DELIVERING PROCESS DESIGN VALUE TO MINING CLIENTS

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Keywords: SAGDesign Test, SAG mill, Comminution, Process Design, Production

ABSTRACT

The mining industry is well accustomed to taking the risks inherent in investing capital an orebody we can neither see nor touch. Despite this, we as an industry have often shied away from spending the upfront capital required to adequately de-risk a project. In Canada this has led to a recent history of start-ups which have failed to achieve design tonnage, and which require significant additional capital reinvestment early in their life. Diligent front end engineering, including accurate comminution testing and design work is the best and lowest cost way to deal with capacity problems. In these underperforming projects, new comminution equipment was selected, sometimes without sufficient information to design with confidence, or at other times without regard to the financial consequences of choosing undersized grinding equipment. To create the highest profitability in a new plant it is critical to understand the geometallurgical units in the ore body, and their relative expected grinding and metallurgical performance.

This presentation is intended to call attention to the value that can be gained (or losses which can be avoided) through robust engineering, application of known fundamentals, and the prior involvement of experienced engineers who can identify design mistakes before they are built. It will include a discussion of the evolution of industry best practices in design, mainly for comminution but also for metallurgical recovery plants, corporate structure, and expectation differences for junior and senior mining companies, as observed during a 55 year career by John Starkey in mining and process engineering. Common mistakes and myths at the project engineering stage will be addressed with a focus on autogenous and semi-autogenous grinding, flotation, gold leaching and iron ore metallurgical recovery circuit designs. Ultimately this presentation is intended to inform engineers, executives and investors about modern project engineering design services available in the mining industry, and how mining companies can derive maximum value from their projects through diligent use of best engineering practices.

Relevant to this, there now exists an integrated toolbox that has been under development for the past 25 years. This toolbox, if correctly used can effectively de-risk a project with respect to its comminution and metallurgical performance. Process design engineers need to lead the way by encouraging clients to do what is best by recommending programs that increase the value of a mine, instead of accepting fast track solutions which decrease the value of a new property.

INTRODUCTION

During the past decade the mining industry has seen periods of unprecedented economic activity and affluence, and more recently a return to reduced metal prices, layoffs and production cuts. Rather than criticize what has recently happened, it will be more productive to look at where we have been and compare it to where we want to go.

At a professional meeting in Timmins, ON, Canada, early in the author's career (about 1968) a phrase was used which had a profound effect on what he has attempted to do during the ensuing years. The government's area mining engineer, when speaking to the assembled group of professional engineers and geologists living in the area, declared that 'good engineering does not start until the money runs out'. The gold mines in the area were either collecting Emergency Gold Mining Assistance, or closing their plants, while Texas Gulf Sulphur had just commenced production from arguably the richest sulphide ore body ever to be found in Canada, namely the Kidd Creek Mine. The gold mines were forced to do good work because they had no choice.

Considering this statement, a lot of good engineering work should be in progress today because the global mining industry is being challenged with low metal prices and reduced incentive to invest in and build new plants. However, this does seem to be starting to happen, because despite the lack of experience that has effectively reduced the level of expertise available to design new plants, there are new and more effective ways emerging to build plants that have the potential to shape the future and benefit mineral processing as we move forward.

The need to involve well-experienced process design engineers to assist in the design of new projects has never been as important as it is today. Many opportunities exist for a new consensus to be formed centering on how to build a new plant and maximize profits from its operation and to implement new paradigms when the need to do so becomes evident.

For new plants, design parameters need to be set and followed. Starting in the mine, the production achieved, creation of a clean sustainable environment, and financial results, need to be considered and integrated. The term 'best practices' can only apply to designs and operations which have made deliberate choices to optimize these concepts, by studying, comparing and then selecting and integrating the best options. Failure to do this has led to milling capacity problems.

Indeed, the main focus for delivering value to a client comes from the fact that comminution and comminution design are intimately involved with defining the correct capital cost, operating cost and achieving the design throughput, which in turn controls the revenue that the plant will produce. Simply stated, the comminution equipment selected is the single largest driver for profitability in a new plant. On top of this, good grinding and metallurgy cannot be achieved if the tonnage fed to the plant is fluctuating hour to hour, because a SAG mill is too small.

Because of previous errors in constructing plants by choosing incorrect SAG mill sizes, whether by poor design or incorrect selection, corrective action is needed to restore owner/investor confidence in the mining industry's ability to build profitable SAG milling operations. Stakeholders need to recognize that SAG milling should be an integral part of this renaissance.

There is no doubt that there are a number of comminution methods that can be used to process a new ore body. Because SAG milling works for any ore at either low or high capacity, and for all finesses of grind, it should be considered the leading method by which other methods should be compared when starting a project. Using a SAG mill ensures that the grinding circuit will work.

However, the SAG mill circuit must be designed correctly, and the correct chamber size and motor power for the SAG mill selected must be included in the purchase order. There are reasons why this has not been routinely done. Up to about the year 2000, SAG milling was not always considered the best place to start because poor operating results, private design practitioners and mill manufacturers using proprietary design methods controlled the sizing and selection of SAG mills. Naturally, clients wanted to reliably design their own equipment but this was very difficult due to the proprietary methods being used for SAG mill circuit designs. Clients started looking for other methods that were more open and less proprietary.

COMMINUTION DESIGN

Comminution is needed at the beginning of every beneficiation process. The concentrator receives feed from the mine and delivers it to the concentration process as a finely ground product, whether it be a gravity, magnetic separation, leaching, or flotation process. The comminution energy that is required is a function of how hard the ore is, how coarse the feed coming to the SAG mill is, and also the fineness required to liberate values so that metal bearing minerals can be physically recovered after liberation. The size of the SAG mill and motor selected determines how much particle size reduction can be accomplished at the stated tonnage.

In recent years three major projects in Canada have failed to produce design tonnage due to the incorrect selection of the SAG mill (smaller than required). On average, the value of losses so created were in the order of $200,000,000 US per project. This shows that comminution design and/or mill selection is a problem for some new plants. This needs to change. Since 2015 at the SAG Conference in Vancouver, it has been recommended that grinding mill sizing, particularly for AG and SAG mills, need to be sized by an independent consulting firm and not left up to grinding mill manufacturers who supply the mills. A manufacturer has a vested interest in supplying a smaller mill at a competitive price so that his firm can win the order. This directly leads to undersizing of SAG mills and underperformance of a new plant.

Today new elements have been added to the tools available to design a new mine and mill. The invention of SPI, SMC and SAGDesign testing has created a different dynamic for the design of comminution circuits. These circuits also now include High Pressure Grinding Rolls as well as the tumbling mill options that have been used in our industry for 60 years. Other design systems have also emerged to provide confirmation of mill sizing and alternatives in the event that a local laboratory has not yet added the most accurate test methods available, to their suite of comminution tests offered. Every method has its pros and cons but this presentation will focus on methods that produce SAG mill design accuracies in the range of plus or minus 5 to 7% as demonstrated by comparing laboratory results with plant results.

This paper has also been prepared to summarize the comminution design achievements of the author during the past 55 years. The most recent test method so developed represents an industry leading, stand-alone method to design SAG and AG mill grinding plants with respect to production accuracy, time required to deliver the final mill design result and the total cost of the design testing and mill size determination. Others have done confirmatory checks of mill sizing for their projects using other methods, but in every case to date, the mill sizes and power from the new test (SAGDesign) were confirmed as correct. In addition, every project to date, designed using the new test and method has performed as intended in the plant.

The new method is patented and therefore open to public scrutiny and use. Starkey & Associates Inc. (S&A) in Canada, with partners around the globe, shares all design calculations with clients. The difference is that with the new test, ore hardness is accurately measured and the SAG and ball mill sizes required are calculated, not simulated, for both SAG and ball mills. A number of S&A's clients have realized the value offered using the new method and have designed and purchased mills using only the new method.

Accuracy and flexibility are the drivers for defining the base cost of a comminution circuit and its design. SAG testing to 1.7 mm is available with +/- 5% accuracy on the required power while the Bond Wi on SAG ground ore is about +/- 10%. Not surprisingly, benchmark results for a single stage SAG mill grinding to 75 microns is within about +/- 7% on average hardness ore. SAG mill sizing can now be measured within +/- 5% and often closer than that compared to a benchmark test result. Mills designed using the most accurate tests can thus give a good starting point for doing trade off studies using other comminution methods such as pre-crushing/SAG, or fine pre-crushing/HPGR. Either full JK Dropweight tests or SAGDesign tests including Bond Work Index tests on SAG ground ore, are recommended for final SAG mill design. No other SAG testing method can match these accuracies when testing individual samples.

The new test was invented by the author and introduced to the mining industry for the direct purpose of providing value to clients building new plants. This applies to every stage of a plant's development, from scoping level studies to final design for grinding mill purchase. Every step in the new test process is aimed at providing value to the client. This is really important because to date, every SAG mill designed using the new test method has achieved design production.

Some key factors that describe the features that were considered to be necessary for creating the best SAG test and rotating chamber type test mill possible, are listed below:

- The test mill must be designed to use any commercial exploration half cut drill core, nearly always readily available on a mine site. Additional drilling is not normally needed.

- Composite samples should represent an open pit by bench, depth, ore zone, or year, depending on the mining method and the mining sequence chosen.

- Composite samples should be selected by taking one small piece of ore from every row in a suite of boxes, to provide a composite sample that is at least 15 kg in a single 20 L pail.

- The new SAG mill should be large enough to hold enough ore for a Bond BM Wi test to be done on the SAG ground ore after the SAG test is completed.

- The new SAG test mills should be sold only to established labs which already own a Bond mill for Bond BM Wi testing.

- The batch SAG test should be done using conditions as close to commercial optimum conditions as possible. Ore is removed every 10 minutes to prevent overgrinding of fines.

- The accuracy of the test can be achieved by removing minus 1.7 mm fines from the mill at every grinding cycle. (Returning fines will create cushioning and inaccurate results).

- 11% by volume of steel balls should be added to the test SAG mill. These balls should consist of a mixture of 51 mm dia. and 38 mm dia steel balls.

- The SAG test should use 15% by volume of ore so that the volume of ore in every test is the same. This means that the grinding conditions in the mill are the same for every test.

- Total load in the test mill is therefore 26% by volume, the known optimum level for maximum throughput in a plant SAG mill running at 75% critical speed.

- Deliverables for the test should be ore SG, revolutions to achieve the specified size reduction which is then converted to kWh/t, and a Bond BM Wi on SAG ground ore

Calibrating of the SAG grinding test was done using SPI and confirmed by benchmark testing. Results showed that the kWh/t required were proportional to the revolutions in the mill that are needed to reduce the sample in the mill from an F80 of 19.05 mm to a P80 of 1.70 mm. The only difference between samples is the hardness of the ore. The equation is therefore linear. This has many added benefits when calculating the hardness of ore blends or when forecasting plant throughput when geo-metallurgical data is available as measured using SAGDesign testing.

Accuracy of the new test is plus or minus 5% for SAG mill energy as noted above and this measurement is even closer for reproducibility when retesting the same sample for SAG energy.

This is where the real value of the new test lies. It allows composite samples to be made and tested using only one test so that 10 good composite samples for a new project gives the same accuracy as other methods where 30 to 50 samples are tested. And because the hardness is measured in kWh/t, results are scalable in blending and throughput calculations as noted above.

In 2006 at the SAG Conference in Vancouver, the new test was defined as the Standard Autogenous Grinding Design test, and all the work done since has demonstrated the validity of that name. Since 2004 there have been 200 projects completed using the new test and 1080 tests have been completed in 10 partner laboratories world-wide.

In addition to the new SAG test, Starkey & Associates Inc. (S&A) has developed an empirical model for calculating the power draw in a SAG mill, based on the Nordberg power draw equations used for ball mills. Modifications for SAG mill loading were introduced which show the change in power required (B factor) in a SAG mill. The Nordberg A Factor has been adjusted to account for the higher lift in a SAG mill using square cut lifters, an increase of about 11% when compared to a ball mill. The B Factor inputs now include: ore SG, steel SG, total charge % by volume, and steel added % by volume. Also used is the C Factor or mill speed % of critical (unchanged from Nordberg), and the D Factor which is simply the length of the effective grinding length of the mill (EGL), expressed in feet, to calculate the required HP, which is then converted to kW. The equation is therefore A*B*C*D = HP.

By using these calculations, the accuracy of the mill power draw model for SAG milling has been enhanced to the point where the power draw predictions are equal in accuracy to the SAGDesign test results. This is concluded from the observations made during benchmark tests.

Not only does the new test reveal the correct power required to grind the ore similar to that tested, but the mill chosen to process the specified tonnage is also accurate to within the same tolerance as the testing. This explains why every SAG mill design to date using the new technology and the 80^{th} percentile, works as intended and produces design tonnage.

The door is now open to design a SAG mill circuit that produces design tonnage from day one. The acceptance of long startups of 6 to 12 months or more is unnecessary and can represent a massive problem in lost revenue when a new plant starts up.

There are other compelling reasons why accurate SAG.testing should be used. Design tonnage must be maintained at a stable design level if the following metallurgical processes are to be optimized (highest recovery at saleable grade - to create the highest NSR for a flotation plant). By pushing a SAG mill to the limit all the time, variable – and lower tonnes per day of ore will result. Not only that, but the maximum recovery and grade of concentrate produced, will also be lower if tonnage is fluctuating. The true effect of not designing for steady design tonnage is to accept lower t/h, recovery and grade than design. The quantification of lost value has not been calculated as yet but will be much greater than expected, considering the state of liberation of the minerals and the current metal price. This is the reason that Starkey & Associates Inc. have formed a Joint Venture with Dr. Norman Lotter's company Flowsheets Inc. - to ensure that maximum values possible are economically recovered from every ore tested and that a client receives top value for the test work and designs created by this new Joint Venture.

MYTHS

It is intriguing to note that some myths that were around in the 1960s have survived until today. The only difference is that we now know they are myths. What are these old myths?

OLD MYTHS	EXPLANATION
The ore has a critical size problem.	Not enough power for that t/h.
Increase AG throughput with coarser feed.	Coarser than 150 mm F80 decreases t/h.
Peak power equals peak tonnage.	Power peaks at 35% load, t/h at 26%.
Testing shows ore is 'amenable' to SAG.	Every ore is amenable to SAG milling.
Use representative sample for good design.	The only ore that a SAG mill will never see. Instead, design is now done on many samples in order to understand hardness variability.
Large mills break ore better than small dia.	Not true for all ores tested to date - kWh/t is the same at any diameter. This discovery allowed new progress to be made for accurate SAG mill design.

RECENT MYTHS	EXPLANATION
Add SAG EGL to apply more power.	Leads to errors when D/L is < 2 on soft ores.
Push power to maximum all the time.	Leads to overloading, less t/h, and more kW used (when 26% load is exceeded).
Transfer size (T_{80}) does not matter.	T_{80} controls power split and SAG/ball mill power. Failure to provide size control of the T_{80} is one of the biggest problems in SAG milling today.
Design by simulation and comparison.	Design by calculation. Other mines don't matter - design is based on a client's ore. New flowsheets and provision for the future can now be included.
Geometallurgy data is required for design.	Geometallurgy allows accurate t/h fore casting to be done. Good design can be done at a lower testing cost by selecting good composite samples.

MISUNDERSTANDINGS

Misunderstandings occur frequently but are difficult to discuss because of the obscurity that exists regarding best SAG mill design practices. An example comes from the way in which SAG mills are designed for the apparent lowest capital cost – with little or no regard to what operating costs will be, or what contingency should be provided to ensure that design tonnage can be achieved on a monthly and yearly basis. Selection of the hardness variability percentile for design (80th% is recommended) relates directly to the capacity contingency of the new grinding facility. A fundamental principle that was learned more than 40 years ago by the author, was to ensure that a client will always have the comminution facilities installed in a new plant to achieve design tonnes per hour at all times. That was the process design engineer's job.

Today that is not done or considered necessary with SAG milling, because a SAG mill does the job of replacing secondary crushing, tertiary crushing, rod milling and in some cases ball milling as well. The ore hardness variability for SAG milling is a much bigger component in plant throughput variability. Crushing dominates the effect on the ore hardness variability by treating ores of all hardnesses at a relatively constant throughput. The variability does not manifest itself until the tumbling mills following primary crushing are used. This is why a SAG or AG mill is so much more sensitive to hardness variability. This is also why crushing is more energy efficient than SAG milling. Ore variability can be dealt with by installing a proper ore blending facility in front of the plant as is often done to control impurities in the iron ore business, or by installing the proper SAG mill. The latter solution is much more cost effective.

This leads directly to the next and most significant problem in today's design and operation. Many engineer's feel that the best practices way to operate a SAG mill is to push its capacity to the limit at all times. This deliberately causes the tonnage to fluctuate, in some cases as much as ±20%. In a gold plant with 48 hours of retention time that may not be a big problem as long as the grind size is steady, but in a float plant that fluctuation can cause serious metallurgical losses by creating instability in the flotation circuits.

The design specifications for a process plant do not read - capacity between 800 and 1200 t/h, it is simply 1000 t/h. It is not insignificant that if this specification is properly interpreted, that the SAG mill will be larger than the fluctuating tonnage scenario. This in a nutshell is why SAG mills are often too small and design capacity so difficult to achieve.

If the ore sent for processing at startup is harder than normal, design tonnage will be impossible if the process design specification has not been properly implemented. If the tonnage specification is respected, the SAG mill will be larger and starting up at design tonnage will be easy. When common sense, accurate hardness measurements and sound engineering calculations to determine mill sizes are implemented, the task of starting a plant at design tonnage is easy.

Another misunderstanding comes from the use of inaccurate testing to determine ore hardness, and the test result being in some other units than t/h. Until measuring SAG pinion energy for a sample in kWh/t is standard, the design exercise will be difficult. Numerically speaking, when kWh/t are measured, the results can be combined proportionally on paper or by testing of the same blended proportions to give the same test result as the calculation. This has been proven in the laboratory. By using outdated measurements and overly complicated computational techniques, we have effectively blocked the path to a rational understanding of numbers to allow intuitive and effective decisions to be made by the engineers at a mine who are charged with making the mine to mill process work. If only those with vast experience in the field can perform the design work then new inductees to the industry will be ineffective for a number of years. The design methods must therefore be simplified to the point where everyone in the business can properly design a SAG mill. Until this is done the mistakes will continue.

The most astonishing misunderstanding of all is to ask why the financial drivers for a new project are so flagrantly ignored. In a Feasibility Study, capital costs, operating costs, revenue, discounted cash flow and rate of return are all calculated, as if these numbers are precise. They are not. Greater accuracy in ore hardness measurement creates better forecasting of revenue.

Finally, if the capital cost of the selected grinding equipment will not deliver design tonnage, then there are two additive errors in the DCF calculation. More capital and less profit to repay it.

BEST PRACTICES

In this paper the corrective actions needed to avoid failed cash flow prediction are alluded to. To indicate the magnitude of the problem, eleven start-ups are listed below. This is not a complete list. It includes only those plants of which the author is aware of the details at this time.

PLANT	RESULT
Mercator, USA	Tonnage achieved using used mills.
Tenke Fungarume, DRC	Tonnage achieved at start up.
Tabokoto, Mali	Tonnage achieved.
Climax Molybdenum, USA	Tonnage achieved. (Starkey, Meadows, Senchenko, & Thompson)
Alexandrovskoe, Russia	Tonnage achieved on hard ore. (Kulikov, Senchenko, & Starkey)
Beleya Gora, Russia	Tonnage achieved on soft ore. (Kulikov, Senchenko, & Starkey)
Lake Shore Gold, Canada	Tonnage achieved in three weeks. (Felsher)
Detour Lake, Canada	Tonnage achieved after conveying issues resolved.
Osisko Malartic, Canada	Pre-crushing added. (Osisko Annual Report, 2013)
Copper Mountain, Canada	Pre-crushing required. (Vijfeijken, Filidore, Walbert, & Marks)
Mount Milligan, Canada	Pre-crushing required.

In summary, the first eight plants (above) measured SAG mill design pinion energy and hardness variability in kWh/t, while the last three did not.

Today, there is variance in opinion regarding what constitutes best practices for SAG mill circuit designs. It is reasonable to say that to qualify as 'best practices' a new SAG mill circuit should start up at design tonnage and produce the design product sizes in each stage. There are recent start-up examples where this has been done, so this goal is achievable.

However there are secondary forces at play: the cost of doing the design work and the time to get it done. Spending lots of money is not a guarantee that the design will be correct. It can be said with confidence that the money must be wisely spent on accurate test work suitable for greenfield project development. But testing is not everything, process and ancillary design is important too.

Designing comminution equipment using geo-metallurical testing is possible, but using highly focused accurate testing of composite samples is better and less expensive. However, design and geo-metallurgy are quite different exercises in scope, in elapsed time to create the data, and in cost. Geo-metallurgy is an excellent way to forecast and control tonnage fluctuations in a process due to ore variability, but in most cases is not required for design because many more samples are required, the cost is much higher, and the time to complete the work can be unacceptable, especially if there is a queue for new SAG mills at the mill manufacturer's facility. That is not the case today but 5 years ago in 2011, manufacturing queues were common.

When gathering ore hardness variability information for design, it is prudent to use a hardness test that is suitable for the samples selected and to include the most accurate test available. Some tests are best suited to point samples while other tests are excellent for measuring the hardness of composites as well as point samples. Some methods are limited by ore hardness or small core diameter. It is best to use a test method that has no restrictions.

It has been shown that when kWh/t are reported as the test result, the blending of these numbers produce the same result on a blended sample as is derived from calculation, as long as the measured test parameter and conversion to power equation are also linear. However, when the test result is non-linear when plotted against kWh/t, the blending on paper may not match the testing of the actual blended material. In this non-linear case, the results are not really suitable for easy and accurate geo-metallurgical modelling and mistakes in design can also result.

If the inherent accuracy of the test being used for final SAG mill design is not within plus or minus 5% of the true value, as confirmed by benchmarking, it is not the best practice considering that this level of accuracy is commercially available (Starkey and Larbi). When requesting a quote for test work services, the vendor should be asked to provide proof that the test work accuracy and number of tests is sufficient for the work being done. If it is not, another source of testing supply should be sought including changing the test method used and adjusting the scope.

There are two parts to SAG mill design best practices after accurate testing is done. First is to choose the SAG mill (chamber size and power discussed above) that will process the design feed every day, including those days when mostly hard ore is available. Secondly, other engineering decisions need to be made to complete this start-up target. Most important is the addition of screen classification in the plant to control the transfer size (T_{80}) that the SAG mill produces. A good rule of thumb is to use a screen with slotted opening width of 3 times the desired particle size (F_{80}) needed to feed the ball mill. A way to sample the SAG mill discharge must also be provided. The actual P_{80} leaving the SAG mill trunnion, needs to be measured daily on start up so that proper SAG mill operating adjustments can be made. Failure to provide this sampling point adds months to the time required to properly operate the SAG mill. Other parts of the engineering process design are also critical, such as getting the correct pumps, cyclones and conveyors, to run trouble free, with proper allowance for circulating loads, operating room and maintenance access.

The last item of Best Practices is not to by-pass the final steps required prior to purchasing the grinding mills. The fact is that some mills are chosen because the cost was determined during the Feasibility Study and there is no time available to confirm that the mill size is adequate prior to purchase. When this happens, the whole project is put at risk because the required extra capital to buy the correct mill can be multiplied by 10 to provide the required adjustments to capacity by retrofitting after start-up, and the operating costs after a retrofit could be higher as well, especially if high steel is needed in the SAG mill. There are professional services available where mill size and power can be verified to within 5% of actual requirements in less than 2 months, so there is no reason for not confirming a mill size prior to mill purchase. It represents money well spent. The cost of retrofitting the plant, lost production and possible legal fees and damages for a failed design will make checking worthwhile for everyone concerned.

CLIENT EXPECTATIONS

The client's expectations used to be simple and straightforward: start on time, with no budget overrun, and achieve design tonnage immediately. But over the years the concept of "Production Ramp Up" gave credence to starting up at lower tonnage and today the term has become "Normal Production Ramp Up" as was seen in the write ups from a recent Canadian project that did not come close to achieving design tonnage on day one.

For those who have never witnessed a project starting up on time, on budget, at design tonnage and with no capital revisions, the author confirms that this has always been possible. Kidd Creek in Timmins, ON, Canada (rod/ball grinding) started at full tonnage on day one in 1966 and did not shut down for 30 days. In 1979, Gays River lead zinc (rod/ball grinding) started on time, at design tonnage during the first two weeks and 10% under budget. The Lake Shore Gold startup (2014), is an example of a good recent SAG start-up, and is referred to above.

SAG milling is different than crush/rod/ball milling and has taken a longer time to become reliable technology. During the last 20 years it has been replacing rod/ball grinding for new projects because the lower ore grades now available must be mined at higher tonnages to be profitable. At the same time the expertise to design and operate these SAG plants needed to be developed. Private technologies for SAG mill design have not helped yet have dominated the market prior to 2000. The first fully open design technology for SAG mills was invented in 2002 and was first offered commercially in 2004 as a patented design method. Only in the last 5 years has this open technology come into widespread use. It is not surprising that clients trust no one, buy the cheapest SAG mill available, and use trial and error methods.

In the past, the way to correctly operate a SAG mill was not fully understood. High loading of the SAG mill, and high power usage were thought to produce higher tonnage. On hard ores this is not true and leads to misjudging of the capacity of a given SAG mill which may have the required power for more tonnes but not the chamber size to use it productively to increase throughput. For original lifters, the phenomenon of maximizing tonnage at 26% load and 75% critical speed is now becoming accepted by mill operators and designers, except in Chile where some operators prefer more aggressive design conditions, including high steel loads but the economic justification for this choice has not been publicly documented and may not pass the scrutiny of full economic evaluation. Costs come in two forms, capital and operating costs. If additional capital reduces operating costs, the magnitude of each must be included in the study and the influence of these cost changes on revenue and overall profitability need to be evaluated as well. Because lack of capital is such a big issue, and SAG mill performance is not well understood by many, the proper economic evaluations are not being done. Great harm can result.

SAG mill liners are chosen to produce best results at the selected speed, usually 75% of critical. Vari-speed mills are necessary to protect mill liners from steel ball damage when treating intermittent soft ores, and are also chosen for convenience. Because the SAG mill lifters are designed for a specific speed, the mill does not grind effectively at other speeds. This has been confirmed in recent operating plants where it was discovered through analysis of operating data, that changing the mill speed destabilized the operation and caused lower tonnage to be processed. The point here is that client expectations need to be guided by reliable facts and proper information.

Client structure is an issue because there are typically two types of clients. First are the major industry players who build concentrators to run them and make a profit. Included in this group are intermediate producers who are usually very capital conscious, but are also interested in making maximum profit. These producers often have in-house technical groups who take responsibility for the processes that they build.

There is also a second group of clients, usually, but not limited to junior exploration or operating companies, who are building the concentrator in order to sell the property, or for internal reasons do not maintain an expert process design group in-house. In these cases the selection of a competent consulting/engineering house is really important. It is probably more cost effective if the process design consultant is not part of a large engineering house. But times change and effective engineers change employers, so each decision is really a point in time decision to select a firm that will deliver a competent process design for a reasonable price. For a company without an internal design group, the choice of a skilled design consultant is recommended.

The goal here is to have sufficient expertise involved so that the really bad equipment selection decisions are avoided. Skilled consultants can add great value to a project by forseeing future changes and making provision for these changes in the original equipment selection.

TOOL BOX

A modern metallurgical design tool box, or method by which a new mine and mill to recover metals from ore can be effectively developed, include four major items. They are: 1. Representative sampling; 2. SAGDesign Testing - to correctly define the size and power for SAG mills and ball mills needed for the project; 3. Modern mineralogy – to determine the liberation and amounts of the ore minerals present and 4. High accuracy flotation testing – to determine through testing the exact flowsheet configuration required.

Other tools are added to this list as needed and include GRG determination, gravity and magnetic separation testing and gold leaching testwork, all similar to what is now normally done for the recovery of gold, silver, iron, tin, base and rare earth metals.

FINANCING

At this time it is suggested that some owners and investors are unhappy because financial losses in cash spent to fix capacity problems and project value caused by incorrect mill selection are measured in the order of hundreds of millions of dollars. The problem is part technical and part administrative. It is recommended that project managers need to insist that technical reports on mill sizing be implemented, or if the mill sizing reports do not exist that they be generated. If administrative and technical experts do not correct this problem immediately, regulatory government measures and penalties could follow for future projects. It is astonishing that professional societies or government agencies have not become involved already considering that much financing for mining projects comes from the public investment sector.

Project financing, tonnage treated, revenue from production, capital and operating costs, are all things that are required to be defined in a credible Feasibility Study. If the design tonnage is not possible to achieve, and more capital needs to be spent to achieve this level of production, what is the significance of the discounted rate of return that is so meticulously calculated for every new project as if it were true? If the financial parameters cannot be defined accurately, then the whole purpose of doing a financial analysis is pointless.

With the implementation of strict project definition and financing controls, the casual way that these discounted cash flow numbers are used will rapidly become a thing of the past. Since it is now possible to measure ore hardness within 5%, it is also possible, with a reasonable understanding of the mining methods to be used, to measure the overall ore hardness of planned mill feed and purchase a SAG mill that is big enough to grind the required tonnage. It is inconceivable that this lack of financial and technical discipline will be allowed to continue. If the mining industry does not make this happen for the benefit of the investors, then those investors will ensure that larger and more sophisticated entities will purchase the mines and enforce the disciplines that are required to give shareholders their share of the rewards for finding and bringing a new mine into production. Financial entrepreneurs thrive on seeing opportunities and making good things happen, for them and for the things that they invest in. If this happens it is unlikely that it will be beneficial to the people who work in the mines.

Required information that is beyond the scope of this presentation, includes calculating the impact of errors in mill design on DCF and revenue, for current improperly designed projects. The basis should be actual results studied in the context of published 43-101 reports. It is already known that the magnitude of revenue shortfalls and capital overruns add up to astonishing totals. Unfortunately this is money that comes directly from shareholder value, dividends and/or bank loans. Instead of returns, the shareholders are being asked to either invest more or suffer dilution because of this revenue shortfall. Either way, it is unacceptable.

CONCLUSIONS

It is now possible to design and start-up a SAG mill at design t/h from day one.

Independent consultants/engineers should design SAG and AG mills.

SAG and AG mill design is a big professional responsibility. Today, passing responsibility for the design is the easiest way to avoid taking the responsibility, and this is why design work is often referred to manufacturers.

A paradigm shift in how SAG mills are purchased is required. Owners should never ask a mill vendor to size the SAG mill because the owner's interest in making design tonnage at all times may not be respected. If the price is not low the vendor will not win the order. Having mill vendors design SAG/AG mills leads to undersizing and lost revenue for a client.

Engineering companies need to be more independent and either retain proper design consulting expertise or provide training for their staff to do the SAG mill design job properly. Excellent SAG mill design courses are available.

With the advent of highly accurate ore testing comminution and metal recovery processes that allow a new plant to be built that works as intended, the importance of using highly accurate process design methods has become an urgent priority.

The cost of a poorly designed SAG mill to an owner is so large that it cannot be ignored. Adequate SAG mill design work must be done prior to initiating the project because it is not possible to conduct a meaningful financial analysis for a project unless the SAG mill has been properly designed to deliver the design t/h - and revenue.

To speed up the confirmation of mill sizes before purchase, the most sophisticated and accurate hardness measurements must be used, regardless of what data was used in the feasibility study. Because +/- 5% accuracy is available, the confirmatory tests required can be restricted to ten and can be completed in less than two months.

Consulting engineers can deliver great value to a client's project by using the most accurate testing methods available and choosing the grinding mills prior to the project being given to an engineering company. Then the bids for the grinding equipment will be comparative for the required equipment. A manufacturer can always propose a lower cost alternative but only as an optional extra.

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