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Mining technology – trends and development

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17 Mining technology – trends and development

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Mining is still done following the same process steps as in the 19th century: drilling, blasting, ventilation, this step only underground, loading, and transport to crushing and mineral processing. A batch process, which is no doubt, being scaled up continuously but is still based on the step wise batch process. There is a need for serious R&D work both from within the industry and with state support in order to speed up technological development and find new solutions to develop a contomuous mining process.

17.1 Number of mines

The total number of mines in the world is huge. However, the exact figure is, to a large extent, dependent on how a mine is defined. In China, for example, it is reported that there are over 8,300 iron ore mines (and this after the closure of a number of small operations in recent years). Only 48 of these mines are classified as major operations, although the smaller of these (less than 1 Mt/y of ore production) are small in global terms. The group of 'medium-sized' mines in China consists of 60 operations. The remaining 8,200 iron ore mines produce, on average, only 15,000 t/y (less than what the Morenci open-pit copper mine in Arizona can produce in 20 minutes). An even higher number of small-scale coal mines are in operation in China and India. Small-scale gold mining is another example, with thousands of artisanal mining operations spread all over the developing countries.

If these small-scale mines are excluded, and only 'industrial-scale' operations are counted, there are some 2,500 metal-producing mines in the world. There are no reliable figures for industrial minerals and aggregate quarries. However, in the US, there are some 100 metal mines, 900 mines and quarries producing industrial minerals, and 3,320 quarries producing crushed rock. Assuming that there is a similar relationship elsewhere, there would be some 25,000 mines in the world producing industrial minerals and almost 100,000 quarries producing aggregates for construction purposes.

17.2 Underground/open pit

Of the total number of metal mines some 52 % are open-pit operations, 43 % underground operations and 4-5 % are placer or tailings operations. Of total tonnages handled some 85 % come out of open pit operations (including placer operations), 15 % from underground mines. There is a debate going about the increasing or decreasing share of underground operations but so far there are no factual indications of an increasing number of underground mines. During the last decade of the 20th century and the first decade of the 21st century there has been a slow trend recently towards open-pit production. Two of the most important reasons for this are:

- *Lower ore grades*. Due to depletion of the richer ore bodies, the higher-cost underground extraction methods are not economic.
- *New technologies*. The more efficient exploitation of lower-grade deposits using new equipment (such as the hydrometallurgical SX-EW methods for copper extraction) has enabled companies to work economically on lower grades than traditional methods.

17.3 Size

Global metal ore production is around 6 000 Mt/y. Open-pit mining accounts for some 83 % of this, with underground methods producing the remaining 17 %. Waste production from underground operations is small, not exceeding 10 % of total ore production, but the waste production from open-pit operations is significant. Open pits typically have a strip ratio (i.e. the amount of overburden that has to be removed for every tonne of ore) of 2.5. Based on these assumptions, the amount of waste produced can be calculated as some 10 000 Mt/y. In total, the amount of rock moved in the metals mining business globally is hence around 15 000 Mt/y. The dominance of open-pit operations stems, to a large extent, from the necessary removal of overburden (which is often, but not always, drilled and blasted). By necessity, the open-pit operations are larger than the underground ones.

Mines, as opposed to other industries' production facilities, cannot be relocated following a merger. Further, the geological characteristics of a mine often limit the potential to increase production and hence, after a merger of a company with two competing mines, one cannot simply be closed down and the production of the second doubled. This means that it is more difficult to reap advantages of scale of production in mining compared with other branches of industry. Indeed when mining sectors such as zinc and copper are studied in detail, and the size profile of the individual mines is compared over time, it is seen that there was limited growth in scale between 1996 and 2001 – in spite of the merger and acquisition funds being pumped into the sector.[1] The situation is a bit better for copper, partly due to a massive wave of new investments in large-scale open-pit mines over the same period.

17.4 Technological review

Technological developments in recent years have been based on a couple of main strategies:
- Scale up of equipment
- Automation of processes
- Continuous processes

Scale up of equipment has been based mostly on the development of the giant oxide ore copper open pits in Latin America and elsewhere. The lower grade of the ore has made it necessary to move increasing larger volumes of ore and waste. In the Kennecott mine in Utah alone almost 100 Mt of ore and an additional 200 Mt of waste is handled every year. This requires bigger trucks, shovels and other equipment.

[1] Ericsson, M., Consolidation – A way forward for the zinc industry? presentation at the 47th session of the International Lead Zinc Study Group in Stockholm, October 2002.

The automation of mining has been brought forward primarily by a small number of companies with underground mines in high labour cost countries: LKAB in Sweden, Inco and Falconbridge in Canada. The progress has been slow but steady and at present the Kiruna mine can be remotely operated in almost all steps of production. These developments require large deposits with fairly continuous ore bodies such as the iron ore in Kiruna. These mines require a highly skilled workforce where a miner often has an engineer's training.

The hydrometallurgical processes first introduced in copper production (SX/EW, solvent extraction electrowinning) and later in nickel (HPAL, high pressure acid leach) are perhaps the prime examples of the development of continuous "chemical processes" specifically for mining and mineral processing in recent years. The new advanced nickel projects in Australia might not yet have been completely successful but no doubt has the technological barriers in this area been greatly reduced. The introduction of hydrometallurgy into copper processing took perhaps 50 years or even a little more. For nickel the time lag was greatly reduced to perhaps 10-15 years. The next step for zinc ores could be even quicker.

In addition to these trends, there has also been strong pressure on manufacturers to deliver technologies and equipment that are safer and less polluting. Together with evolutionary improvements in reliability and availability, both technical and organisational, productivity as gradually increased during recent decades.

In 1998 the National Mining Association in the US organised a so-called "Crosscutting technology road mapping" workshop. This was followed by a work shop establishing a roadmap for exploration and mining in May 2001[i]. The purpose was to identify barriers and technology options, to specify technological requirements, set priorities and establish research pathways in three areas:

- Exploration and resource characterisation
- Mining
- Mineral processing

The resulting documents give important hints where technology developments might take the industry in the next 20 years.

17.5 R&D priorities

Some of the key areas for future R&D efforts are:

- Ability to work in thin veins and seams
- Linking collection of data on minerals and geological structures with production
- Minimize waste
- Roof stability

In general the demand for lower emissions to the environment means that greater emphasis is placed on how to dewater, transport and store all types of wastes, which most probably will also affect the choice of equipment used. The typical batch wise process, which most mines follow with drilling/blasting, ore transport followed by a continuous mineral processing circuit might not be as dominating in the future as it is today?

As discussed above the quick developments in hydrometallurgy is projected to continue also in the next decades. The case of hydrometallurgical zinc processes might be the prime example of new technologies that might revolutionize the industry both in terms of where production takes place (new technologies could make hitherto unprofitable deposits economically viable) and what process equipment is used. The limits between the various unit operations which are today well established and clear cut: drilling, loading, blasting followed by transport to crushing and grinding might be replaced with more emphasis being put already at the drilling stage of making sure that the fragmentation achieved is suitable to the mineral processing the ore will treated with at a later stage.

Some important changes are noticeable. The number of mines producing less than 0.5 t/y of gold has been cut to less than half of the total. Gold is a by-product for many of these mines, but some are pure gold producers. The fall in the number of mines continues for producers up to 3 t/y, and above this level there is an increase in the number of mines in each size bracket. When looking at the volumes produced, the changes are clearer, the size distribution of gold mines has been pushed heavily towards the bigger operations, even if the average size has not increased that much. As but one example, the mines producing more than 15t/y have increased their production by almost 30% between 1995 and 2001.

17.6 Mining

Drilling and blasting is the most frequently used method of removing ore from the bedrock, and will undoubtedly remain so for many years to come (at least for hard rock). This is technology which has been developed by evolution over the centuries. It is not continuous and very often also closely embedded in the macho culture of a traditional tough and rough miner. In dimensional stone quarries, where fragmentation should be avoided, alternative methods have been developed and there is a possibility some of these might be applied to traditional ore mining.

In other applications, such as shaft sinking and raise developments, mechanical rock excavation is already a competitive alternative. But, in actual production, it is only in mines with soft and non-abrasive bedrock and minerals, such as potash and coal, where these methods have gained wide spread acceptance. In these established applications the tabular form of the deposits is an important prerequisite for their successful employment. Recent developments in hard rock cutting have however made substantial progress, and it is reasonable to believe that the mechanical methods will gain wider acceptance in the mid-term future. Particularly in narrow vein and reef mining, where more selective methods will create less waste rock, and hence less pollution, and at the same time lower dilution and hence increase capacity of the mineral processing plant. Furthermore, the continuous mining methods will give great economic benefits and also reduce risk for accidents.

The traditional drill and blast cycle can also be perfected by introducing various methods of fragmentation control and blast design to create rock fragments specifically designed to suit the next step in the beneficiation chain. The use of specifically adapted explosives and the mechanisation of charging and wiring up are other areas of likely technical progress in the next decade. Entirely new methods, including electric and ultra sonic energy or high voltage pulses to generate plasma in the rock and explode them from within, are however far from becoming feasible to use on a large scale with acceptable economic results.

The increased size of equipment for open-pit mines has been based partly on the development of the giant oxide ore copper open pits in Latin America and elsewhere during the mid and late 1990s. The lower grade of the ore made it necessary to move increasing larger volumes of ore and waste. In the Kennecott mine in Utah, for example, almost 100 Mt of ore and an additional 200 Mt of waste is handled every year. This requires bigger trucks and shovels etc. Seen over a long perspective, such development has proceeded in steps, which was particularly intense in the late 1990s and early 2000s. The pay load of trucks has increased from around 200 t in 1990 to almost 350 t. At the same time the installed power has increased by a similar factor. In just the past five years, the bucket volume of wheel excavators has increased from 25 m^3 to over 40 m^3. Bucket volumes of hydraulic excavators has undergone a similar development, while for dragline buckets the pace has been slower increasing (by some 5%) in the same period.

17.7 Mineral Processing

Comminution developments in recent decades have, to a large extent, been focusing on improving energy efficiency and reducing the amount of fine particles produced and hence reducing waste. Gravity separation has been further perfected using centrifugal forces but there remains considerable amount of research to understand the importance of the various parameters involved. The development of various sensors will be important (for example to determine the degree of liberalisation during milling and monitoring the performance of a flotation cell).

With the lowering ore grades and the demand for reduced waste volumes, as well as the increasing complexity of many ores, it will become crucial to develop equipment and technologies (perhaps even including new unit operations) that can perform these tasks and a least partly improve total recovery while minimising energy input and waste output. The system approach will have to be integrating both mining and mineral processing to find new solutions to problems arising.

17.8 Research and Technical Development

Research and technical development (RTD) will become one of the prime competitive factors in the dawning 'new mining industry'. But how much RTD is actually done by the mining companies and the suppliers?

The following comments are based on the R&D Scoreboard prepared for the UK Department of Trade and Industry. The report has been published regularly since 1991 and is acknowledged as the premier source for RTD and related data.[ii]

The analysis is based on annual reports of the companies studied (for details about the methodology please see the full report). There are certain definitions and conventions related to mining industry:

- Surveying and prospecting (‘exploration’) activities of commercial companies are almost entirely excluded from RTD.
- Investigation of proposed engineering projects (‘feasibility study’ in this volume), using existing techniques to provide additional information before deciding on implementation, is not included.

- Construction and operation of a pilot plant is a part of RTD as long as the principal purpose is to obtain and to compile engineering and other data 'for a new process/product'.
- For large scale projects and costly pilot plants, only the additional costs due to the prototype nature of these products are included in the RTD expenditure.

The 2003 report covers RTD spending for the top 700 international and 700 UK companies. Minimum RTD spending required for entry was £34 million for international companies and £30,000 for UK companies.

Selected results from the 2003 study:

- Total RTD-spending was £206.7 billion for the 700 international companies.
- Total sales of the same companies were £4,807 billion.
- Accordingly RTD-intensity (RTD as a percentage of sales) was 4.3%.
- No mining company was included in the international list because of the minimum limit of £34 million.
- Four mining companies were included in the UK-list:
  - Total RTD-costs for these companies were £35 million.
  - RTD-intensity was 0.23%.
  - The top single RTD spending company was Ford with £4.8 billion.

The study also report RTD spending by industry sector. Commodity-related industry RTD-intensities for the 700 international companies were:

- Chemicals 4.3%
- Steel and other metals 1.2%
- Forestry and paper 0.7%
- Oil and gas 0.5%

Mining, based on the UK-list, only reached a meagre 0.23%. Is this sufficient to meet future challenges?

A successful mining company should maintain a balance between its investment in the future such as RTD, exploration, capex, marketing and M&A-activities. The balance between these activities differs for different industry sectors. In the DTI study there was no details about the mining sector.

- RTD institutes in mining and minerals processing is one area that national governments can influence to improve the competitiveness of its domestic mines. It is also one of the areas where mining companies can benefit from increased size. As in the rest of the mining world, there has also been co-ordination and concentration in the global world of applied mining research. There is still important research being done at many of the traditional school of mines around Europe, the US and in other countries (such as Chile and the former centrally planned economies), but a handful of institutions are quickly becoming global leaders in the relevant fields of science and research. To mention some of the most important: Mintek and CSIR Miningtek in South Africa, Camiro (Canada), CSIRO and Amira in Autralia, MIRO (UK), the Minerals and Metals Innovation Cluster (MinMet) in Sweden.

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