust problems
2. The calcine cooler has been changed to an pneumatic air transfer cooler
3. There appears to be no mill to deal with clinker, should that prove to be a problem
4. The acid addition/ mixing is in a plough type mixer at higher temperature and the "roasting reaction" occurs in the same vessel and the roaster has been omitted

Merrow et al.**Error! Bookmark not defined.**[v] suggested that the impact of the number of new steps on plant performance in the first 7 – 12 months could be estimated from the performance formula as is shown in Figure 4. Although it should not be taken more than indicating a trend, it does suggest that making multiple changes can have a dramatic effect on the ramp up.

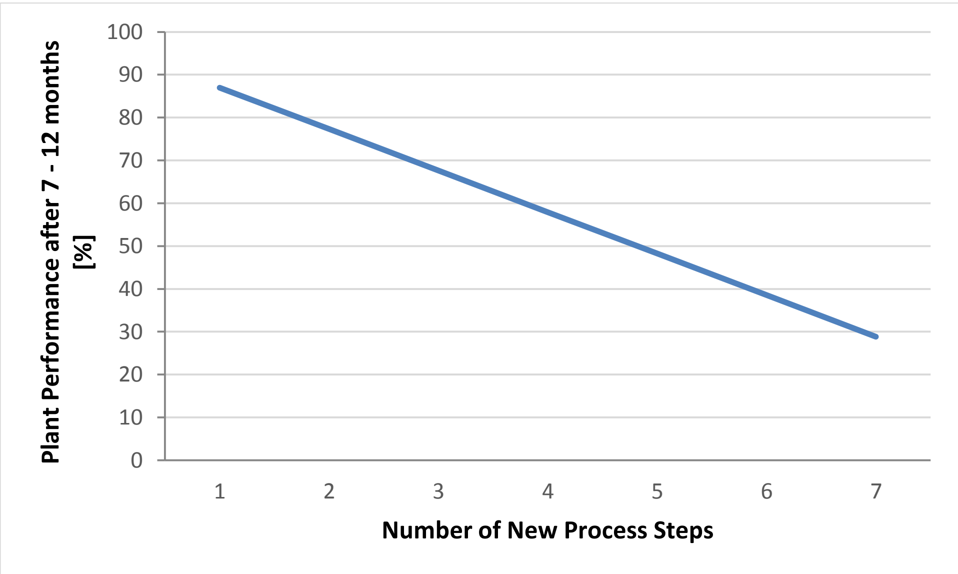

Figure 4: Prediction of the impact of number of new steps on Plant Performance

The lessons that Talison has learnt from the current projects is:

- To limit the number of new unit and unproven operations in the proposed plant, and
- To incorporate actual reaction and equilibrium data derived in the pilot plant in the process modelling

Lessons Learnt as a Guide for Future Plants

There are a number of companies that are conducting feasibility studies to determine the viability of their lithium projects; this includes Talison Lithium, Australia. The lessons learnt by the current pioneering companies are extremely valuable in understanding which unit operations have worked or not, and even the feedback from vendors who are certain to incorporate the learnings from the equipment offered. This can include material selection or abrasion lining recommendation.

Even with this hindsight it is critical to conduct full pilot plant trials which, based on Talison experience, take in the order of a couple of years. This pilot plant work can be run in parallel with the engineering design, which would have slightly longer duration of around 3 years prior to starting detailed design.

Clearly, novel design, be it a radical change in unit operations or simply a change in operating conditions, introduces risk. Extreme care must be taken to ensure as much design and testing is completed, as they are the only ways in which to mitigate the risks.

In the event of introducing a totally novel or radical unit operation, such as changing from water cooling the calcine to air cooling, it is critical that the engineering design includes consideration as to what would need to be done, if in worst case, the novel unit does not achieve near the design capacity. This may be as simple as allowing real estate where the novel equipment can be replaced with conventional equipment can be installed or materials handling equipment that can be cost effectively reconfigured in future.

Fast tracking a project simply means taking short cuts in not fully conducting pilot plant work and or shortening the engineering design time. Both should be avoided at all costs and especially for single project companies. Single project companies are those that do not have an existing operation and therefore do not have any incoming revenue to fund potential plant modifications that may be required.

The future plants will almost certainly be supplying the growing electric vehicle market and will be required to produce battery grade, or better, lithium carbonate or hydroxide. This puts pressure on producers to supply increasingly higher grade lithium chemicals, which means lower levels of impurities. This reinforces the importance of pilot testwork with locked cycle programmes to fully understand the build-up of impurities in the recycle streams and the ultimate impact on product purity. These include chloride, potassium and calcium.

In summary, future lithium chemicals producers, such as Talison Lithium can learn from the current pioneer plant currently being built. Key learnings are:

- The importance of completing the pilot plant work including quantifying the build-up of impurities in the recycled streams, and incorporate actual reaction and equilibrium data into the process modelling
- Not to skip a skip a stage in engineering development of the plant design,
- Limiting the amount of novel or new equipment and unit operation introduced into the design, and
- Realizing that external factors such as such as labour unrest, limited labour resources, weather and force majeure event can probably be mitigated through planning and competent management.

References

[i] Ellestad R. B., Leute, K. M., "Method of Extracting Lithium Values from Spodumene Ores", US Patent 2,516,109, July 1950.
[ii] Hader, Rodney, "Lithium and its Compounds", Indust & Engineering Chemistry, Vol 43, No 12, December in 1951
[iii] McNulty Terry, "Minimization of Delays in Plant Startups", in Management of Process Technology Development, Plant Operator's Forum 2004: Things That Actually Work!.
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[v] Merrow E. W., Phillips K.E. and Myers C. W., "Understanding Cost Growth and Performance Shortfalls in Pioneer Process Plants", 1981, prepared for the US Department of Energy, Rand, Santa Monica.