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Title:
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Date:
2013-02

Citation:
Batterham, R. J. (2013). Major Trends in the Mineral Processing Industry. BHM Berg- und Hüttenmännische Monatshefte, 158 (2), pp.42-46. https://doi.org/10.1007/s00501-013-0109-0.

Persistent Link:
https://hdl.handle.net/11343/282921

Major Trends in the Mineral Processing Industry

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Received 26 August 2012; accepted 20 September 2012

Abstract:
The paper starts by considering the broad framework of the industry, and in particular whether the current boom in production and the threatened shortages of certain strategic minerals are likely to lead to scarcities. The paper suggests that shortages are unlikely and that minerals will become even more widely available and at lower cost. That said, energy and maintaining the license to operate will drive the introduction of new technologies.

Using copper as an example, we point out the inevitable lower grades that will be processed and for ever lower selling prices in real terms, as has happened for centuries. Technological innovation is the driver of these trends, and the paper highlights several areas where significant changes are poised to occur: in pre-conditioning and in minimizing grinding by removing gangue at coarser sizes earlier in the flowsheet; in recognition that the excessive energy used in comminution may be largely caused by the formation of force chains that bear the load and resist breakage events; and finally, two developments by Jameson [1] for more energy efficient fine particle flotation and a significantly new concept for coarse particle flotation to 1400 micron.

Keywords: mineral processing trends, comminution, flotation, coarse gangue removal

Aktuelle Trends in der mineralverarbeitenden Industrie

Zusammenfassung:
Zunächst werden allgemeine Aspekte der mineralverarbeitenden Industrie betrachtet; insbesondere die Frage, ob der derzeitige „Boom“ bei der Produktion und die drohende Knappheit bestimmter strategischer Mineralien eventuell zu Engpässen führen könnten. In der vorliegenden Arbeit wird die These aufgestellt, dass Engpässe unwahrscheinlich sind und dass mineralische Rohstoffe zunehmend zu niedrigeren Kosten verfügbar sein werden. Außerdem werden Energiefragen und die Erhaltung von Betriebsbewilligungen die Einführung neuer Technologien vorantreiben.
Am Beispiel von Kupfer wird auf die unvermeidliche Verarbeitung armer Erze und auf die stetig sinkenden realen Verkaufserlöse verwiesen, was bereits seit Jahrhunderten zu beobachten ist. Technische Innovationen treiben diese Entwicklungen voran. Einige Gebiete, in denen wesentliche Veränderungen zu erwarten sind, werden in der Arbeit vorgestellt:

- Reduktion des Zerkleinerungsaufwands durch frühere Abtrennung von grober Gangart,
- Bedeutung des Kraftflusses über Materialbrücken für die Zerkleinerungsenergie,
- Aktuelle Entwicklungen von Jameson bezüglich der Flotation im Fein- und Grobkornbereich (bis zu 1400 µm).

Schlagwörter: Mineralaufbereitung - Trend, Zerkleinerung, Flotation, Bergevorabscheidung, Stammbaumentwicklung

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Introduction: the Economic Drivers of Technology

There have been many suggestions that some minerals are likely to be in short supply in the near future and that action may be needed to prevent undue market influence by any country with a near monopoly (as with rare earths). Equally, a perceived rise in demand for electric vehicles is seen by some as unsustainable in the light of available supplies.

To quote the European Commission [2]:

> *"Access to commodities and raw materials is essential to maintaining the productive capacity of the economy and securing the well being of citizens… The challenge is to ensure that commodity and raw materials needs are met in a way which supports wider goals for development in source countries, environmental protection, open trade and stable markets which do not pose risks to the wider economy."*

The European Commission is more concerned with financial dealings that can distort the market than with the fundamental availability. Essentially, there are substitutes for any mineral in terms of its application, it is ultimately about price. The EU report [2] lists 14 materials that are considered critical in terms of supply, mainly because their production is from a handful of countries. The materials include cobalt, platinum group metals, rare earths, tantalum and tungsten. As is listed in the table in the appendix ([2], p. 21), all 14 critical materials are substitutable.

Similarly, the UK House of Commons Select Committee on Science and Technology looking at strategically important metals [3] noted that most strategic metal reserves are unlikely to run out over the coming decades.

For the more common minerals associated with the common metals (copper, aluminium, iron), demand is expected to increase significantly, e.g. the prediction that copper demand in the next 25 years will equal all that previously mined.

Fig. 1. Predictions of copper usage into the future [4]

The justification for this escalation in demand flows primarily from economic development around the world.

Fig. 2. Intensity of use of certain commodities as a function of GDP [5]

The Rio Tinto data in Fig. 2 shows how as GDP per capita rises, so various commodities plateau in their demand. This is a trend that has been evident for over 200 years and is unlikely to change significantly in the next few decades. Whilst substitution and recycling will inevitably increase, primary demand from developing economies seems unstoppable.

The more recent Club of Rome report [6] is less dogmatic about predicting dire shortages as with the first report [7], but does carry an appropriate warning on the importance of energy and suggests that we will not see significant reduction in emissions before 2030. One can question as to why the earlier Club of Rome work was so far from the reality: petroleum did not run out in 1992, nor did natural gas in 1994. The reality is that technology advanced very considerably. Horizontal drilling for gas and oil and deep-sea platforms were simply not envisaged by the Club of Rome.

The lesson here is that the predicted consumption of raw materials over the next 25 years can be viewed as quite plausible and that it will drive, as has happened in the past, the inevitable onward march of technology. When one considers the fall in real prices of commodities over long periods of time, the inevitable reason is that despite increasing demand and falling grades [8], technological innovation drives the costs down.

Fig. 3. World copper price and production [9]

This long term trend of falling prices in real terms can only be due to the scale of operations and to technological developments. As is well known, ore grades are also falling on a long term basis and mines are becoming more complex.

Fig. 4. Copper mining is becoming more difficult and grades are falling. [10]

The only limitation to this inevitable decline in real prices is short term supply and demand balances and how long it takes in such a capital intense industry that mineral production is for any new development to be widely employed. For major developments such as open pit mining, flotation and solvent extraction coupled to electro-winning, the average time for a technology to spread was of order 15 - 30 years.

We conclude from the macro-economics that there is no foreseeable shortage of key minerals, and technological developments will continue to reduce the long term price of commodities in real terms.

Industry Consolidation as a Driver of Technology

Industry consolidation has been significant in recent years. The top 4 companies constitute of order 40 % of the 40 largest mining companies [11]. With such consolidation and the fierce competitive pressures the question comes as to whether having a handful of large players increases the likelihood of major advances in technology or not. Certainly, from one point of view, the major players have more resources to bring to bear on the many challenges. The major players, however, also have more opportunities that work against technology development. The time taken for major new technologies to be embedded into process plants is long.

The conundrum here is that while larger companies have more capability of undertaking breakthrough innovation and technology development, they also have more opportunities in that certain developments (e.g. autonomous trucks) can be applied across several of their businesses. Innovation, apart from cost cutting, is not in the top 10 priorities for mining companies [12].

Yet we do see major new technologies introduced from time to time. Hollitt [13] has neatly summarized the special circumstances that must simultaneously be met to justify major new technology development:

- Seen as critical for a new resource or a major expansion. This generally is because of the nature of the resource, e.g. low grade, unusual contaminants, excessive energy demand, environmental concerns, etc. Clear business value and good NPV,
- Better NPV than conventional technology,
- Strategic significance, i.e. it positions the company with a long term, low cost resource, or with a technology that once proven at a modest scale can be implemented at much larger scales with little risk,
- Sufficient cash flow and resources available for more than one business cycle, reflecting the long time span for technology development and commercial implementation.

Some Promising Developments

There are several ways that one could pick, the technological developments in mineral processing most likely to come into production within of order 5 - 10 years. One could analyze the rate of improvement in a given technology in terms of costs per unit of production. This is of course very scale dependent, and the way flotation cells have increased in volume would be a good example. Alternatively, an analysis can be made of where current performance stands relative to theoretical performance. This latter approach would suggest three areas where significant development is possible. All are related to a concern with reducing the energy requirements of mineral processing while at the same time, reducing costs.

The three key areas are:

- Circuit design – why do we grind everything to final size?
- Comminution – why are our processes of order 2 % efficient in energy terms?
- Flotation – uses too much energy and can't handle coarse material.

<u>Circuit Design</u>
When one considers the theoretical energy needed to create fresh surface and compares it with the energy actually expended in grinding circuits, actual performance is well short of theoretical. While some of this is to do with breaking material in compression and shear rather than in tension, the gap is still large. This leads to the focusing question around the necessity of grinding the bulk of material in a circuit to final liberation size. Existing circuits may be relatively simple and have low unit costs, but their energy consumption is well above what could be achieved.

The key to alternatives is the nature of the liberation of the valuable mineral. In many cases some gangue liberation is possible by sorting, and this topic is well reviewed by Wotruba [14].

As Pokrajcic [15] has pointed out, it is also often possible to liberate gangue in stages, i.e. size reduction, gangue separation, size reduction, gangue separation and so on. This type of more complex circuit is rarely pursued on the basis that capital costs are likely to be higher and, importantly, the ability of common separation processes such as flotation to work at coarser sizes is highly limited.

The figure from Pokrajcic, O'Halloran, R., and Jones [16], however, shows an analysis of an existing, large mineral processing circuit and the NPV of two alternative circuits, one based on including High Pressure Grinding Rolls in an otherwise conventional circuit and the third, repeated size reduction and gangue separation. The improvement is dramatic with the extent depending on the local cost of energy and how it is generated.

Fig. 5. The economic benefit of split processing can be large but depends on how the local energy for milling is generated. [16]

<u>Energy in Comminution</u>
Buchholtz et al [17] showed the importance of force chains in comminution. Force chains are a string of particles in close contact that take an applied load, like a column. They are held loosely in position in a lateral sense by neighbouring particles. The key factor is that the applied load is largely taken by the particles in the force chain, not by all of the particles. A slight rearrangement of the force chains due to movement will dislodge the arrangement and result in the strain energy stored by compression of the particles in the force chain essentially being lost. New force chains then form which will absorb strain energy of the applied load. Force chain rearrangement is

conceptually one of the key reasons that much of the energy applied in real comminution environments is “wasted”.

Pöschel [18] shows that force chains are essential for comminution. “Particles in force chains feel a much larger force than particles that are located in the neighbourhood but are not members of force chains.” Buchholtz et al [17] argue from DEM modelling that comminution occurs mainly due to the existence of force chains and that a statistical analysis of these chains explains the spatial distribution of comminution efficiency in ball mills as measured experimentally.

There is an interesting prospect of combining compression and shear. Such a concept might significantly reduce the effect of energy dissipation through force chain formation and breakage. Tordesillas and Muthuswamy [19] have shown that for uniaxial compression of a confined bed of particles, allowing breakage of particles when a critical local stress is reached, they can predict the overall comminution behaviour in that the load carrying capacity and energy dissipation are intimately linked and predictable using continuum properties as a way of connecting particle scale information into macroscopic information, i.e. into robust predictions of overall comminution behaviour.

The investigation of different regimes of combining compression and shear is underway and holds some promise of reducing the energy of comminution, at least in rotating devices such as High Pressure Grinding Rolls.

<u>Recent Advances in Flotation</u>
Flotation is well established in the 20 – 150 micron particle size range. Extending this range significantly is a key to implementing the type of split circuits described above. Jameson [1] and Jameson [20] have described a new type of fluidized bed cell with markedly superior performance on coarse particles. It has been named the NovaCell™. Jameson notes, “The aim of the NovaCell™ is to increase the top size at which particles can be recovered by flotation. Currently the top size for base metals is limited to 150 µm approximately, as a result of the highly turbulent environment in mechanical flotation cells, which tends to favour detachment of larger particles. Using the gentler flow conditions that are possible in a fluidized bed flotation cell, laboratory experiments show that the top limit can be raised very significantly.”

Fig. 6. Comparison of normal flotation performance with the Jameson NovaCell™ [1]

Simple calculations indicate that using a flotation device capable of operating at 400 – 800 micron, the energy required for ball milling (as well as the media) is quite markedly reduced.

Summary

Technology developments in mineral processing will help to ensure that there are no long term shortages of minerals for decades to come. Competition in the industry will continue to drive innovation, especially in terms of costs and increasingly, energy requirements.

It is envisaged that some key trends in mineral processing will include pre-processing (sorting) and split circuits where the comminution is staged and gangue is split out at each stage of comminution.

The combination of compression and shear in comminution devices at a theoretical level has been shown to reduce energy requirements. This breakthrough is yet to be realized at scale.

Finally, the work of Jameson has now demonstrated at laboratory scale that flotation is possible at 400 – 800 micron. Scaling up of this new development seems possible and will also lead to much improvement in circuit performance, particularly on costs and energy consumption.

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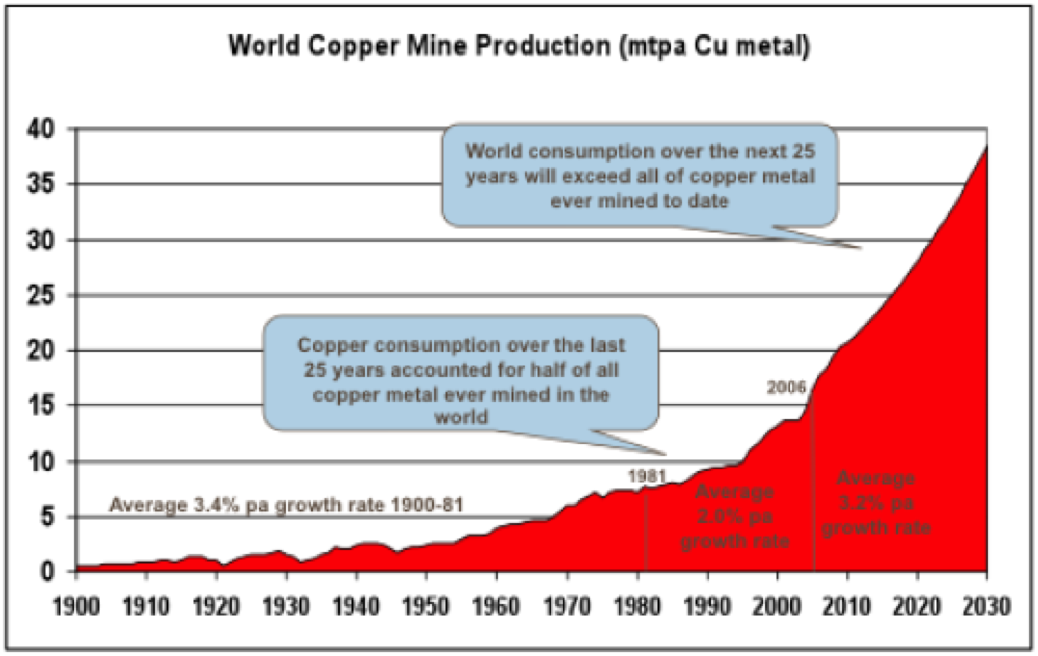

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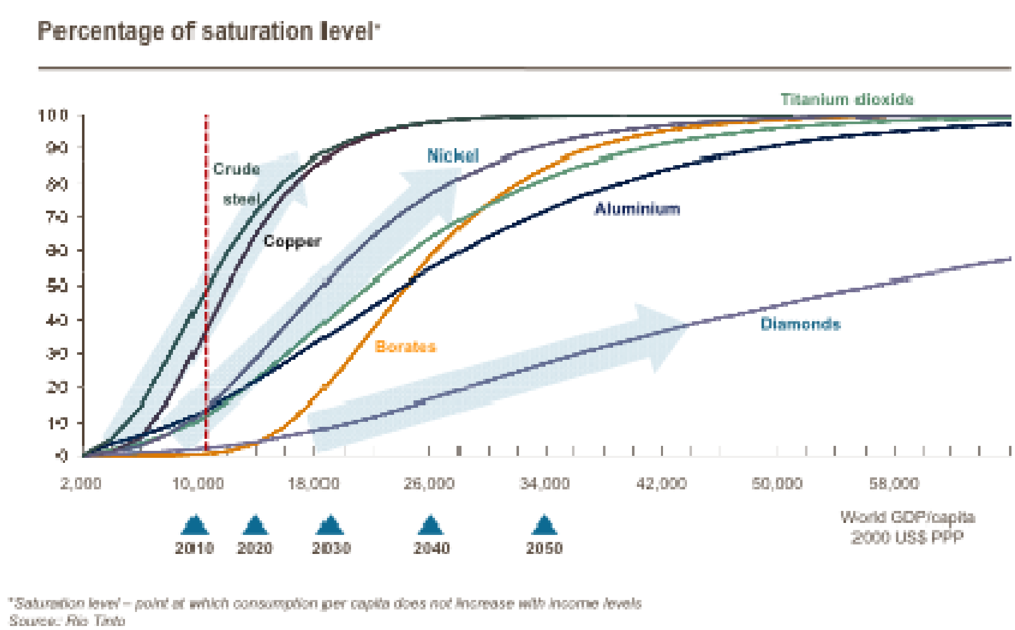

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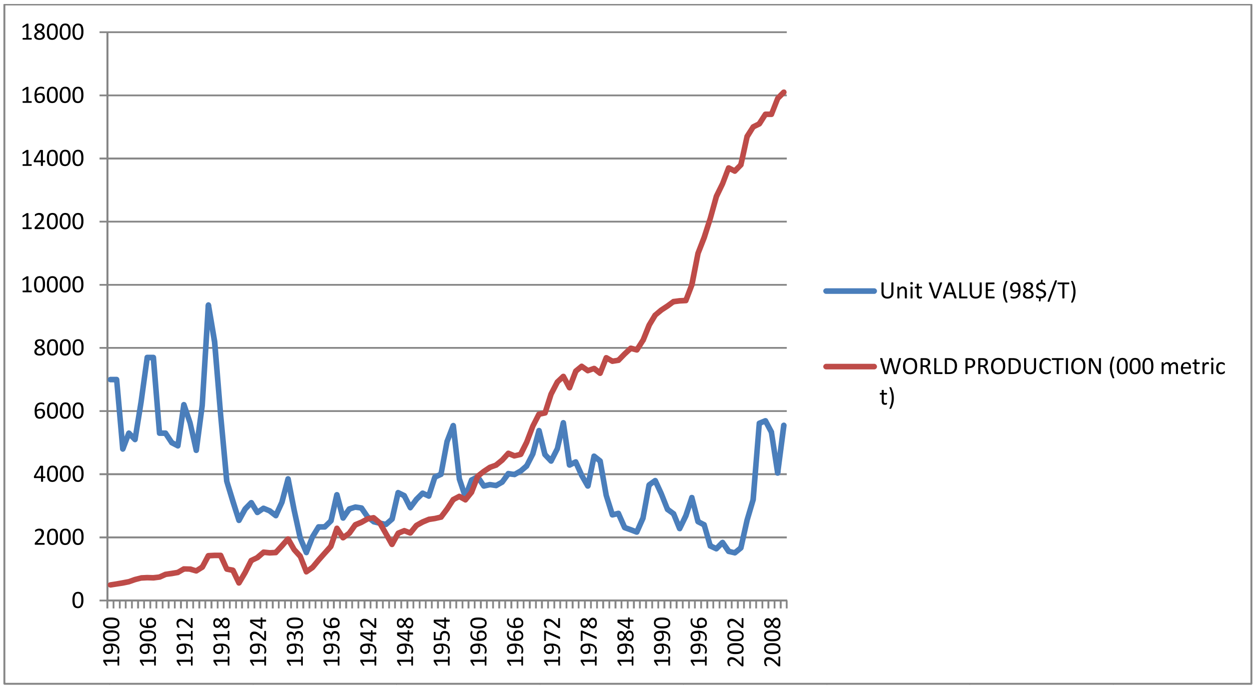

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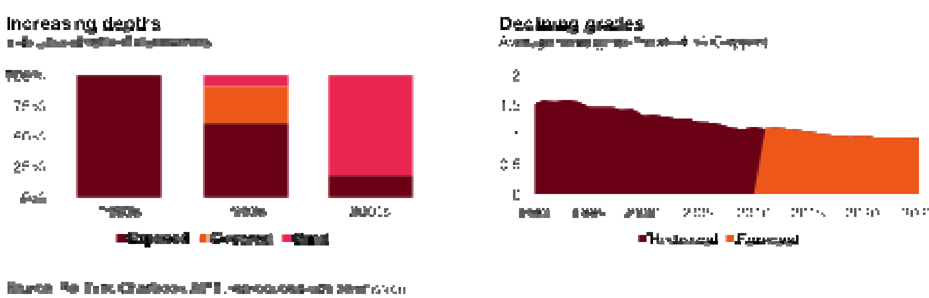

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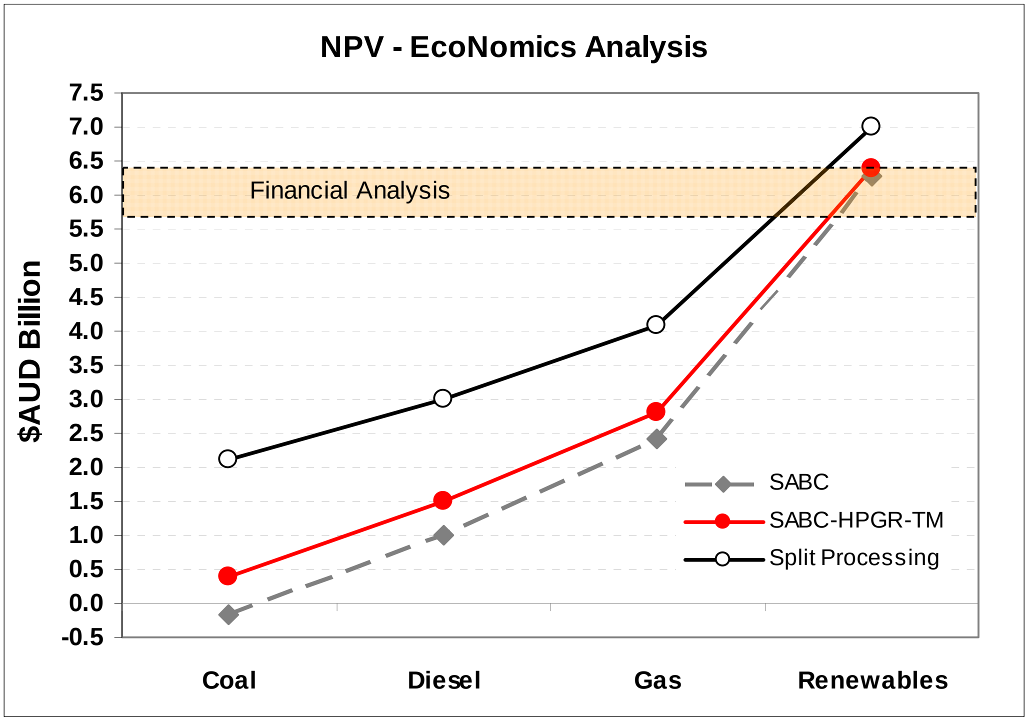

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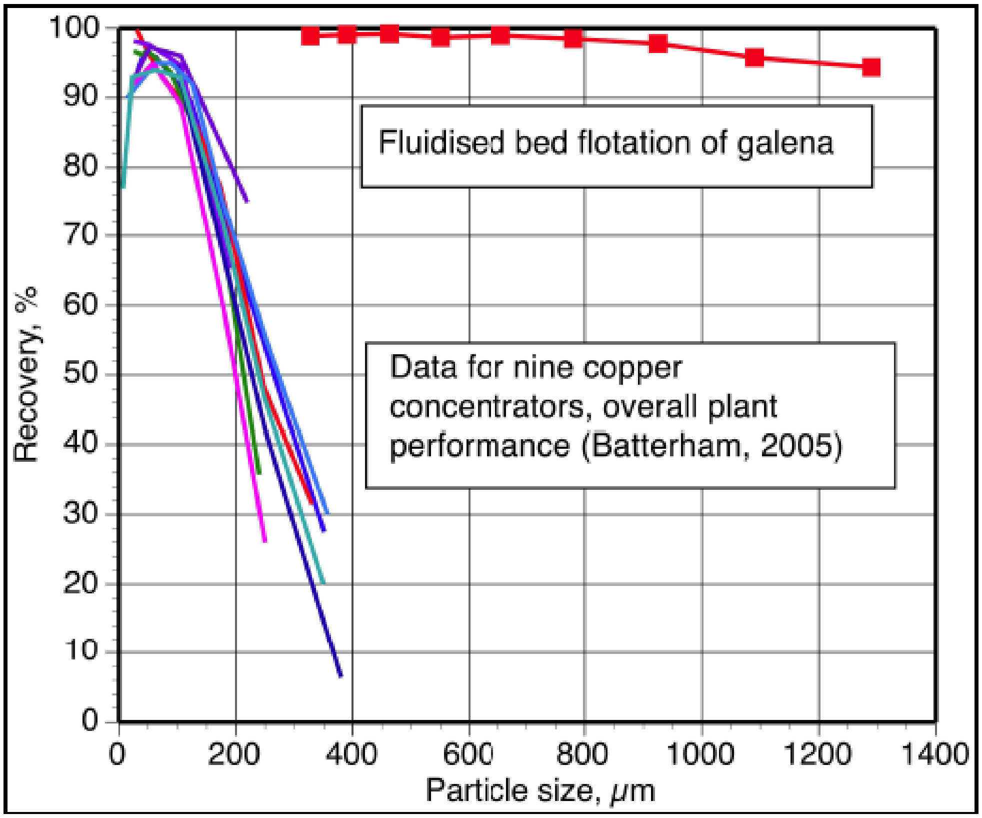

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