Transferring R&D results into optimal process design – the good and the bad

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ABSTRACT

A lot of emphasis is either placed on the design and execution of an effective research and development programme (including a good metallurgical test work programme) or on the detailed design of a process circuit using the results from a test work program. Usually these are not done by the same company and individuals. Disconnects between the two are very common and thus the best design outcome is not always achieved.

The purpose of this paper is to explain the importance of understanding and interpreting research and development results by the design team to ensure an optimal design, both in regards to process functionality and cost. There are various pitfalls along the way and this paper will try to show that a systematic and optimised approach can reduce the risks of over/under design, cost escalations as well as incorrect equipment and layout, thus not an optimal design.

The author will use an example to explain the various decisions that can be made in a design process and to show the reader that making different design decisions from the test work results can have major different cost and process outcomes on the plant proposed. Effective interpretation of test work and research results, understanding the gaps, good collaboration (one team between client, researcher and designer), zero base design, optimal flowsheet and effective use of appropriate equipment are some of the factors that can be used to mitigate the issues to deliver an optimal final product.

INTRODUCTION

A rule of thumb states that for every 1,000 prospects, 100 come to be drilled and only one becomes a mine (Brock, 1985). Several reasons for success are noted in an article by Trench (2011), which may be responsible for minerals companies to succeed. Not all of these are positive or complementary, for example, the 'Dodgy Brothers approach' or the 'Eureka moment', which is based on the fortune of chance. However, vision, strategy and recognised expertise are also highlighted in the article and are undeniably important aspects of the mix

It is clear that the focus points and the priorities of large mining majors, mid-tier mining companies and the small mining juniors, will differ significantly. Size does matter; this is an undeniable truth in the resource industry, both from the perspective of the Mineral Resource itself and also from the perspective of the organisation hoping to develop the resource. From the onset the larger organisation has access to better internal technical resources, financing and other services, compared with the organisation carried by a small number of generalists. The smaller company may have the luxury of appointing one or two specialists, but in an informal survey of smaller mining companies it was evident that these companies are relying on internal generalists, while occasionally appointing specialists on short-term contracts to develop a mine plan or process flow sheet for the company (Muller and Lorenzen, 2012).

Identifying from a sample group of 105 projects, Table 1 (Lorenzen, 2011) clearly highlights that metallurgical testwork and process design are major areas of inadequacy within feasibility studies against common experiences in commissioning and operational problems. As scheduling of ore to be processed is listed as one of the major issues, the selection of process plant to handle the selected schedule become even more important.

Each ore is unique and no two ore deposits are the same. To manage technical risks in metallurgical flow sheet development and overall process development, we need to consider the following:

- Minimising risk via testwork;
- Effective flowsheet development via study phases;
- Project risk assessment; and
- Project optimisation.

Area of Problem	Frequency
Mine design and scheduling	32%
Geology, reserve and resource estimation	17%
Metallurgical test work, sampling and scale up	15%
Process plant equipment design and selection	12%
Geotechnical	9%
Cost estimation	7%
Mine equipment selection	4%
Hydrology	4%

TABLE 1 – Process Engineering Risk (Lorenzen, 2011)

The purpose of this paper is to explain the importance of understanding and interpreting test work results by the design team to ensure an optimal design, both in regards to process functionality as well as cost. There are various pitfalls along the way and this paper will try and show that a systematic and optimised approach can reduce the risks of over/under design, cost escalations and incorrect equipment/layout.

ISSUES WE SHOULD CONSIDER IN PROCESS DESIGN

The mining industry contains numerous examples of projects that have failed to achieve desirable financial outcomes. Metallurgical process plants that are unable to achieve design production rates and/or product quality, particularly during the early stages of project life are a contributing factor in these failures.

Often poor process plant performance can be attributed to the use of inadequate and/or unsuitable testwork when designing flowsheets and specifying process equipment. Inadequate testwork may lead to increased project development costs since expensive testwork and engineering may have to be repeated. It should be noted that for higher level engineering studies, larger scale testwork is recommended and is a requirement for feasibility level studies. This would apply even if the technology is considered mature and well proven, as each ore body may have its own unique characteristics, which, if untested at a larger scale, could result in significant design shortcomings, which will have to be rectified at later stages of the project, usually at significant additional cost. Design errors based on incomplete or insufficient larger scale testwork have been responsible for significant cost blowouts on many metallurgical projects. When developing a process flowsheet, risk is minimised by ensuring adequate testwork supports engineering and cost estimation at each phase of project development.

Samples and Testwork Programme

The characteristics of the samples to be taken should also include the mass as well as particle size distribution. The type of samples that can be used for metallurgical testwork and their limitations are listed in Table 2 taken from an excellent paper on the subject by Hanks and Barrett (2002).

The authors has observed over many years that the quality of sampling and quantity of metallurgical testwork carried out during the various phases of engineering studies is often insufficient to truly support a robust plant design. Good outcomes are often the result of plant design based on benchmarks of apparently similar ore bodies or buoyant metal prices supporting cash flows until rectifications can be implemented.

The quality and type of samples used for metallurgical testwork are just as important as the metallurgical testwork itself. The key characteristic required of any sample is that it represents some defined portion of a mineral deposit. Representivity should take into account the spatial orientation, lithology, alteration, degree of oxidation, mineralogy and competency of the ore.

Statistically representative sampling procedures and an appropriate testwork programme should be designed to bring Metallurgical understanding up to Feasibility Study standard and to give a basis for process plant design.

Sample Characteristics	Type of Sample				
	Grab	RC Drill Cuttings	Small Diameter Core	Large Diameter Core	Bulk
Coverage	Poor	Good	Good	Varies	Varies
Mass of Sample	Low-Good	Low	Better	Good	Best
Particle Size	Poor-Good	Poor	Fair-Good	Good	Good
Cost	Low	moderate	Moderately high	high	Moderately High

TABLE 2 – Characteristics of Samples (Muller and Lorenzen, 2012)

The testwork requirements for various engineering studies are highlighted in Tables 3 which are based on the paper by Hanks and Barratt (2002).

Obviously, the test work will be adjusted to the type of ore, the resource and the size of the project. The temptation is to reduce the amount of larger scale testwork or pilot scale test work, by not simulating the full flowsheet before moving forward towards the basic and detailed engineering stages of the project.

Analysing the results

The results achieved (thus data) from the testwork programme needs to be analysed and where possible apply process modelling which involves building a mathematical model of the process by describing its fundamental physical and chemical relationships allowing process outcomes to be described – it's a tool (see Figure 1). Simulation is one of the activities you can perform with a well-designed process model – using the tool. So why is the modelling of the process important?

- Identify or test opportunities to optimise the process design without having to physically change the process
- Review potential impact of proposed changes on:
    - Product purity
    - Process safety
    - Capital Costs
    - Operating Costs
- Metallurgical Accounting
- Cost Saving – expensive testwork
- Properties of certain equipment and / or unit processes as reactors, columns, evaporators, mills, etc.
- Understand relationships
    - Develop correlations between a small number of measurable physical properties and process parameters and use these relationships to calculate many other data

Type of test	Type of Study			
	Scoping	Pre-feasibility	Feasibility	Basic Engineering
Comminution				
Unconfined Compressive Strength (UCS)	(X)	X	X	X
Bond Crushing Work index (CWI)	-	X	X	X
Bond Abrasion Index (Ai)	X	X	X	X
Bond Rod Mill Work Index (RWI)	X	X	X	X
Bond Ball Mill Work Index (BWI)	X	X	X	X
SAG Milling Tests: • JK Tech drop weight test (DWi), or SAG Mill Competency (SMC) test	-	(X)	X	X
High Pressure grinding Mills (HPGR)	-	(X)	(X)	(X)
Process design criteria -Comminution	-	(X)	X	X
Heavy Media Separation				
Heavy Liquid Separation	(X)	X	-	-
Gravity/magnetic/electrostatic Separation	(X)	X	X	X
Process design criteria - HMS	-	(X)	X	X
Leaching				
Small Diameter columns (variability)	X	X	X	X
Larger columns	-	X	X	X
Bottle Roll (variability)	X	X	X	X
CIL/CIP batch or semi-continuous*	-	(X)	X	X
Agitation tests (Rheology and Suspension)	-	-	X	X
Process Design Criteria		-	-	X
Flotation				
Preliminary reagents/pH	X	X	X	X
Rougher Grind-grade-recovery	X	X	X	X
Regrind and cleaner flotation	X	X	X	X
Locked-cycle	-	X	X	X
Optimization of major ore type (variability)	-	X	X	X
Process design criteria - Flotation	-	(X)	X	X
Dewatering				
Concentrate Thickening	-	(X)	X	X
Concentrate Filtration	-	(X)	X	X
Tailings Rheology (pumping)	-	(X)	X	X
Tailings Characterization (TSF design)	-	(X)	X	X
Process design criteria	-	(X)	X	X

Note: (X) as required, * as required for carbon loading, kinetics, etc. . Pilot plant testwork can be performed for each category during feasibility and basic engineering studies for complex or refractory ores where only limited benchmarking information is available.

TABLE 3 – Typical testwork required for engineering studies

There are various tools to describe the analysis of data, namely:

- Multivariate statistical methods and relationship models (see Figure 2);
- Steady state models and dynamic models;
    - Steady state models perform mass and energy balances of stationary processes (i.e. processes in equilibrium or steady state) but any changes over time are ignored,
    - Dynamic models are an extension of steady-state models whereby time-dependence is built into the models via derivative terms i.e. accumulation of mass and energy.

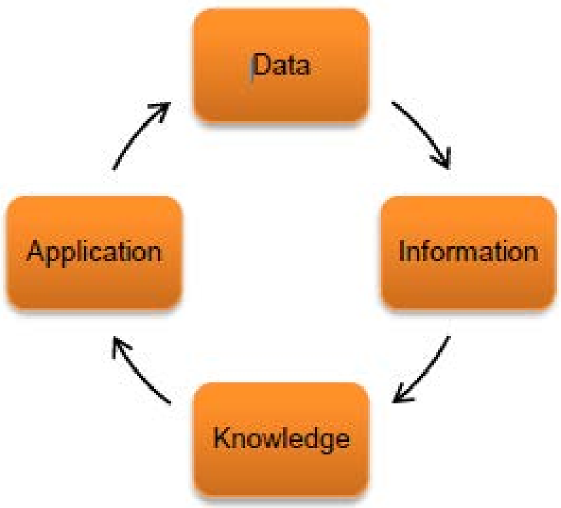

FIG 1 – Data Analysis Process

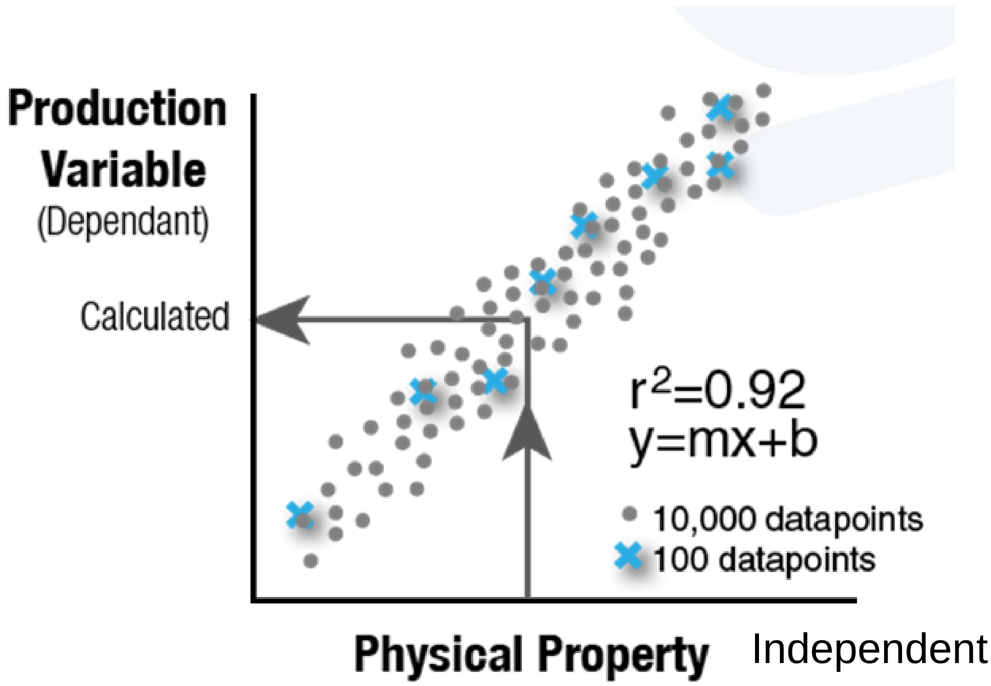

FIG 2 – Relationship Model

Figure 3 shows the difference in approach with regards to modelling in greenfields and brownfields studies. It is evident from this figure that data is usually more readily available for brownfields studies but with a lot of “noise” associated with it However, it allows for reconciliation and optimisation during brownfields studies where in greenfield studies it provides you with a relationship or model to be used without full validation – see case study 1 later.

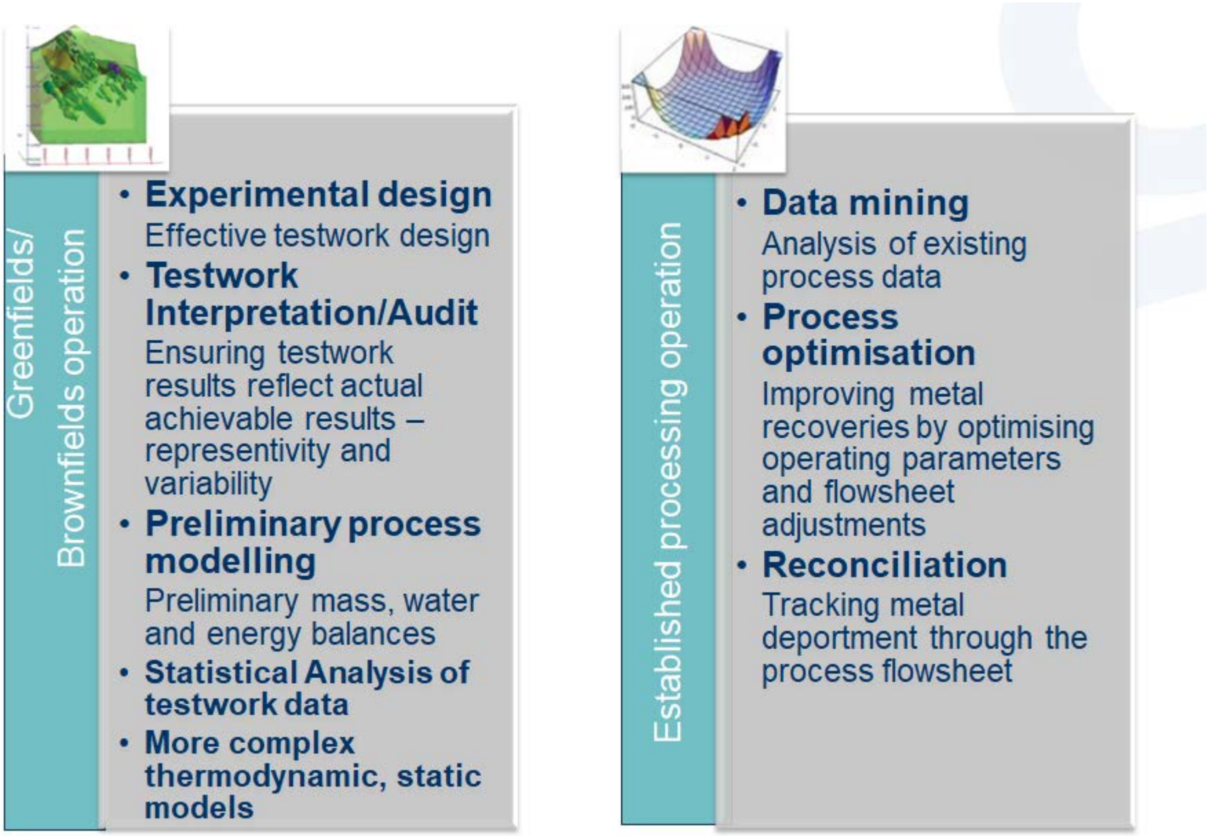

FIG 3 – Greenfields and Brownfield Modelling

Identifying the best process flow sheet

The best process flow sheet for the orebody under consideration may not be the most commonly used flow sheet and it may not necessarily be based on technology that is applied at any other similar orebody. Yet, the developers are often forced to consider these alternative flow sheets due to:

- the orebody being too small to implement some of the flow sheet options that only make sense at significant economies of scale;
- the preferred process flow sheet being protected by patent rights and the owner of the IP making it very difficult for the developer to operate at a profitable level.

In spite of this, some of the most innovative and creative flow sheets have been created and tested by the various mining companies (large and small). Out of personal experience in several larger companies, one of the first questions asked during the review process is: where else is this technology applied? The answer to this has to be:

nowhere – that is why we call it ‘new’, the new process or technology seldom makes it across the first hurdle. The junior mining company is not only looking for a cheaper and more cost-effective process option, but is also prepared to take more risk on board than the mining major and will be more prepared to test the process on a commercial scale if initial test work results are confirmed by larger pilot scale tests. Commercial scale for the junior is sometimes barely a pilot scale operation for the major, but the key is that the technology is tested in an environment where it has to succeed to provide the project owner with a financially viable operation.

MISTAKES WE MAKE

Similar test work

Previous test work will never be a good substitute for test work specific to the orebody and process option in question, yet juniors have often assumed recoveries and reagent consumption on test work for 'similar' orebodies. Admittedly, this is not a regular occurrence, as most managers are aware of the risk and impact that relatively minor differences in mineralogy can have on the recoveries and impurities deportment, but it is still a fairly common practice during the early stages of a project.

Scale of test work

Before at least some well-designed bench scale test work has been completed, assumptions about recoveries and impurities in product are best not made. An example of some of the test work recommended for the development of metallurgical engineering studies is shown in Table 4. The temptation is to reduce the amount of larger scale testwork or pilot scale test work, by not simulating the full flowsheet before moving forward towards the basic and detailed engineering stages of the project. Pilot scale test work is typically aimed at sections of the flow sheet where uncertainty is highest. Although it is commendable that the test work is done on an appropriate scale, failure to test the full flow sheet can lead to processing errors on a full commercial scale that can be very costly. A guideline here is that options and expected operating conditions are established at bench scale and then tested on a pilot scale.

Scale	Scoping Study	Pre-feasibility Study	Definitive/Bankable Feasibility Study	Detail Design
Laboratory	√	√		
Small Pilot		√	√	
Pilot Plant			√	√
Trail Plant			√	√
Samples	DDH	DDH	DDH; LDC;BS	DDH; LDC;BS

DHH – diamond drill hole (core), LDC – large diameter core, BS – Bulk sample

TABLE 4 – Sample Selection for Studies

CASE STUDY – COMMINUTION CIRCUIT DESIGN AND OPTIMUM GRIND SIZE

Some assessments of the optimum grind size for designing the milling upgrade at an existing process operation have been undertaken. The assessment was based on comparing the anticipated incremental costs (operating and capital) against the expected increase in gold recovery.

The cost aspects of finer grinding were reasonably definable. However, the marginal revenue from increased recovery was much harder to assess. Recent testwork carried out for the operation by a reputable laboratory on a single domain sample, showed a very clear relationship corresponding to a 4% recovery gain for change in grind size from 180 microns to 106 microns. The regression coefficient for the four test points was 0.91. However as is generally known, using only four test results is a very slim statistical basis for optimising a major project (see figure 4).

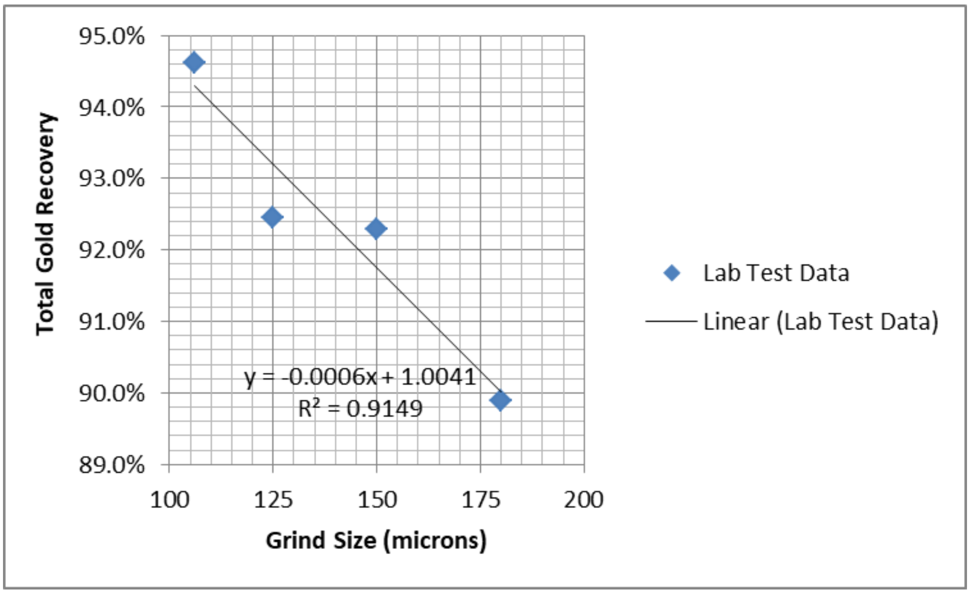

FIG 4 – Recovery/Grind Relationship from Laboratory Testwork

The other source of grind/recovery information was a table of daily production data selected by senior staff at the current operation. Overall 33 days were selected from a two year period, with the following criteria, namely:

- that mill throughput was close to the design throughput, and
- that the feed was at least 90% from the future ore domain to be treated, thus the domain tested in the laboratory (data for figure 4).

This recovery data as depicted in figure 5 showed a much lower dependence on grind size, about 1% increase for the same change in grind size compared to laboratory tests. The correlation coefficient at 0.05 was almost insignificant. That says the measured plant performance could easily be considered independent of grind size within the range of the data (~145 to 225 microns). This was in accordance with tails grade in Figure 6 and from plant data over many years.

The conflict between these two data sources makes the grind size optimisation more challenging. In laboratory testwork, sizing is applied by batch milling and physical screening, so the particle sizing is defined solely by particle dimensions. In the plant the mill circuit cyclones apply an enhanced gravity separation which splits according to both size and density. For most of the ore particles the density is 2.5 to 3.0 kg/m^3 so the separation is effectively on size. Gold-bearing particles can be very much denser (gold SG is 19.3 kg/m^3) and these will be usually selected to underflow and returned to the mill. The gold-bearing particles will only report to leaching via cyclone overflow when they are considerably finer than the nominal cyclone split size. That is, the plant process circuit selectively grinds the payable particles finer than the laboratory testwork for the same bulk P_{80}. Consequently the leaching results in the plant would correspond to a finer laboratory process.

However, it is important to state that you would expect at least a similar trend between laboratory testwork and plant results.

Using an economic evaluation tool to determine the economic optimum grind size was the next step in the design process. Now the decision of which data set to use becomes of utmost importance. In this section the authors show the implications of using different data sets on the outcomes achieved. When both sets of recovery data (I.e. both curves as provided in figures 4 and 5) are used, it provided different optimum grind size and comminution circuit for the upgrade as well as the financial outcomes as explained below.

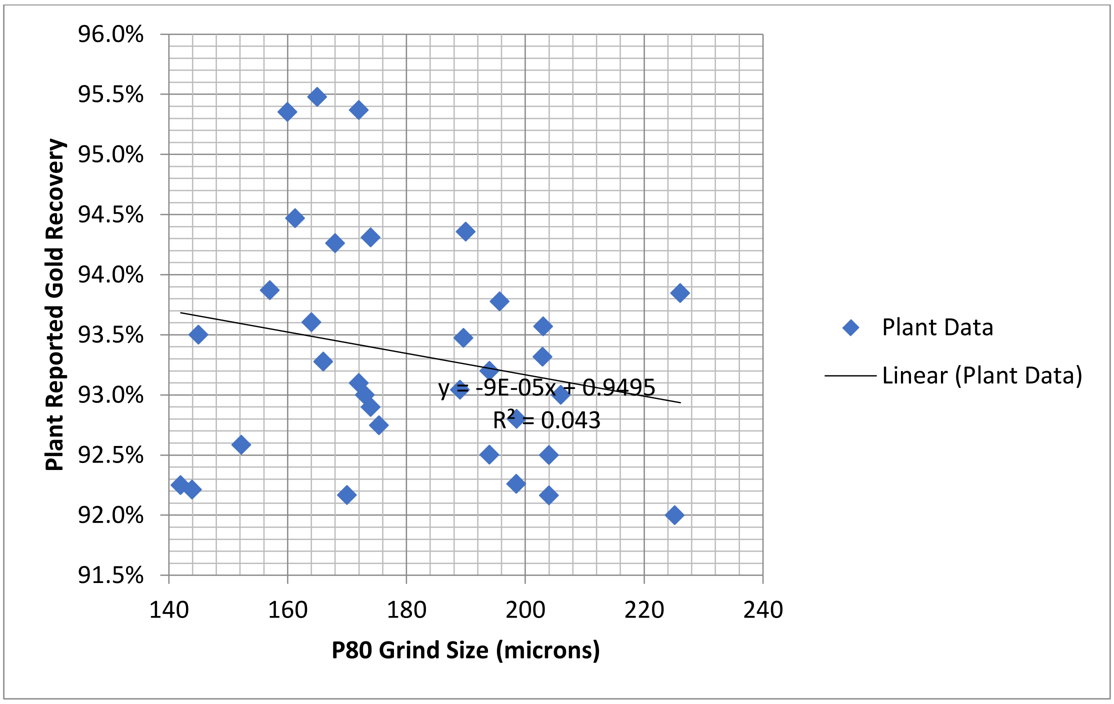

FIG 5 – Recovery/Grind Relationship from Plant Data

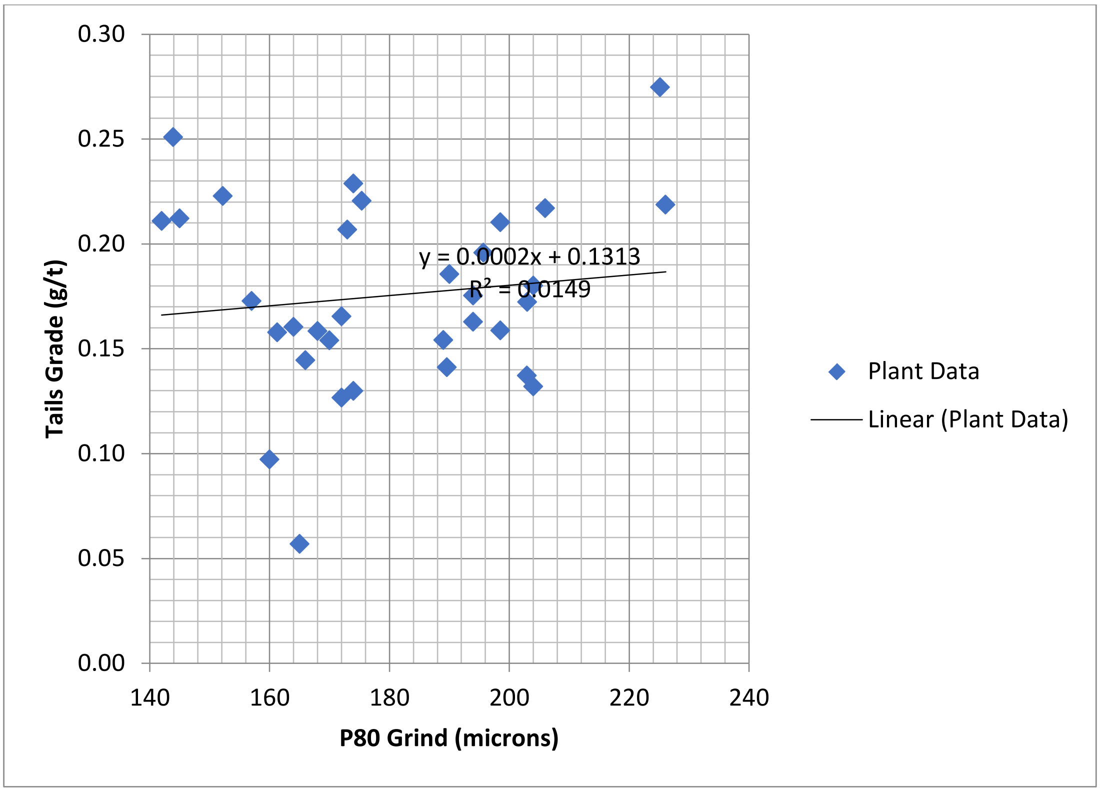

FIG 6 – Tails Grade Relationship from Plant Data

The basis of the grind size optimisation is to maximise the net revenue obtained from processing at a fixed ore throughput i.e. consider incremental revenue less incremental costs. This was applied to evaluate four grind sizes, namely 180 µm, 150 µm, 125 µm and 106 µm.

The revenue benefit of a finer grind is solely through the expected higher gold recovery. The increasing costs considered in the assessment to achieve a finer grind size are, in approximate order of significance:

- Mill circuit power;

- Grinding media and mill lining;
- Capital payback;
- Labour factor based on additional plant capex.

The following items are specifically excluded on the basis that cost changes are considered inconsequential:

- Reagents for leaching and gold room;
- Labour and maintenance for CIL and gold room.

The results of the economic evaluation of the optimum grind size are depicted in figure 7 and 8 for laboratory and plant data respectively.

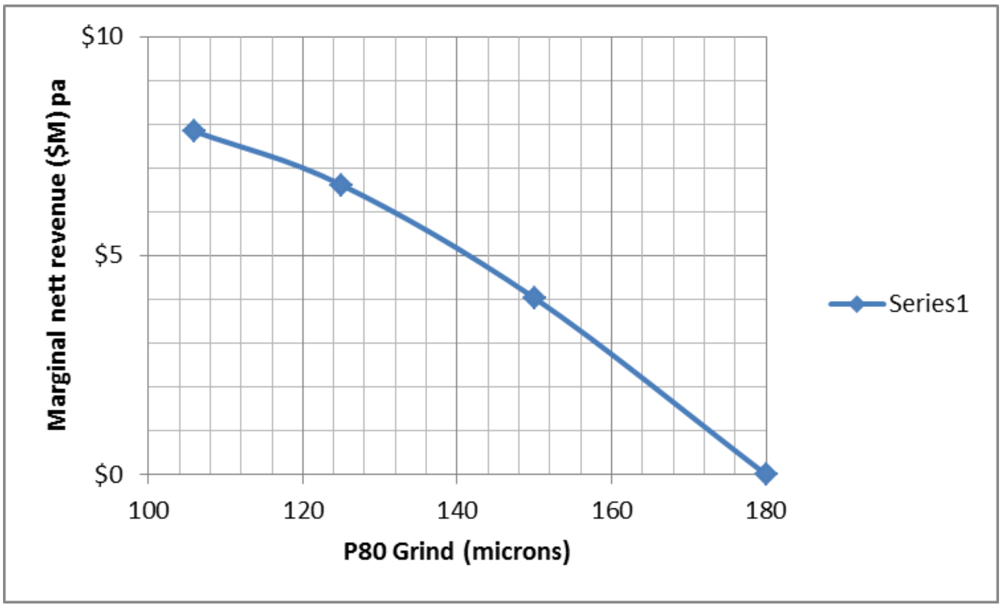

FIG 7 – Grind optimisation estimates based on Laboratory testwork

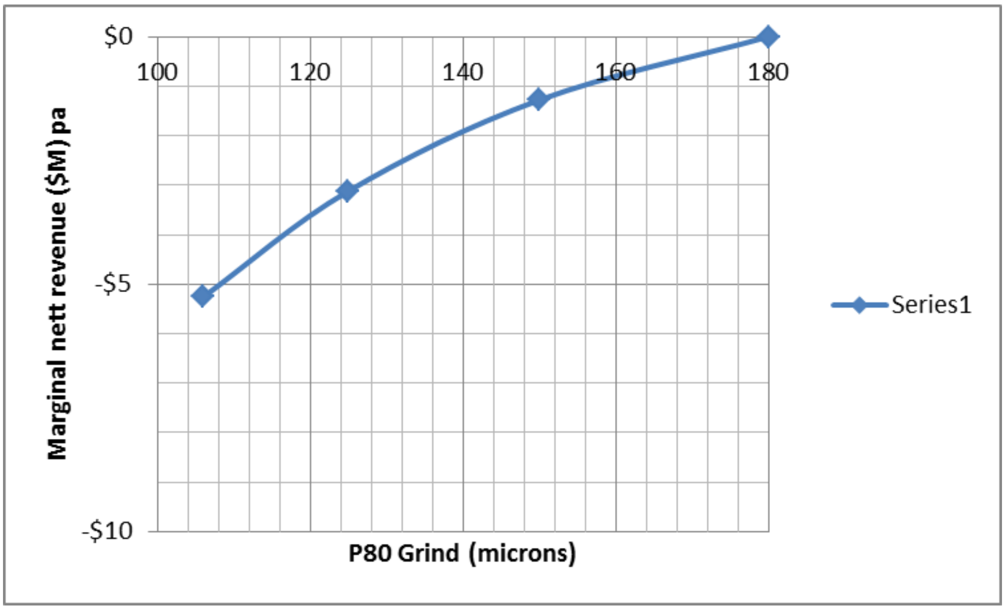

FIG 8 – Grind optimisations estimates based on plant data

Clearly these graphs present totally conflicting conclusions. Thus, it is obvious that data selection, verification and confidence is of utmost importance in making design decisions.

In this case it is evident that the laboratory testwork has limitations, namely:

1. Only one domain sample was used which was then split into 4 samples and ground to various particle sizes (no representativity and variability);
2. Making conclusions from trends using only a limited number of samples (four) is not statistically acceptable;
3. No duplicate tests were done on those four laboratory samples to confirm recoveries.

Thus, the use of plant data in this case could be more reliable than laboratory data in making design decisions. This relatively simple evaluation show that the;

- trend and shape of the recovery curve is of utmost importance, and
- confidence in the data and representativity is of utmost importance to make final recommendations with regards to optimum grind size and circuit design.

From the case study it is evident that if only laboratory test work results were used for sizing an designing the upgrade circuit, a different grind size and circuit (for specific throughput) would have been selected compared to what was selected using the plant data. Thus a higher capital cost and operating cost solution would have been selected with the assumption of higher revenues due to higher recoveries.

CONCLUSIONS

The grind/recovery information to confidently guide the optimisation of grind size for an operation depends totally on the quality and confidence of the metallurgical testwork data used for the design This paper showed that planning and review of metallurgical data as well as design implication of such data is of utmost importance in the design process.

Effective interpretation of test work and research results understanding the gaps, good collaboration (one team between client, researcher and designer), zero base design, optimal flowsheet and effective use of appropriate equipment are some of the factors that can be used to mitigate the issues to deliver an optimal final product and minimise future cost issues for the client

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REFERENCES

Brock SJ, 1985, “Funding a promotional exploration company, Finance for the Mineral Industry, (The American Institute of Mining, Metallurgy and Petroleum Engineers: Engelwood), Chapter 11, pp 584-589

Hanks J and Barratt D, 2002, “Sampling a Mineral Deposit for Metallurgical Testing and the Design of Comminution and Mineral Separation Processes”, Proceedings, Mineral Processing Plant Design, Practice and Control, eds A.N. Mular, D.N. Halbe, D.J. Barratt SME Inc, pp 99-116.

Lorenzen L, 2011, Managing Technical Risks In Metallurgical Flowsheet and Plant Development, Snowden Risk Workshop, Perth, May 2011, 12 pages.

Muller H and Lorenzen L, 2012, “Project Selection and Process Development for Mining Juniors”, AusIMM Project Evaluation Conference, Melbourne Australia, 24-25 May 2012, pp 149-158

Trench A, 2011, “The seven habits of successful mineral companies”, MiningNewsPremium.net (online), Available from: <http://www.miningnewspremium.net/storyview.asp?storyid=2491537&sectionsource=s88&highlight=seven> [Assessed November 2011].