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Metallurgical Errors- Where Things Went Wrong

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The views expressed are those of the author and while projects are referred to as an example the full facts or counter arguments may not be presented. The views expressed are personal and no responsibility is taken for errors of fact or missing information. Some of the information is not drawn from the experience of the author but information relayed by colleagues.

ABSTRACT

The development of metallurgical projects involves high risks and high returns. There is a high degree of uncertainty. Minerals need to be extracted into concentrates or metal products. Design metallurgists are specialists in mineral processing who undertake test work and flow sheet development and use the principles of chemistry, physics and mathematics to achieve successful operating projects. Metallurgy is not an exact science and knowledge, experience and skill with interpreting results plays a significant role in developing successful projects. Project statistics show that only 50 per cent of projects turn out as predicted and there are many reasons for this. The common belief that a bankable feasibility study (BFS) guarantees success is flawed. Even quantitative risk analysis will not eliminate inherent risks or make up for some of the common metallurgical errors.

There are many complex sulfide gold ores, uranium, nickel, tantalum, vanadium etc which can be problematic. Refractory gold ores and refractory uranium ores are further examples. Even beneficiating iron ores is not as simple as it first appears. Floating fresh sulfides, while generally straight forward, the range of liberation sizes, optimised reagent regimes and problems with weathered ore can be challenging.

Metallurgical problems result from different objectives, common mistakes and incorrect interpretation or no interpretation of results. Experience has shown that unless these mistakes are identified and understood they are likely to be repeated.

MISTAKE 1 – FAILURE TO OBTAIN REPRESENTATIVE ORE SAMPLES

There are numerous examples of project failure which have resulted from not conducting test work on the transition ore or finding surprises. Not picking up changes in ore characteristics with depth or the presence of ‘‘nasties’’ in the ore can lead to problems in processing. Diamond drill core is expensive to obtain and companies commonly say they are ‘‘reluctant to drill too many metallurgical holes’’. Drilling holes to prove up reserves are less problematic.

Testing a sample that is not representative of the ore to be processed is the single biggest risk in metallurgy with resource projects. The fact that the flow sheet is based on a supposed representative sample is critical. Ore bodies are not ‘‘typical’ or homogeneous and it can be extremely difficult to obtain a representative sample. Metallurgists take samples of oxide, transition and primary ore and along strike in order to cover the ore types. This can also include variability testing to test the optimised flow sheet on parts of the ore body.

Compositing is very good at hiding metallurgical characteristics and can, in fact, increase the risks, particularly when defining a flow sheet from a bulk sample.

The best solution defined to date is the geometallurgical approach where geological ore domains are defined and understanding of structural controls and mineralogy are included in the testing. Similarly, understanding the pit shell and including the mining schedule plus mining dilution will result in better sample testing and representivity.

The highest importance should be placed on ore treated in the first few years, particularly for the loan period and less emphasis on ore in years 5 to 10 and beyond. As a general rule any resource that represents greater than 10 percent of the ore should be tested.

One project drilled six metallurgical holes and as it turned out the holes were biased - indicating a hard ore. This had very bad outcome with regard to over grinding the ore that was treated.

A significant iron ore concentrator was designed on the basis of something like 11 pit samples. One sample was finer than the rest and it was removed from the design set on the belief that it was not representative. Of course, once the plant was operating, the pit had moved into areas remarkably like that 11th sample. Hence, a major project was undertaken in the 1980's to modify the plant to handle these fines. Clays were also a major problem with the Dense Media Separation (DMS) plant. Anecdotally, the same plant suffered from severe pipe and pump wear due to pumps having been oversized. The word was that 'let's go one size up' had been applied successively several times during the design process. Again, a major study and work was undertaken in the early 1980's to fix this over design.

MISTAKE 2 – FAILURE TO COMPREHEND THE MINERALOGY AND VARIABLITY

Always remember that the ore's mineralogy drives the metallurgical process. Process mineralogy, as it is sometimes called, does not get the attention it deserves. Sometimes mineralogical investigations will not find any gold, so no further mineralogical studies are carried out. Hence, predicting gravity gold in a deposit is very difficult and many get this important aspect wrong.

Metallurgists have pushed on with multiple float tests or leach tests when the upfront mineralogy would have predicted success or failure.

Similarly, ore changes in depth along strike or with different domains can be identified by mineralogical studies before attempting to process the ore.

QEMSCAN (Quantitative Evaluation of Minerals by Scanning Electron Microscope) is a mineralogical analysis technology which combines a scanning electron microscope with Energy Dispersive (EDS) X-Ray analysis to identify mineral composition, mineral associations, mineral grain size and liberation characteristics (CSIRO 2008). It is has been an enormous help to metallurgists in understanding and developing improved processes.

Too often, problems have been discovered once the project starts. Such examples include finding talc or arsenic in nickel ores and mercury in gold deposits or the impact of silver in epithermal gold ores. The poor history of early identification of the impact of copper in gold ores is another case of too little attention being paid to the mineralogy.

With one project, the presence of scorodite and its ability to lock up gold was not appreciated in the BFS where the model of a free milling oxide ore on top of a refractory sulfide ore was adopted.

The presence of gersdorfite and its negative impact on the roasting of refractory gold concentrates is another example of the need for early mineralogical knowledge.

Similarly, the presence of fluorite in an ore, resulting in a copper heap leach failing because the fluorine killed off the bacteria, is a further case.

An original manganese beneficiation plant was installed in 1968 and the flowsheet was configured as a jig plant. It was unsuccessful because the gravity differential between the ore and gangue was insufficient and the amount of near gravity material was therefore excessive. The plant was retrofitted with Mitchell Cotts Heavy Media (HM) Drum and HM Cyclones.

A previous Australian Copper Mine Reserve was established based on sampling and testing of the ore. There was a disconnect between the mine schedule and the samples tested. The mining activity subsequently extended into the 'sub grade' resource causing a major increase in the soluble manganese (Mn) content of the ore. This soluble Mn built up in the electrowinning circuit (EW) and oxidation of the solvent extraction (SX) reagent lead to total collapse of the SX circuit. It took a 3 month rehabilitation plan to get back to 90 percent of throughput.

The impact of preg-robbing carbonaceous gold ores was not recognised in some of the early Carbon In Pulp (CIP) projects and thankfully now, as a matter of course, companies assay the ore for organic carbon content. The early days at Stawell Gold Mine and Macraes Gold Mine (New Zealand) were very difficult maintaining gold recovery because of preg-robbing graphite.

MISTAKE 3 – INSUFFICIENT BENCH SCALE OR PILOT METALLURGICAL TEST WORK

The undertaking of only six bottle roll tests before launching into a heap leach project (which was subsequently unsuccessful) sounds fanciful, but it actually happened. The author believes that 50 percent of heap leach projects are failures and that this is caused by too little test work being undertaken on representative samples, investigating such things as crush size sensitivity, percolation, understanding the oxygen demand, etc.

The fact that some in the lateritic nickel industry go from bench scale test work to scaling up hundreds of thousands of times is one clearly identifiable cause of those failed projects, but not the only one. The second generation plants are being pilot plant tested before going to full scale.

It is only in recent years that metallurgists have understood the laterite profile and which ores can be heap leached, atmospheric leached and that are suitable for high pressure acid leach (HPAL) or suitable for ferronickel processes.

A recent base metals project was unsuccessful as no testing of the transition ore was conducted. The geologists did not know how much there was. The test work was undertaken on the primary ore but the transition ore had to be mined to get to the primary ore – hence the problem.

A heap leach project carried out two column tests on ore that was thought to be 'average' ore. The actual mined material bore no relationship to the test ore sample. Project budget cuts caused agglomeration and conveying test work to be left out of the metallurgical evaluation so it should not have been a surprise that the plant had major issues with leach kinetics and acid consumption. It seemed that it was more important to have a good camp than a treatment process that worked.

The pilot plant for a polymetallic project discovered a fatal flaw in the project plan. The blister copper was found to be radioactive due to the ore's uranium content's daughter elements reporting in the blister copper. This necessitated the inclusion of an electo-refining step in the process flow sheet. Another benefit from the pilot plant testing was that sufficient copper concentrate was available to develop a process to remove uranium and produce a clean smelter feed.

An open cut gold-copper-zinc project in the Philippines failed and a contributing cause was that there was no metallurgical test work on the transition ore which subsequently proved to be a problem. The quantity of transition ore could not be defined and all work had focused on the primary ore.

Bacterial leach projects have suffered because of early failures due to insufficient test work or pilot plant testing, particularly over selling the technology and not fully disclosing the operability issues.

The Tennant Creek smelter failed twice because of the inability to successfully remove bismuth from the blister copper, making the product unsaleable.

MISTAKE 4 – FAILURE TO CHARACTERISE THE ORE AND INTERPRET THE RESULTS

It is often not appreciated that metallurgical laboratories test ore and provide factual results. They do not interpret the results or fit the results to a flow sheet. This resulted in the toll milling company rejecting the ore because of its high talc, high arsenic and non-sulfide nickel content.

A number of projects did not recognise the presence of soluble copper or nickel in the ore and how this would build-up in tailings returns water and leads to pyrite activation.

A number of projects have tested ores by cyanidation but not appreciated that the cyanide-soluble nickel or copper content of the ore would result in an unworkable operation. A gold project recognised the problem during the BFS, but by the time there was only high copper ore left, no solution had been developed. The project closed as a result.

Other projects fail to recognise reactive sulfides and to test for ore ageing. With base metal projects this can result in significant recovery losses.

Another project tested the pentlandite ore and the violarite ore separately and achieved acceptable recovery. In the actual operating plant, when the violarite ore was added to the pentlandite ore (even in amounts as little as 5%) the good pentlandite ore gave poor recovery. The failure here was that while the individual ores were tested the blends were not.

Similar problems have been encountered with copper oxide ores containing native copper being blended with fresh copper sulfide ores.

Column leach tests, where gold was recovered in test columns after thirty days, were not scaled up to reflect performance on heaps where the same recovery was achieved in 90 to 180 days, resulting in a much slower cash flow.

MISTAKE 5 – TEST WORK DID NOT COVER THE LIMITS

There are many projects where the grade, ore hardness and clay component of the ore has exceeded the design feed grade, resulting in the plant not being able to cope. Similarly, the mine schedule can result in large changes in ore type and extreme difficulties with flotation plants, for example.

A base metal mine was designed for low copper high zinc, but in fact it had a high copper and low zinc ore. The plant design as a result did not match the ore feed.

Ore hardness is a classic case where the plant is designed, say, for average ore with a Bond Work Index (BWI) of 18 kWh/t and for several days the plant has to treat ore with a BWI of 27 kWh/t. As a result, throughput drops significantly. There have been a number of examples where the ore hardness has increased with depth and throughput suffered as a result.

In another case the mine schedule and pit shells changed and no one communicated this to the metallurgists, resulting in a project that could not process the throughput.

The same has happened with stripping capacity in gold plants where capacity mismatches have been encountered.

There are also sometimes significant differences in treating massive ore, disseminated ore or low grade mineralised ore.

The lesson here is that while an average ore may be the basis for design it is rare for the average ore to be treated on a day to day basis in the actual plant.

MISTAKE 6 – SKIPPING STAGE GATE STUDIES

In a number of projects the owners simply wanted to ‘get the show on the road’ and are not interested in doing a Scoping Study but instead proceed straight into a BFS. The net result is that options are not looked at, the best outcomes are not arrived at and decision milestones for thorough evaluation do not exist to change the project scope. As a result money is wasted, time is saved, but the project that comes on stream has a number of problems.

The proper procedure is to undertake a Scoping Study, make decisions to stop or go and repeat this after Pre-Feasibility and Feasibility Studies.

If projects do not indicate favourable economics at a Scoping Stage there is no point going forward.

Choosing very optimistic assumptions without any factual basis in a project financial model and using this to develop a project can result in a very financially robust project on paper, which probably cannot be achieved because everything is ‘maxed’ out and not probably not achievable.

MISTAKE 7 – FAILING TO RUN THE ‘WHAT HAPPENS IF’ SCENARIOS

Many times it is said ‘that will not be a problem’ and the natural reaction is to then not address it. However, invariability such non-issues do become a problem.

Consider if critical size builds up in the mill, the ore floats are slower than predicted and the tailings water recovery is lower than predicted.

One project designed a clay washing circuit ahead of the milling circuit. Once water was added to the clay the materials handling was impossible and there was no provision to bypass. The ‘what happens if’ scenarios had not been considered. For example what happens if the ore cannot be thickened? The answer would be to put in a bypass facility. If these questions are not raised and addressed then the process plant will be deficient in performance.

MISTAKE 8 – FAILURE TO ADDRESS OPERABILITY AND MAINTAINABILITY

Sometimes not considering the prevailing wind direction can become an issue. If dust blows into the power house or the off gas from the power house blows over the Carbon In Pulp (CIP) tanks, it makes it very difficult for the operators to work on the tanks.

Other examples are having cyclone feed pumps that have no access; launders that are so flat that the solids settle before they arrive at the end of the launder; sump floors with insufficient floor slop; and insufficient bunding to cope with spills.

Also, not allowing for flotation circuit changes or splits on cells may result in the circuit being inoperable.

MISTAKE 9 – FAILURE TO OPTIMISE COMMINUTION

A plant needs flexibility for dealing with changes in ore hardness and for ore blends. Leaving out a pebble crusher for a Semi- Autogenous Grinding (SAG) mill by saying it will be retrofitted later is unwise.

Putting in a single stage SAG mill (to save capital) when a SAG-ball circuit is required is an example of false economy.

Not appreciating that the mine schedule and ore changes over time and having a strategy to deal with the changes is a mistake.

A gold project was commissioned with a SAG mill but the ore was found to be not amenable to SAG milling when the test work was finally carried out. This resulted in the SAG mill being converted to a ball mill and the installation of a three stage crushing plant. The reason given for not doing the SAG mill test work was that there was not enough time.

A number of SAG mills have proved difficult so designs have improved, including incorporating far more flexibility, including testing and circuit simulation.

MISTAKE 10 – FAILURE TO OPTIMISE FLOTATION

Poor definition of weathered and transition ore has been a major mistake in planning copper, nickel and other sulfide ore projects. The problem is that these recovery issues occur early in the project life and the lower metal recovery affects cash flow in a seriously negative way.

Not allowing for surge capacity and removing conditioning tanks to save capital are examples. Other common problems are having no back up reagent pumps resulting in no metal recovery when the lime pump blocks.

The Mt Keith froth handling is another example of poor metallurgical planning. The test work was done and the froth was firm (mainly due to the fine clays, in the author's view). Someone measured the volume of froth and divided it by the volume of slurry and called it the froth factor (being ~7 it set a new world record, but was not noticed). The sumps and pumps were subsequently oversized.

The pilot plant operation on the Bougainville copper ore identified the optimum flotation reagent. Once the operation started, however, the ore behaved differently and potassium amyl xanthate (PAX) or sodium ethyl xanthate (SEX) gave better results. The three months supply of the other reagent was never used and could not be sold.

MISTAKE 11 – FAILURES WITH LEACHING

Gold heap leaching is littered with failures, although there have been a number of very successful heap leaches. The critical issues here are crush size sensitivity and percolation issues.

The three first generation HPAL lateritic nickel projects were problematic and that is a terrible shame because the projects offered a breakthrough in lateritic nickel project development. Cawse had the best flow sheet, but failed because it was too small. Bulong failed because it had the worst flow sheet and the gypsum scale problem in the Bulong plant made things very difficult and a major problem for the operation.

MISTAKE 12 – FAILURES WITH SOLID LIQUID SEPARATION

A mineral sand project did not recognise the impact of the clays in the tailings and the presence of marcasite, which generated acid. The net effect was project closure because they were too close to the river and could not solve the potential pollution problem.

MISTAKE 13 – FAILURES WITH ROASTERS AND CALCINERS

Fluo-solid roasters require steady feed, steady sulphur levels and density, with the ability to control the temperature using water addition.

The Bogusu roaster was problematic because of insufficient sulphur in the feed and similar problems were experienced in the old Syama gold project.

Problems with fluo-solids dryers on iron ore are not uncommon. The Beenup mineral sands project fluo-solids dryer was problematic. The Coates vanadium project near Perth failed in the 1980's because of the high dust carry over which could not be managed from a fluosolids roaster.

MISTAKE 14 – FAILURES WITH PUMPING, MATERIALS TRANSPORT, DRYING AND STORAGE

Incorrect assessment of viscosity has often resulted in lower throughputs and de-rating of pump capacities. A gold project, when commissioned, could not pump the tailings away because of the very high viscosity and the pump calculations had not taken the de rating effect into account.

The fluid bed dryer at Hamersley in the original pellet plant was very problematic causing problems with dry grinding and spalling in the indurator. The problem was solved, but it took a number of years because of the variable nature of the feed and moisture content.

Many problems were experienced in diamond plants when high clay ores were processed causing major viscosity problems in the Heavy Media Separation plant and subsequently poor separation. Eventually, wet scrubbing circuits after primary crushing were used.

A manganese project was designed with pumps that were too small and operated at a high speed resulting in the pumps wearing out in a matter of days. All of the pumps had to be replaced with larger pumps operating at much lower speeds and more manageable change out times.

MISTAKE 15 – TAILINGS DISPOSAL, WATER BALANCE

The design and operating requirements for tailings dams has involved tighter design requirements. There have been issues with tailings dams leaking, contaminated ground water, etc.

At one tailings dam, the event pond was only installed after the dam overflowed and the cyanide water ran into the sea and killed fish. The resultant shutdown and government intervention was very costly for the company. If the event pond had been a part of the design, the spill would not have occurred.

MISTAKE 16 – LACK OF CONTINUITY WITH PROJECT MANAGEMENT, DATA MANAGEMENT

Generally, metallurgists come on board fairly late in a project and there is also a lack of continuity with people coming and going. As a result such projects suffer.

One engineering company had a problem with a CIP tank design which had been solved many years before. The lessons learned had been lost but fortunately one person remembered the experience and was able to ensure the mistake was not repeated.

In an expert witness case involving the author, the personnel had taken all the files and the company did not have all of the project records. Thus it was extremely difficult to defend the company on a technical basis without the missing test work.

MISTAKE 17 – FAILURES WITH MATERIAL OF CONSTRUCTION

In many bacterial leach projects, the bacteria can damage the equipment by eating the rubber lined tanks, plastics, etc. In the gold industry, Sulphate Reducing Bacteria have caused major shutdowns and tank relines within the first twelve months, despite good quality water being used.

One solvent extraction project selected the materials based on test samples in laboratory solutions. When the plant started up the corrosion was a major problem and yet the chemical analysis indicated no major change in the process solutions. Some other factor was involved causing extreme pitting and corrosion.

MISTAKE 18 – FAILURES START UP TRAINING AND COMMISSIONING

Commissioning requires extensive planning and experienced personnel. However some operations have tried to cut costs and corners and the result is that the commissioning stage is difficult.

Some projects have used local personnel, who were inadequately trained. This was particularly so for operations such as SAG milling, flotation and thickening. Flotation requires skilled operators and as such when inexperienced personnel are used the result can be high zinc losses, poor management of circulating loads and resultant low concentrate grade.

The author has seen projects cancel critical spares because the project is over budget and say they will place the orders once they have cash flow.

MISTAKE 19 – FAILURE TO UNDERTAKE A REASONABLENESS CHECK

There are a number of projects where a reality check would have revealed the tanks are all at the same level and there is insufficient fall on the tanks. It is too late when the plant is built and during commissioning the pulp won't flow through the tanks but simply overflows.

An iron ore concentrator (in about 1970) is a specific example. This was originally an iron ore sorting plant for coarse material (- 80 + 30 mm). The principle employed was the difference in surface conductivity between hematite and shale. This worked very well when pilot scale tested, but the plant did not succeed. Why? The ore tested in the pilot scale was wet screened with clean surfaces. The actual plant was all dry screening and all particles were covered with the same coating of dust, hence the surface conductivity was that of the dust, not the particle.

MISTAKE 20 – THINKING PROBLEMS CAN BE SOLVED ONCE PRODUCTION STARTS

Solving problems at the development stage are low cost, but solving problems during operation when lost mill revenue represents say $30,000/h can be very costly.

The ramp up for a gold plant might be six weeks, but for a base metals project it could be six to 12 months. For a HPAL or Pellet Plant it could be several years.

A number of hydrometallurgical projects have found recycle streams cause a build-up in impurities and this can eventually report to the product resulting in off spec products. The alumina industry has managed this issue better and better over time.

For a number of base metals projects the build-up of gypsum and scale in the process water was a major operating problem. The problem was eventually managed using dispersants added to the water.

MISTAKE 21 – NEW TECHNOLOGY AND FAILURE TO PILOT THE PROCESS

A complex base metals project initially focused on development of the Sulphide Project. The sulfide ore contains graphite, copper nickel, cobalt, lead, zinc and pyrite and is classed as a very complex sulfide ore.

There was a critical decision to subsequently focus on the oxide ore. The project was based on crushing, grinding and acid leaching the ore followed by solvent extraction, world first resin in pulp (RIP) and precipitation and electrowinning.

The company had a philosophy of doing things themselves and used second hand equipment. They used no external Due Diligence of the project as would be normal for bank financing and there was no piloting of the process. There was a disconnect between the ore tested and the plant feed and resulting flow sheet. The process flow sheet contained world first new technology. As a result of these and mitigated by the Global Financial Crisis (GFC) the project was unviable.

CONCLUSIONS

It is impossible to assume that all risks can be eliminated. However to progress, the ‘lessons learned’ need to be carried forward for the benefit of future projects. Metallurgists have their limitations solving technical issues and the classification of ‘good ores’ and ‘bad ores’ highlights this. Complex sulfide ore, refractory gold and high phosphorous ores are not simple problems to solve. This is why the Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves (JORC Code) correctly applies modifying factors to ores that may in fact be waste because of process metallurgical difficulties.

This paper has examined some of the common metallurgical mistakes in developing mineral projects. There is no simple solution and each project brings its own unique challenges, but a successful metallurgical programme requires a geometallurgical approach. This applies to sample selection, a thorough understanding of the mineralogy and carefully thought through metallurgical test work to ensure all aspects are covered. Several iterations of ore characterisation and interpretation of the test results are required to develop the Process Design Criteria and Process Flow sheet.

'What happens if' scenarios should be applied and mitigation solutions developed for all resource projects at every study stage gate.

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