RESOURCES EFFICIENT MINING PROCESSES OF TOMORROW

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ABSTRACT

In the face of increasing energy costs, limited water resources, more stringent legislation, and lower feed grades, the mining industry is searching for more sustainable technologies and practices. Metso Process Technology and Innovation (PTI) is undertaking a research project, Improving the resource and eco-efficiency of mining operations, to help the industry meet these challenges. The project is investigating alternatives in mining and processing that reduce energy and water consumption, minimize emissions and waste, and maximize the value recovered from the deposit. The targets are to reduce energy usage by more than 30%, and greenhouse gas emissions by more than 50% compared to current practice. This paper discusses the investigations and key findings from the project so far; highlighting the possibilities for reducing energy consumption, water usage and carbon emissions. Mining processes of the future may incorporate any combination of the alternatives identified, and require tailored solutions based on a detailed understanding of the ore deposit, the process and local conditions. The focus is on improving resource efficiency; creating more value with less impact, and consequently a better economic return from the available resource. Technologies that exist today can transform mining into a more efficient industry for tomorrow.

KEYWORDS: eco-efficiency; energy; water; greenhouse; mining; processing.

RESUMO

Em função do aumento do custo energético, da escassez d’água, das restrições ambientais e da redução nos teores de alimentação, a indústria mineral busca tecnologias e práticas mais sustentáveis. O departamento de Tecnologia de Processos e Inovação (PTI) da Metso está conduzindo o projeto Melhorando os recursos e eco-efficiência de operações mineiras para auxiliar a indústria a atingir estes objetivos. Este projeto investiga alternativas no mineiro e na usina para reduzir o consumo de energia e água, além de minimizar a emissão de gases de efeito estufa e a geração de rejeito, o que maximiza a vida útil do mineiro. Os objetivos são reduzir o consumo de energia em 30% e a emissão de gases causadores do efeito estufa em mais de 50% em comparação com as práticas atuais. Este artigo apresenta os estudos e as principais conclusões, destacando as possibilidades para reduzir o consumo de energia e de água e a emissão de gases causadores do efeito estufa. As operações do futuro podem incorporar qualquer combinação das alternativas identificadas e exigem soluções personalizadas com base na compreensão detalhada do corpo de minério, da rota de processamento e das condições locais. O foco está na melhoria da eficiência dos recursos; criar mais valor com menos impacto, e, consequentemente, um melhor retorno econômico do recurso disponível.
Tecnologias que existem hoje podem transformar a mineração numa indústria mais eficiente no amanhã.

**PALAVRAS-CHAVE:** eco eficiência; energia; água; gases estufa; mineração; processo.
1. INTRODUCTION

The mining industry is facing growing challenges associated with the cost and supply of energy, limited water resources, and more stringent legislation. Estimates of the energy consumed by the mining industry in South Africa, Brazil, the USA and Australia range from 3 to 7% of each country’s total energy production (Carvalhoa and Millarb, 2012). Correspondingly, industry emission of greenhouse gases will also be significant. More than half of the total energy consumption in the industry is associated with transportation of ore and its subsequent comminution. Processing is also conventionally performed wet, and often only 40 to 50% of the water is recovered from tailings, resulting in water consumption of between 0.5 and 1.0 m$^3$ per tonne of ore processed (Wiertz, 2009). To address these challenges, Metso PTI is conducting a research and development project entitled Improving the resource and eco-efficiency of mining operations. The aim is to investigate alternative technologies and practices in mining and processing that reduce energy and water consumption, minimise emissions and waste, and maximise the value recovered from the deposit. This paper discusses the investigations and key findings of the project to date.

2. OVERVIEW OF A RESOURCE AND ECO-EFFICIENT MINING PROCESS

Novel application and adaptation of existing technologies are proposed in a conceptual resource and eco-efficient mining process. Conventional and the proposed eco-efficient routes are compared in Figures 1 and 2.

A resource and eco-efficient mining process may incorporate high intensity selective blasting (HISB) to improve blast fragmentation and reduce energy consumption in downstream comminution. Pre-concentration could be implemented to discard barren material in the pit or just prior to comminution circuits. New comminution circuits may include alternative energy efficient and dry technologies such as vertical roller mills (VRM) or high pressure grinding rolls (HPGR) and air classifiers. Conducting flotation at coarser size could reduce the energy consumed in the previous grinding. Finally, filtration and dry stacking of tailings can significantly reduce water consumption, with a much higher recovery of water than can be achieved from a traditional tailings dam.

![Figure 1. Conventional process.](image)
2.1. High Intensity Selective Blasting (HISB)

Blasting is the first stage of size reduction in most mining operations, and is the most energy efficient and cheapest comminution stage. Increasing blasting energy even further combined with advanced electronic initiation systems is expected to provide another step change in energy efficiency. With the use of electronic detonators, it is now possible to achieve high intensity blasting without increasing dilution or causing wall damage. The blast can be designed to focus the resulting stress waves and increase micro fractures along the mineral grain boundaries. These micro fractures are expected to reduce comminution energy and increase metal recovery. The Run-of-Mine (ROM) top size may be decreased to below 400 mm compared to traditional ROM top sizes of about 1 to 1.5 m. Benefits include: maximisation of system throughput (mine and mill), increased excavation and loading efficiencies, better overall process stabilization, and minimisation of the overall operating cost.

2.2. In-Pit Crushing and Conveying (IPCC)

In-pit crushing and conveying (IPCC) is the use of fully mobile, semi-mobile or fixed in-pit crushers coupled with a conveyor system and spreaders and/or stackers to remove material from an open-pit mine. These systems are more energy efficient than traditional truck and shovel operations. The main advantages of IPCC are low operating costs, reduced manning requirements and high capacity. The benefits depend on the site conditions; however, operating costs are typically 20 to 60% lower than a truck and shovel system, with a fully mobile IPCC system (Foley, 2012). In addition, reduction in greenhouse gas emissions and improved safety are also growing drivers for IPCC. Studies have indicated large potential reductions in greenhouse gas emissions of 100,000 to 150,000 t CO2/y (Koehler, 2010). Conveyor belts require only about 20% of the energy needed by heavy-duty trucks (International Mining, 2009).

However, IPCC requires careful evaluation of geological, technical and economic factors specific to the operation. The capital cost is higher for IPCC, but is typically paid back within four or five years. (Carter, 2010).
2.3. Pre-concentration

The aim of pre-concentration is to remove barren material at as coarse a particle size and as early in the process as possible. This can reduce the energy and water consumption of downstream processes and ore transport requirements such as hoisting and truck or conveyor haulage. Pre-concentration significantly improves resource efficiency by upgrading below cut-off grade material and/or increasing production rates. There are several technologies that may be applicable for pre-concentration, such as gravity separation, screening and sensor based bulk ore sorting. Their suitability depends on the ore properties.

In existing operations with fixed plant capacity this can increase production, reducing the costs and energy consumed per tonne of product. Net Present Value (NPV) analysis for a 200 million tonne copper deposit with a fixed plant capacity of 40,000 tpd, 0.52% copper feed grade and 15 year mine life, demonstrates that incorporating a bulk ore sorting plant to upgrade the feed grade to 0.62% copper may improve the NPV over the life of mine, (Figure 3).

In new operations, the size of downstream processing equipment can be reduced (reducing the capital and operating costs), or the production rate can be increased.

The environmental footprint of the mine is also reduced due to lower energy consumption, greenhouse gas emissions and water losses per tonne of product.

2.4. Comminution circuits and technologies

Comminution is the most energy intensive part of mining operations, consuming as much as 70% of the energy in conventional circuits (Norgate and Jahanshahi, 2011). Therefore, improving grinding efficiency has the potential to result in significant energy and cost savings.

2.4.1. Fine screens for improved classification

Historically, closed ball mill-cyclone circuits have been the industry standard, and it is well understood that both classification efficiency and circulating load have a major effect on their performance. Sharpening classification and increasing circulating load should improve grinding circuit capacity. However, the potential to increase
classification efficiency through cyclone optimization is limited, with the maximum improvement estimated to be about 7% (Morrell, 2008). On the other hand, a circuit with screens rather than cyclones may have 15 to 20% higher capacity at significantly lower circulating load due to higher classification efficiency. The economic viability of replacing cyclones with fine screens was evaluated for a small scale (1.5 Mtpa) gold ore operation by Jankovic and Valery (2012). The NPV analysis (Figure 4) demonstrated that fine screens could be justified at energy costs of around $US160/MWh or higher if energy savings of 15% or greater are achieved. Benefits are even greater when the valuable mineral is higher density than the gangue; for example, capacity may be increased by as much as 50% for magnetite ores (Nunna et al, 2014).

![Figure 4. NPV of replacing cyclones with fine screens for a small scale (1.5 MT/Y) gold ore operation (after Jankovic and Valery; 2012).](image)

2.4.2. Alternative grinding technologies

The performance of grinding circuits can also be improved by increasing the efficiency of the comminution technology. Vertical Roller Mills (VRM) and High Pressure Grinding Rolls (HPGR), such as the Metso HRC, are widely recognised as energy efficient comminution technologies, offering low overall circuit specific energies in comparison to conventional tumbling mills. In addition, these are dry processes, thus reducing water losses. They use no grinding media, which reduces embodied energy and may in some cases improve flotation performance due to the reduction of galvanic interactions on particle surfaces. HPGR and VRM can both potentially operate in similar roles, from final stages of crushing through to grinding applications. However, very little testing has been done for this type of application for mineral ores.

A pilot-scale HPGR was used to test and evaluate a number of circuit configurations at Metso PTI’s facilities in Sorocaba, Brazil. The circuit options were evaluated in terms of energy efficiency, throughput and size reduction. The best configuration was found to depend on the relative priorities of product size distribution, energy consumption, circuit capacity and costs for a particular operation (Jankovic et al, 2013).

Pilot scale testing of a VRM was also conducted using the same feed material as used in the HPGR and air classification tests above. Comparison with the energy
requirements of a ball mill indicates the VRM is likely to be 25 to 40% more energy efficient to achieve similar degree of comminution. In addition, overflow mode VRM are recognised to be more efficient than airflow mode (used in the pilot trials), and should provide even greater energy savings. Given the potential energy savings and other benefits, further investigation is warranted.

2.4.3. Eco-efficient comminution flowsheet

Stirred mills are proven to be more energy efficient than conventional ball mills in fine grinding applications, and HPGR studies (e.g Rosario and Hall; 2008) have reported direct energy savings of around 10 – 20%. Metso PTI believes that novel flowsheet arrangements using energy efficient comminution technologies such as HPGR and stirred mills have the potential to significantly reduce the energy consumed in comminution. A circuit consisting of HPGR directly feeding a stirred mill such as the Metso Vertimill was first suggested by Valery and Jankovic (2002). Further reduction in energy consumption may be achieved by replacing cyclones with fine screens, as discussed previously for ball mill circuits. A flowsheet which combines high efficiency comminution and classification devices (as shown in Figure 5) could reduce energy consumption by more than 50% compared to conventional tumbling mill based circuits.

![Energy efficient comminution flow sheet](image)

Figure 5. Energy efficient comminution flow sheet.

2.5. Coarse particle flotation

Flotation is not an energy intensive process, but if coarser particles could be recovered by flotation, less power would be required for the preceding comminution stages. If flotation could be performed at 0.3 rather than 0.1 mm, the energy savings in comminution would be around 30 to 50%. This will depend on liberation; but similarly to pre-concentration, a coarse flotation stage could be implemented to reject barren material and reduce the amount of material requiring fine grinding.

Research by Metso PTI using a 3m³ flotation rig has shown that turbulence can have a detrimental impact on coarse particle recovery and suggests there is potential for improving flotation by manipulating turbulence and pulp rheology (Tabosa, 2012). Further studies indicated that coarse particle recovery in the froth zone was significantly lower than that of finer particles. This suggests that the best means of increasing coarse particle recovery is to operate a flotation cell under conditions...
which maximise froth recovery and minimise turbulence at the pulp / froth interface (Tabosa et al, 2013).

2.6. Water recovery optimization

The mining industry typically consumes 0.5 to 1.0 m$^3$ of water for each ton of ore processed by flotation (Wiertz, 2009). Most of the water losses in mining are from tailings dams in evaporation, entrapment and seepage. Plants typically recycle water, and improvements in thickener technology, including paste thickener technology developed in the 1990s, have improved water recovery. However, there is a limit to what can be achieved, and water balances indicate that as much as 70% of the water discharged into conventional tailings dam can be lost.

Dry stacking of filtered tailings is becoming an increasingly common consideration. To date, dry stacking of tailings has only been implemented in a small proportion of operations due to the high cost associated with filtering tailings. However, industry sources suggest that within ten years legislation will prohibit the deposition of wet tailings in some countries (Jameson, 2013). Environmental benefits of dry tails stacking include substantially reduced water requirements, decreased risk of groundwater contamination, reduction in environmental footprint, and improved site rehabilitation potential. The risk of catastrophic failures of storage pond walls is also eliminated, while reclamation and closure costs are significantly reduced.

3. ESTIMATION OF BENEFITS

The estimated energy savings are shown in Figure 6, broken down by activity, for each component of the process. The breakdown of energy by activity for the conventional process is based on an average from mining operations (BCS, 2007). However, this breakdown varies considerably for different operations, and subsequently the energy savings will also depend on the particular operation. A conservative estimate of the total energy saving is over 35% compared to a conventional process.

![Figure 6. Estimated energy savings from a resource and eco-efficient mining process.](image)
4. CONCLUSIONS

The focus of a resource and eco-efficient mining process is to improve resource efficiency; maximising the recovery of value from an ore deposit, while reducing impact. Inherently, improving the efficiency of the overall operation will reduce costs, energy and water consumption, and reduce emissions per tonne of product. This improves the economic returns of the operation while reducing environmental impact. The best solution for a particular operation will require tailored solutions based on a detailed understanding of the deposit, process and local conditions. Mining operations need to operate more efficiently to meet environmental targets, but also to remain economically viable. Improving the resource efficiency increases the economic return of the project, and can make the difference between a project being viable or not.

5. REFERENCES


