Innovation in mineral processing technology

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Abstract

Declining metal prices over the last few years have reduced the number of new metallurgical plants being built and limited opportunities for introducing new processes. However, technological advances are still being made. With increasing economic pressures, the emphasis is now on reducing unit costs by making equipment larger and through use of technologies with lower operating costs. This trend can be seen in the increasing size of grinding mills and flotation cells used in recent plant designs and in the adoption of HPGR crushing as an alternative to SAG milling.

Few new technologies achieve widespread introduction until there are clear economic or operational drivers such as:

- increasingly stringent environmental standards;
- availability of exotic materials for equipment construction;
- increasingly sophisticated instrumentation and control systems;
- the need to treat increasingly refractory oretypes; and
- the length of supply routes to many new plants.

As a result of these drivers, a number of new and revitalised technologies will get increasing prominence in the design of new operations:

- use of MIM's IsaMill for treatment of refractory gold ore concentrates;
- use of thiourea as an alternative for cyanide in sensitive locations;
- novel hydrometallurgical routes for treating base metal ores in remote locations;
- paste thickening for tailings deposition; and
- intensive cyanidation of gravity concentrates.

Introduction

Innovation in the mining industry

Historically, technological innovation in the mining industry is characterised by periods of rapid change followed by consolidation (and stagnation).

The erratic development of technology in the industry has been driven by a number of factors:

- The pace of innovation is driven by opportunity
  - NZ Gold Rush → cyanidation, Brown agitator/pachuca
  - Broken Hill discovery → flotation
  - Gold Standard removal → CIL/CIP
- Many technologies are launched into the wider industry fully formed following extended testing in niche markets e.g. SAG Milling, HPGR
- Major innovation is revolutionary not evolutionary
  - gravity treatment → flotation
  - vats → pachuca
  - 4 stage crushing → SAG Milling
  - Merril-Crowe → CIP/CIL
- Slow initial take-up then rapid spread, for instance while the first flotation patent was issued in 1860, there was no commercial development of the technology until 1904 in Broken Hill

Over the last 25 years there have been a number of major technology advances in gold and base metals processing that have had widespread impact across all sectors of the industry or have had a significant impact on one sector. Particular examples are use of:

- activated carbon based gold recovery systems (CIP, CIL and Heap Leaching);
- SAG milling in place of multi-stage crushing;
- pressure oxidation for refractory gold ores and more recently for base metal sulphides and nickel laterites;
- bio-oxidation for copper and refractory gold ores;
- new flotation cell designs such as columns and Jamison cells; and
- new smelting technologies – AusSmelt/ISASMELT.

Adoption of these technologies, together with increasingly sophisticated automated control systems, instrumentation, and computer modelling techniques, has resulted in a dramatic change in the way processing plants are designed and operated.

The rapid change in technology has been driven by:

- surges in commodity prices that provided increased profitability in gold and base metals;
- new low-cost treatment methods required to treat large South African tailings dumps;
- rapid development of the West Australian Greenstone Belt;
- the need to treat increasingly complex oretypes which required new extraction techniques; and
- the need to update and expand existing facilities with new generation technologies.

Development was facilitated by a number of specialised industry-linked research institutes such as AMIRA and MINTEC, plus innovative approaches by mining and engineering companies to new technical issues.

So where are we now?

Declining metal prices over the last few years has resulted in far fewer new deposits being developed, which in turn has slowed the rate of new technology introduction. Pressure on operating margins has changed the emphasis to reducing capital and operating costs through increasing unit sizes and refining operating practices, rather than development of new technologies with inherent technical and commercial risks.

New mine developments in Asia, South America & Central Africa are away from traditional technically strong mining areas (SA, Aus, US, Canada & Western Europe). Development in technologically "remote" areas tends to result in a conservative approach to design.

Economic head grades have dropped and the size of process plants have increased significantly, requiring focus on availability and operating costs. With increasing plant size and capital, the cost of failure is very high.

The consolidation of the mining industry resulted in an entrenchment of the status quo. Fewer people mean fewer ideas and less growth.

Therefore, this is a period of relatively low technology change!

However, not all is "doom and gloom" - there are still some key drivers for technological change- decreasing margins, increasingly stringent environmental standards, increasingly refractory oretypes, and the physical isolation of many new plants all provide a major impetus for developing new technology.

In addition, the availability of exotic materials for equipment construction, increasingly sophisticated instrumentation and control systems, and on-going industry sponsored R&D creates opportunities for advancing new technology.

Recent technology change

Over the last few years there have been a number of trends in the development of new mineral processing technologies that include:

- use of bigger high capacity equipment – mills, flotation cells;
- development of ultrafine milling equipment for regrinding of base metal concentrates - MIM's 'Isamill';
- novel hydrometallurgical routes for treating base metal ores – low pressure copper leaching, nickel laterites, copper Biox;
- paste thickening for tailings deposition; and
- improved cyanide recovery systems for environmental emission control and high usage refractory ores.

There are also a number of new technologies which are not yet in widespread use, but which are likely to make an impact:

- adoption of high pressure rolls (HPGR) for hard rock crushing/milling;
- ultra-fine grinding plus intensive cyanidation for refractory gold concentrates; and
- use of thiourea as an alternative for cyanide in sensitive locations.

In this paper the focus is on two areas:

- increasing equipment sizes, particularly SAG and ball mills and flotation cells; and
- the introduction of new comminution technology including HPGR's and the IsaMill.

Increasing equipment sizes

Improved mine optimisation techniques, with better linkage between milling costs and mine cut-off grades, have resulted in a reappraisal of a number of low-grade disseminated orebodies. Due to economies of scale, increases in mill throughput result in a reduction in unit milling costs; lower milling costs allow lower cut-off grades and stripping ratios for open pit mines. Providing the reduction in total per-unit operating costs with increasing mill throughput is greater than the reduction in per unit revenue resulting from lower feed grades, net revenue per tonne treated will increase. This net increase in revenue must be offset against higher capital costs as throughput increases.

For some orebodies, where there is a steep grade/tonnage relationship, the increase in net revenue per tonne of extra ore treated can be much greater than the NPV value of the additional capital required to treat the extra ore. In these cases, throughput optimisation will result in relatively large operations that require increasingly large equipment.

As a result, equipment unit sizes offered by suppliers have increased significantly over the last few years. Two areas where this is particularly apparent are dramatic increases in size of SAG mills and flotation cells.

SAG and ball mills

Large mills offer significant economies of scale and simpler plant designs when compared to multiple lines of smaller mills. Maximum SAG mill sizes increased rapidly from the 34' (9.75m, 6 MW) units that were routinely installed 10 years ago to the 40' (12m, 20 MW) Cadia mill commissioned in 1998.

While larger, 44' (13.4 m, 30 MW) mill designs have been proposed by suppliers, none are in production. Limitations associated with manufacturing processes and transport of components will probably restrict further increases in mill size beyond about 44' for some time.

Ball mill sizes have also increased rapidly (Table 1). Stress levels increase more quickly in large ball mills than large SAG mills due to the higher ball charge and greater length to diameter ratio. As a result maximum power inputs are typically half that of SAG mills. High stress levels in mill ends, is one of the main reason why shell supported mills are finding favour.

The Cadia SAG Mill is the largest yet installed (Table 2, Figure 1).

Flotation cells

Flotation cell capacities have increased dramatically over the last 30 years (Figure 2). All major manufacturers now offer large high capacity "tank" cells. Currently 160 m^3 cells are the largest offered, although 200 m^3 units are currently being developed. This may be close to the maximum size physically possible due to the limitations of belt drive systems (gearbox drives are feasible though posing problems with potential for oil leakage).

Scale-up using these large cells has generally been successful provided there are sufficient tanks in series to avoid bypassing of material. However it is possible there may be problems with very large blown cells due to bubble coalescence.

Year Installed	Power (kW)	Maximum Ball Mill Size (m)	Drive
1988	4,000	5.5 x 8.5	Single Drive
1998	9,000	6.7 x 10.5	Twin Drive
1998 +	14,000*	7.9 x 12.2	Twin drive or Gearless.

* (Current limit of gear drives)

Table 1. Maximum installed ball mill sizes.

	SAG Mill	Ball Mill
Motor Power (MW)	20.0	8.75
Diameter - inside liners (m)	12.0	6.5
Length - belly inside liners (m)	6.1	11.0
Length - centre line (m)	8.5	11.0
Trunnion diameter (m)	2.2	2.4
Speed (fraction critical)	0.78	0.74
Ball charge volume (%)	8-12	33

Table 2. Cadia mill specifications.

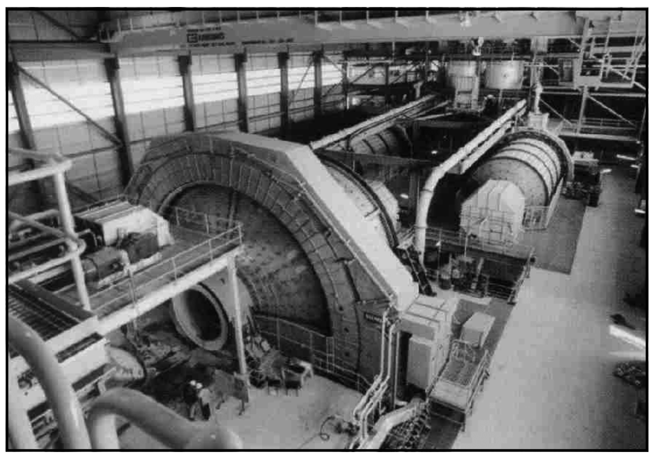

Figure 1. Cadia SAG and ball mills.

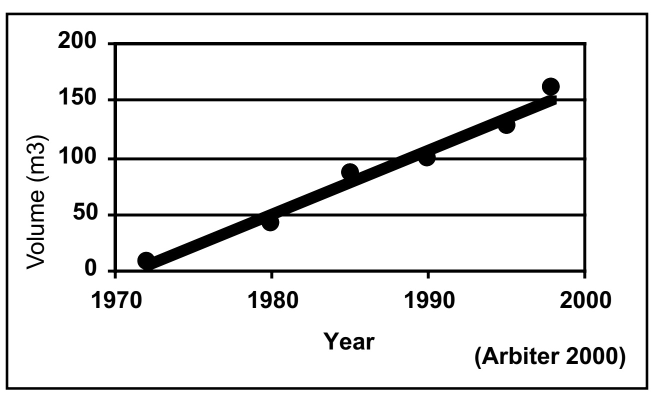

Figure 2. Increasing flotation cell capacity with time.

Figure 3. Tank cell installation.

Large single-spindle “tank” flotation cells (Figure 3) offer increased throughput and simpler flowsheets, when compared to conventional banks of cells with multiple agitators.

Technology developments

High pressure grinding rolls

High pressure grinding rolls (HPGR) are an autogenous crushing system based on “interparticle breakage” in a packed bed. The key elements of a typical HPGR unit are shown in Figure 4. The machines consist of two counter rotating rolls held in a heavy-duty frame. One roll is held fixed, while high crushing forces up to 300 MPa, are applied by hydraulic rams through the other movable roll shaft.

The crushing action occurs in a packed bed between the rolls. As rock is drawn between the rolls they are forced apart until the interparticle crushing force balances the hydraulic pressure on the rolls. The rock is compacted into a cake that has a bulk density of between 80-90% of the true rock SG.

Crusher throughput is a function of final cake density, moisture content, roll width, roll speed and gap. The gap is a function of rock initial bulk density, moisture content & crushing pressure.

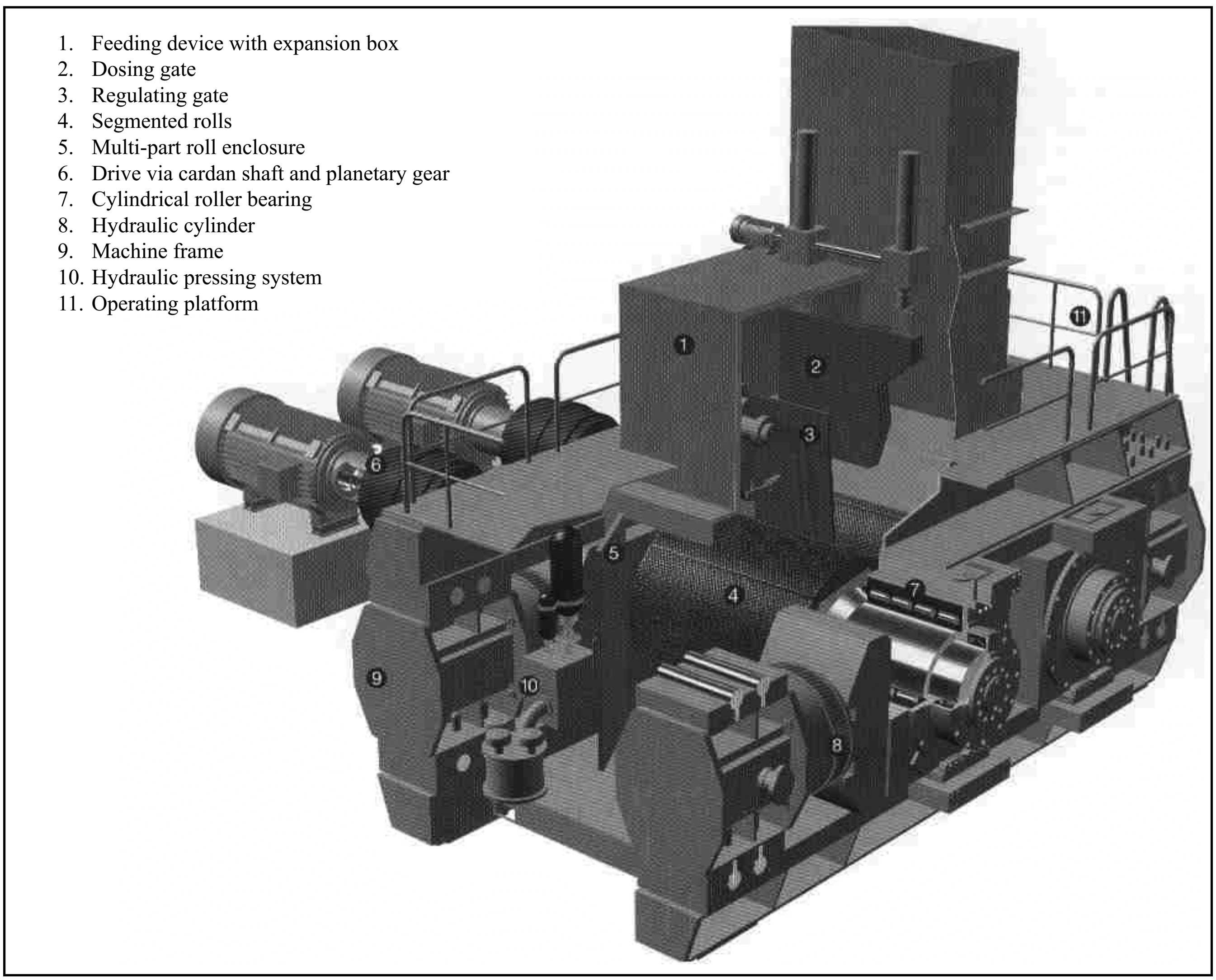

Figure 4. HPGR cutaway.

Size distribution from the crusher is bimodal - with a large proportion of fines being produced together with a coarser fraction of relatively uncrushed material from the edge of the rolls. To gain the best efficiency the crushers are generally operated in closed circuit with a screen or classifier to enable recycling of the coarser fraction.

The high crushing forces cause fracturing within particles (Figure 5). These fractures lower the Bond Work Index by 10-15% for subsequent milling and provide increased contact area for improved leaching performance when treating gold ores.

Power efficiency is much higher for HPGR based systems than for “conventional” (3 stage crush/ball milling or SAG milling) comminution systems. Specific power requirements for an HPGR/Ball Mill circuit are compared to those of a SAG/Ball Mill circuit in Figure 6.

The reduction in total communition power is a function of the size at which the HPGR circuit is closed and can range between 70% and 50% of the equivalent SAG mill circuit (finer screen/classifier closing sizes result in a better power efficiency).

While total purchased equipment costs are similar, installation is relatively simple, so total capital costs for a HPGR based comminution system are lower than for an equivalent SAG Mill based system. Overall operating costs are significantly lower than for SAG milling due to the reduced power usage and lower wear and grinding media costs.

While use of High Pressure Grinding Rolls (HPGR) has been established in the cement and diamond industry since the early

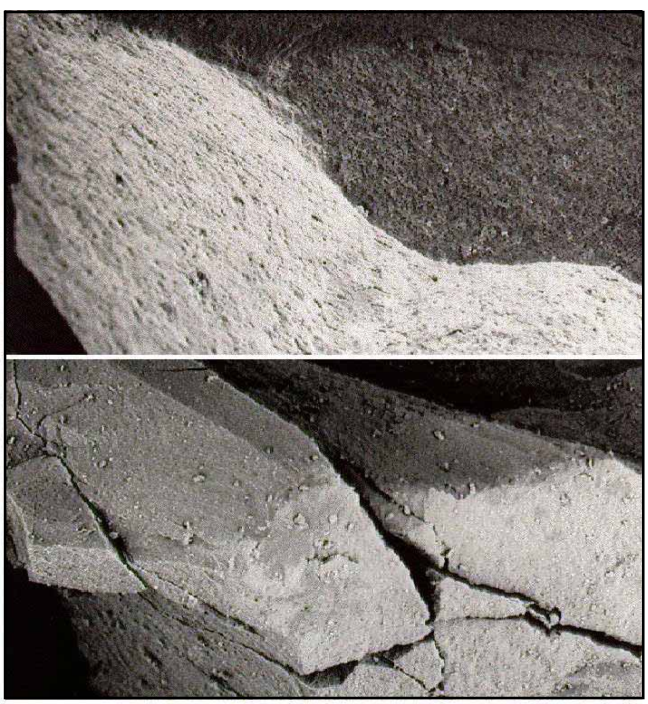

Figure 5. Conventionally crushed rock (upper) and HPGR product (lower).

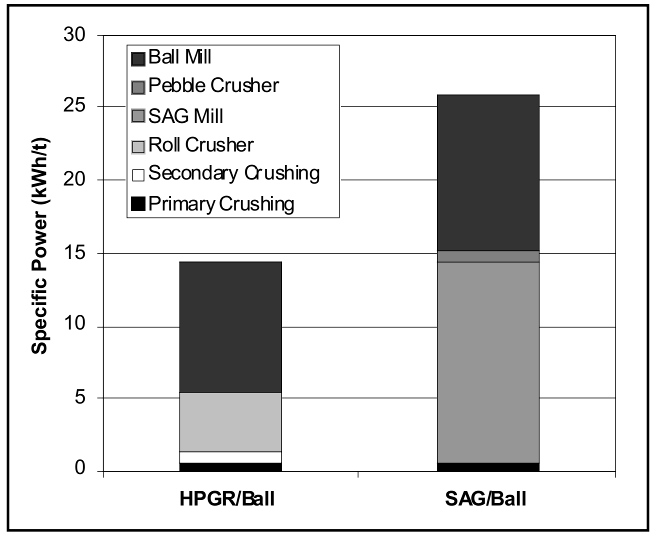

Figure 6. HPGR/ball mill and SAG/ball mill specific power.

1980s, use in mainstream ore milling applications has been limited due to high roll wear rates until development of stud roll liners by KHD (Figure 7). Crushed rock forms a cake between the tungsten carbide studs to provide an autogenous wear surface, greatly extending roll life.

Following development of the stud roll liner system usage has extended into the iron ore industry in crushing taconite ores prior to beneficiation and in preparation of pellet feed. Use in gold and base metals applications has been limited, although it appears that a HPGR based milling system may be used at Boddington if the basement ore project goes ahead.

There are currently two suppliers of HPGR units, Krupp Polysis and KHD Humboldt Wedag, who have a slightly different approach to machine design. KHD use wider lower diameter rolls whereas Krupp Polysis use larger-diameter narrower rolls. KHD have control of propriety stud systems, however they license their system to Krupp Polysis.

IsaMill

The IsaMill is a high-speed stirred mill, which developed by Mount Isa Mines to enable ultrafine (-10mm) regrinding of unliberated sulphides at an industrial-scale in continuous mill. It is an adaptation of a small laboratory scale batch mill developed by Nietze. MIM’s technology sales group markets the mills.

The key elements of the mill are shown in Figure 8. The mill has a rubber-lined cylindrical grinding chamber with feed and discharge lines at each end. Rubber lined discs are mounted on a shaft running through the chamber, as is a media separator at the discharge end of the mill. The shaft is coupled to an electric motor through a gearbox.

Slurry feed plus make-up media is fed to the mill under pressure. The movement of the revolving discs causes

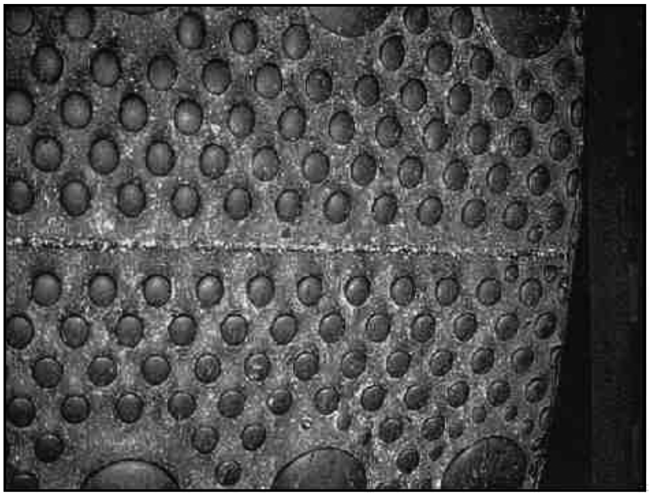

Figure 7. Stud roll-liner.

agitation of the media and attrition grinding of the feed material.

A variety of materials can be utilised as media including mill scats, screened sand or slag and ceramic beads. Media is sized for the specific milling duty – finer media is used for finer feeds. The product separator is the key to efficient operation, allowing ground product and a minimum of media to exit the mill.

Currently only a 3 m^3 mill with an 1100kW drive is available.

Maintenance of the Isamill is simplified by rail mounting of ends and is similar to a large pump. All wear parts are rubber lined and are easily replaceable. The mill shell can be split to allow relining with a new liner sleeve.

Installation costs are minimised due to simple foundation requirements.

High grinding efficiency is gained through:

- ability to use finer media;
- low probability of short circuiting of feed to the discharge;
- full use of mill volume since the mill operates under pressure; and
- the high power intensity of the mill due to the small mill volume and high speed disc operation.

Power efficiencies are an order of magnitude better than competing technologies such as tower mills. Further, the ability to use cheaper non-metallic grinding media and to grind far finer offer further process and cost benefits over traditional fine grinding technologies.

Mount Isa Mines have 12 mills installed at their Mount Isa (8) and McArthur River (4) lead/zinc concentrators. A single machine has also recently been sold to KCGM for regrinding of gold concentrates.

The IsaMill currently largely services a niche market for regrinding lead-zinc flotation concentrates within Mount Isa Mines. Acceptance of the technology has been slow outside MIM due to the sole supplier status of the equipment and potential conflict of interest issues with MIM. However, the main long-term opportunity may be in regrinding gold flotation concentrates prior to intensive cyanidation. This is currently being appraised by a number of Australian companies.

Relevance to the New Zealand mining industry

New Zealand has a strong history of innovation in the mining industry. Recently, the incorporation of a pressure oxidation circuit at Macraes shows that New Zealand operators are capable of successfully running leading edge technologies. New Zealanders are by nature innovative and adaptive; the "No. 8 wire approach" is often what is required for solving problems when developing or implementing new technology.

While New Zealand is a long way from the traditional centres of the mining industry, new technology is often developed

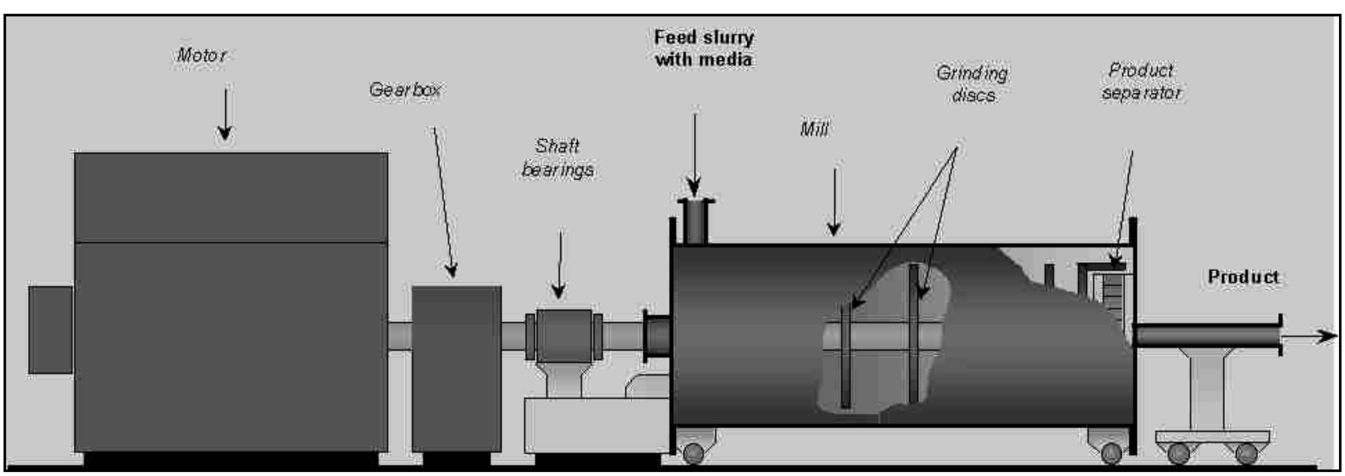

Figure 8. Isamill cutaway.

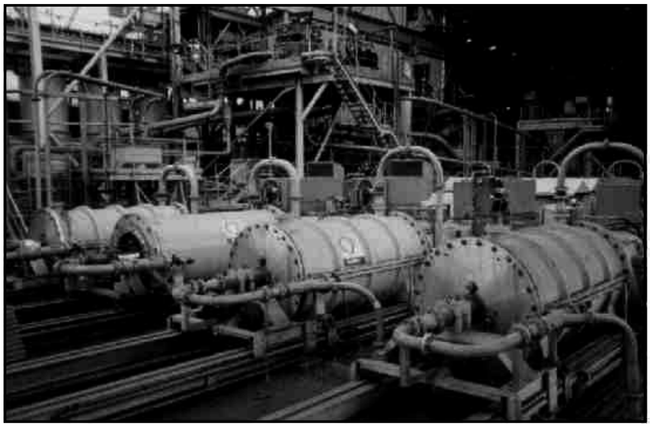

Figure 9. Isamill installation.

and/or adopted at the fringes of the industry. Special needs require special answers, so use of new technology is often the only alternative to making projects viable.Economic cut-off grades drop with improvements in technology. Therefore it is necessary to regularly reappraise the resource base to test viability based on an appreciation of the latest technology. However in order to appreciate the current technology trends there needs to be interaction with the wider industry to maintain an inflow of information.

One possibility to improve the inflow of knowledge may be to place an increased focus on technical content of industry conferences and seminars to attract some of the large pool of off-shore based locally-grown expertise.

Author

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