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A more sustainable approach to assessing comminution efficiency

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Presentation Outline

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- Introduction
- Background – Traditional measures of energy efficiency
- Objectives of this work
- New measures of energy efficiency:
  - Development of method to assess operating efficiency
  - Development of method to assess theoretical efficiency
  - Development of method to assess eco-efficiency
- Conclusions

Introduction

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- The mining and mineral industries worldwide use about 4-7% of global energy use (Rábago *et al*., 2007).

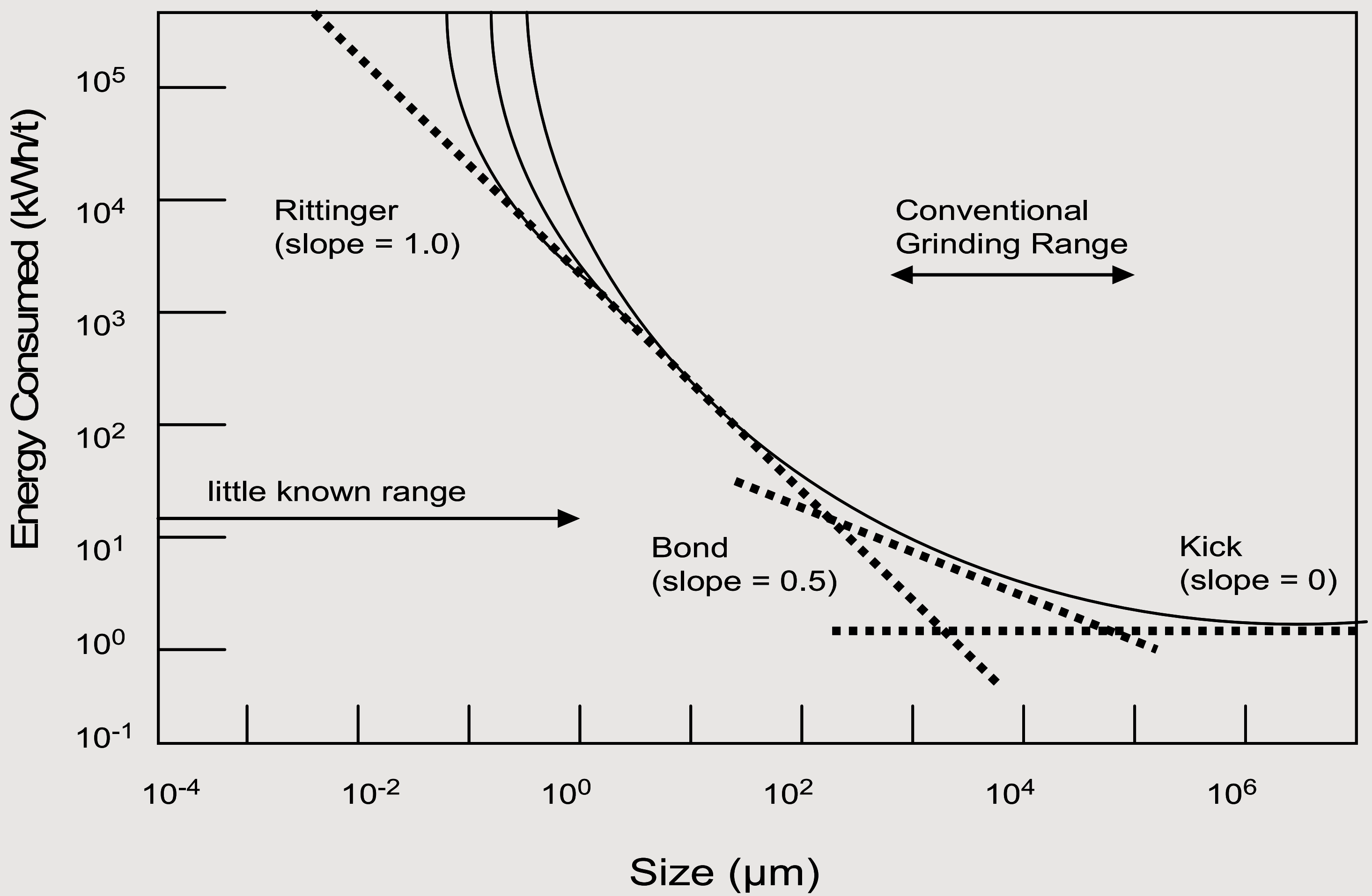
- Comminution uses more than 75% of total electrical energy consumed (Charles and Gallagher, 1982).

- Apart from that, about 50% of energy is related to manufacturing grinding media and liners (Radziszewski, 2002).
- Comminution circuits are the largest contributor to emissions of CO_2 (La Nauze and Temos, 2002)

Background – Traditional measures of energy efficiency

- The "Laws of Comminution"
  - Kick's Law (Energy varies as mass broken)
  - Rittinger's Law (Energy varies as new surface, 1/size)
  - Bond's Law (Energy varies as mass*size)

The “Laws of Comminution”



Background – Bond's method

- Advantages
  - This method is simple.
  - Requires only the feed and product size distributions of a full scale circuit and the measured motor power.
  - Where plant data are not available, the work index can be determined from a laboratory scale closed circuit grinding test
  - Works well for ball mill/rod mill circuit.

- Disadvantages
  - Assumes feed and product cumulative size distributions are parallel when plotted on a log-log scale. This assumption not necessarily true for AG/SAG mills.
  - It is path independent, which means that the type of comminution equipment employed does not matter.
  - Only estimates the direct energy (power drawn by the mill), but does not take into account the indirect energy. All of these types of energy also generate greenhouse gases.

Objective

- This work addresses those deficiencies by developing different approaches which do not suffer from those limitations and which can potentially be used in the industry to estimate the energy efficiency of any comminution device or circuit.

New Measures of Energy Efficiency

- Three (3) new methods:
  - Minus 75 micron method to assess operating efficiency;
  - Theoretical efficiency method based on crusher/perfect mixing model energy estimation;
  - Eco-efficiency method based on a simplified Life Cycle Assessment (LCA).

New method 1 – Minus 75µm

- Based on Rittinger's Law that energy required for size reduction is proportional to the new surface area formed.
- This new method looks at the production of new surface area in the ultrafines region (typically -75µm) where 70-80% of the surface area of comminution product is contained.
- Uses Surface Area Model developed by Michaux (2005) to calculate surface area for all size fractions.

Development of Method 1

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Calculation of surface area for all particle size fractions using the surface area model developed by Michaux (2005)

↓

Setting a marker on the size distribution which contains a significant amount (70% or more) of surface area in the comminution product

↓

Calculation of the standard energy required to produce new material in that marker size fraction for same type of ore using the standard Bond grindability test

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Applying plant data to estimate the energy to produce new material in that marker size fraction

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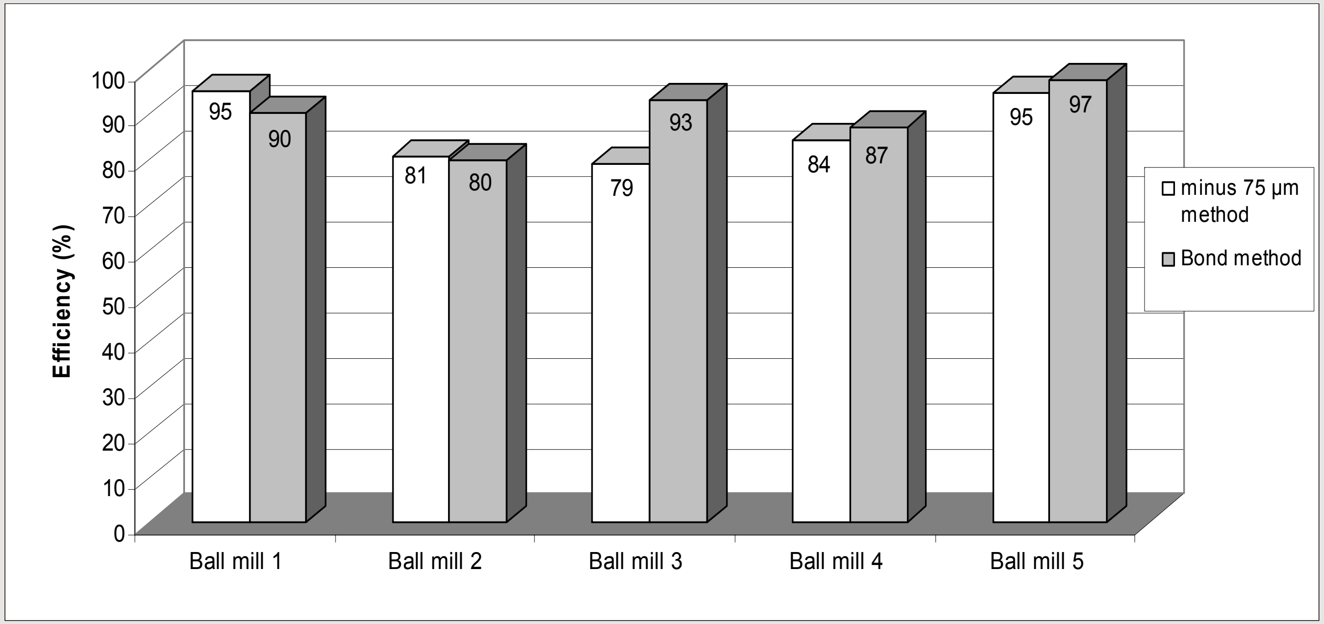
Comparison of the energy to give comminution operating efficiency

Results – Comparison between new method and Bond method

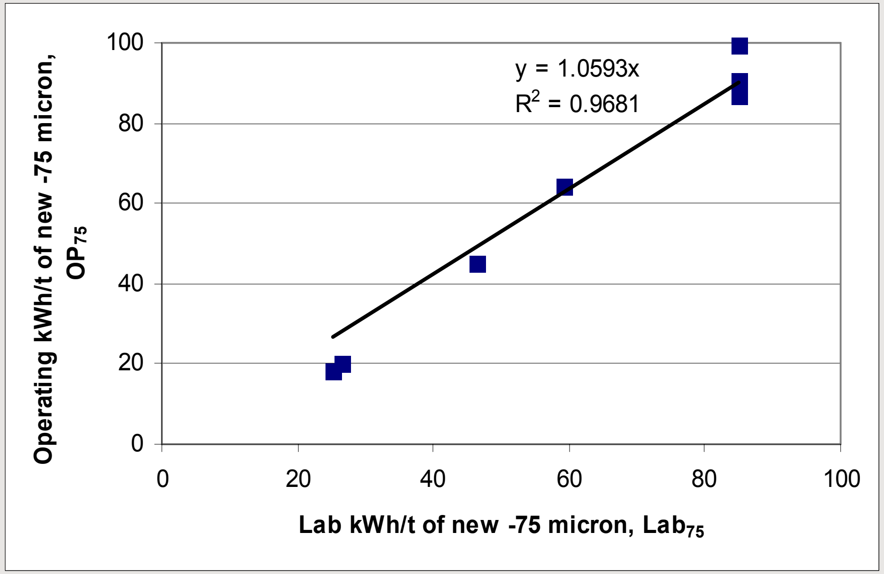
- Tested on ball mills data

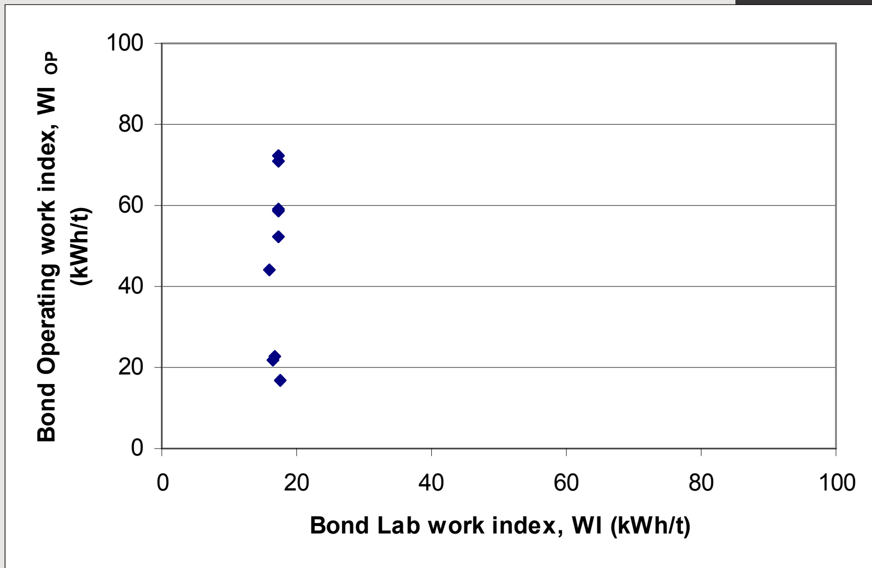


Efficiencies calculated using both method are quite similar. This shows that the minus 75 µm method can provide similar information to the Bond operating work indices for ball mills. However this method does not require parallel feed and product distributions and can potentially be used to assess operating efficiency of comminution circuits whether or not mill feed and product size distributions are parallel.

Comparison between lab and full scale grindability using new and Bond methods

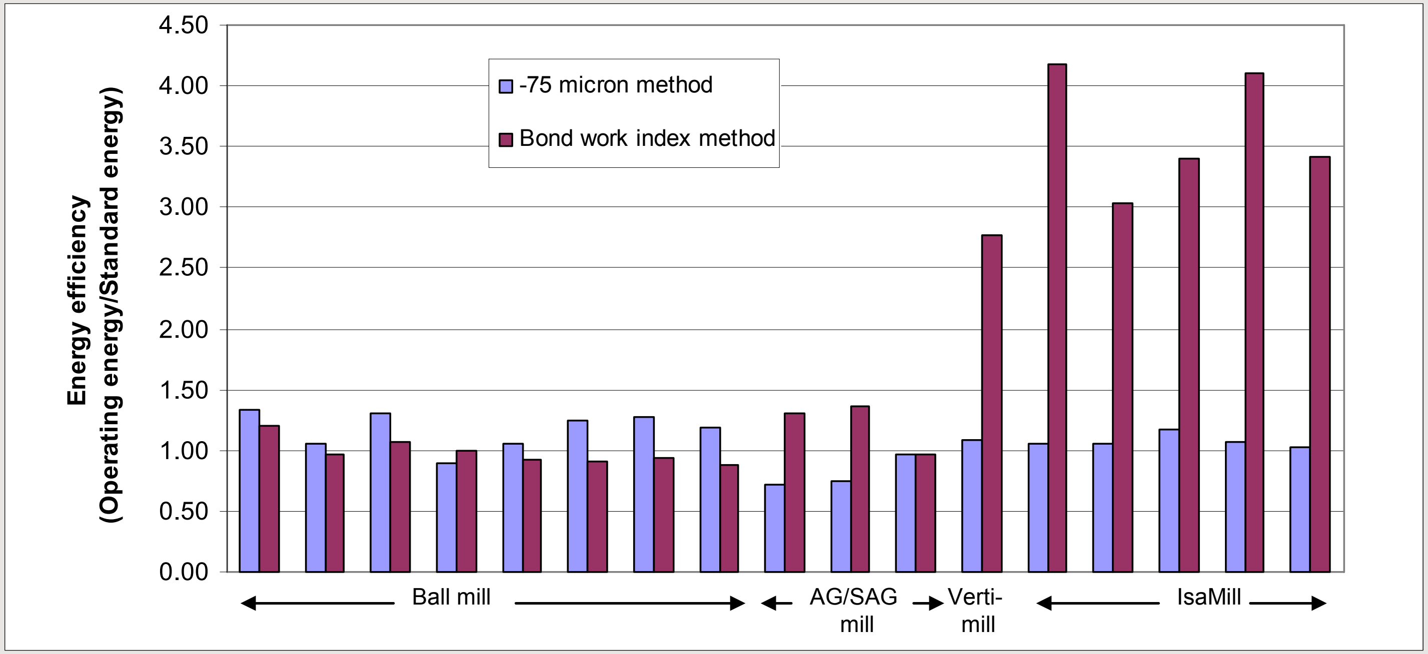
- Tested on other mills data – AG/SAG, Verti-mill and IsaMills





Strong correlation between the calculated standard lab kWh/t of new minus 75 µm and the operating full scale kWh/t of new minus 75 µm measured from plant surveys. The correlation could be seen for all types of comminution devices. However, there is essentially no correlation between the full scale grindability (Bond Operating WI) and the lab grindability (Bond Laboratory WI) for the AG/SAG mill, Verti-mill and IsaMill data.

Results – Comparison of energy efficiency for all types of comminution equipment



Based on the definition of energy efficiency, the ratio of the operating energy and standard energy should equal unity. This is true for the energy efficiency calculated using the minus 75 µm method. However, the Bond method seems to give unrealistic value when applied to mills other than the ball mill.

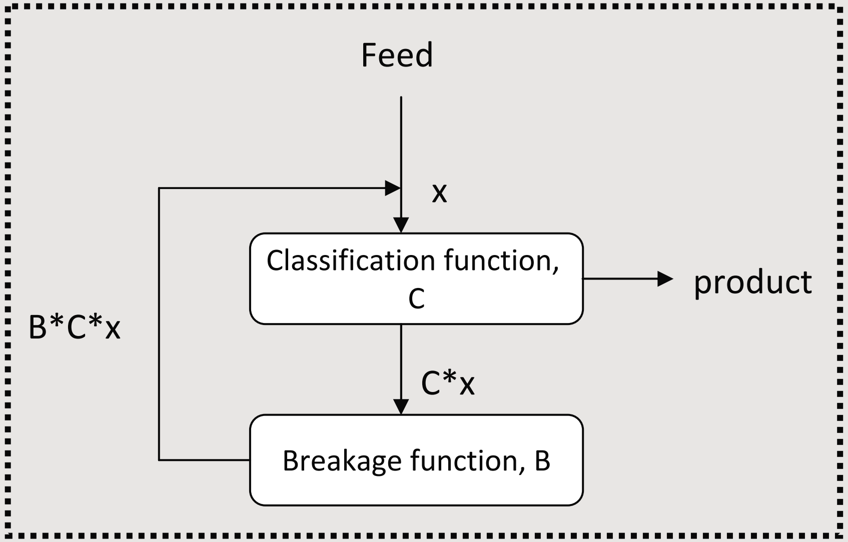
Note: Figure above should not be interpreted to mean that ball mills are more energy efficient than IsaMills.

New Method 2 – Theoretical Efficiency Method

- Uses the same concept as Whiten Crusher model.
- Uses Perfect Mixing model (Whiten, 1972) and new breakage function equation (developed by Shi and Kojovic, 2005) to calculate comminution efficiency.
- This approach should largely overcome the problem experienced by Andersen and Napier-Munn (1988) and Morrel et al, (1992) with larger particles in the crusher model.

Crusher model vs. New Model

- Whiten Crusher model
- New model



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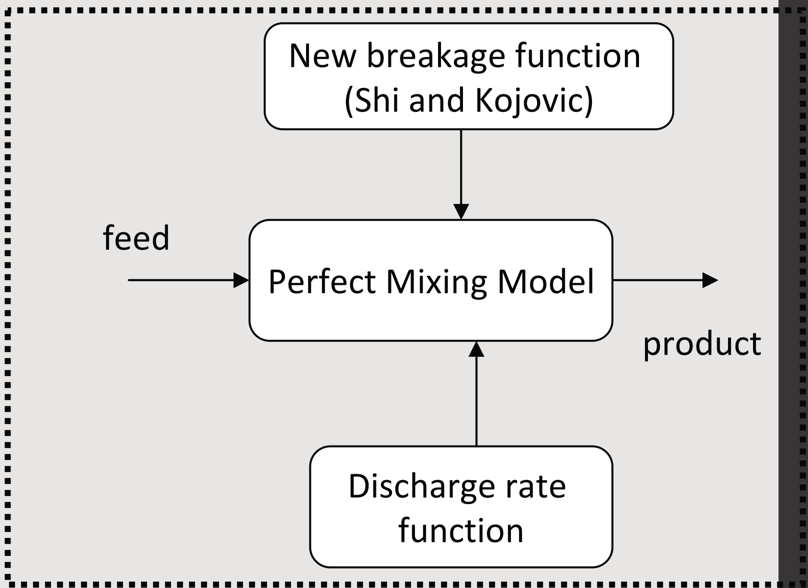
Ecst10 from pendulum test

Pendulum power

$$Ecs_{t_{10}} \cdot \sum_{all\ sizes} C_i x_i$$



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Ecst10 from drop weight test

Drop weight or RBT) power

$$Ecs * \sum_{all\ sizes} r_i * s_i$$

Results – Comminution efficiency for ball mills

Plant survey data	Drop weight test power (kW)	Observed power draw (kW)	Comminution Efficiency (%)
Bougainville 1	960	3448	29.0
Bougainville 2	983	3013	33.0
Bougainville 3	1032	3839	27.0
Mount Isa Mine 1	798	2397	33.3
Mount Isa Mine 2	770	2381	32.3
Mount Isa Mine 3	800	2724	29.4
Mount Isa Mine 4	787	2624	29.9
Mount Isa Mine 5	784	2609	30.0
Mount Isa Mine 6	813	2555	31.8

Ball mill efficiency compared to theoretical drop weight power ≈ 30% !!

Results – Comminution efficiency for SAG mills

Plant survey data	Drop weight test power (kW)	Observed power draw (kW)	Comminution Efficiency (%)
Survey 1	3009	7731	38.9
Survey 2	3036	7695	39.5
Survey 3	3005	7926	37.9
Survey 4	3133	7910	39.6
Survey 5	2915	7577	38.5
Survey 6	2981	7620	39.1

SAG mill efficiency compared to theoretical drop weight power ≈ 39%

New method 3 – Eco-efficiency

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- Based on Life cycle assessment

Construction of system boundary and limits

Data collection

Direct energy
(Electrical energy consumed by equipment)

Indirect energy
(Energy related to grinding media, material handling and classification)

Assessment of Impact

Direct energy consumption

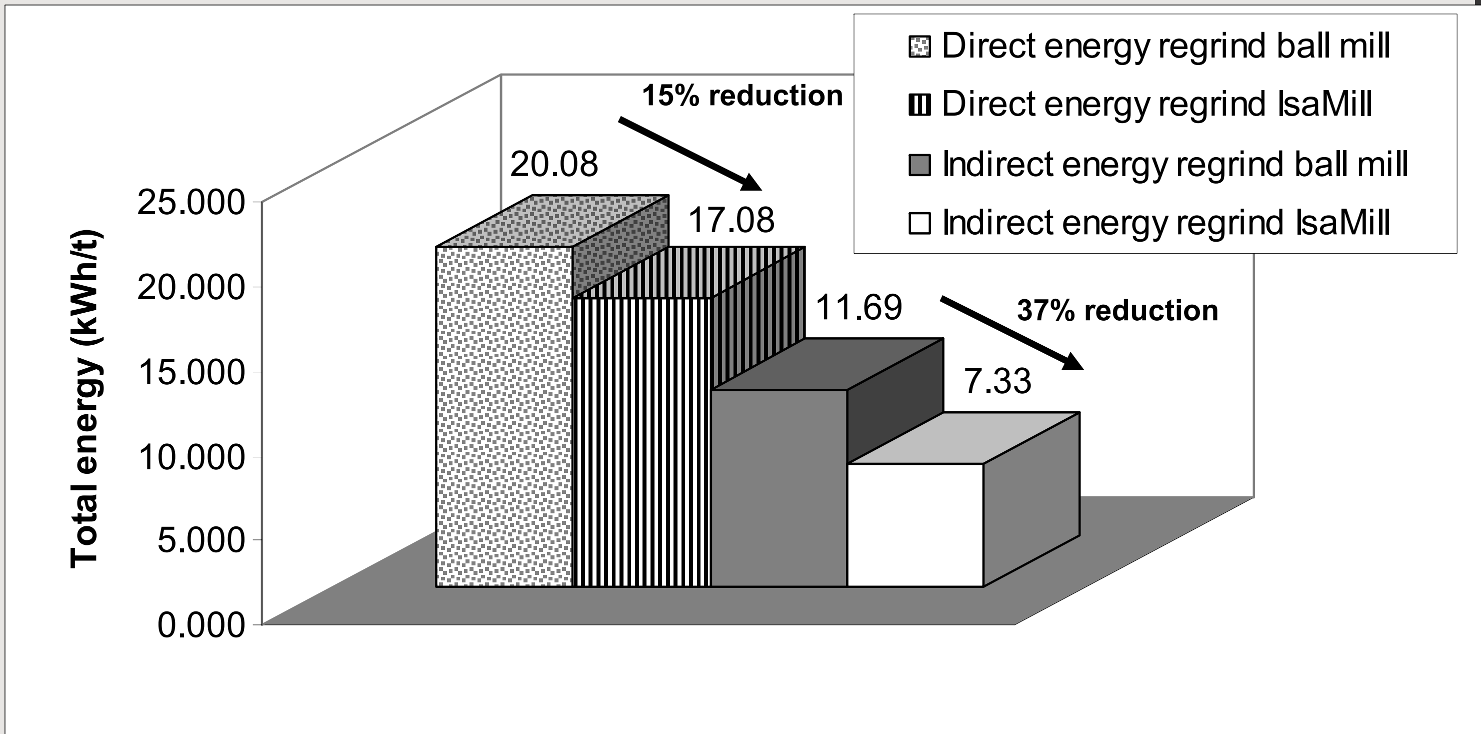
Indirect energy consumption

GHG generation

Case study – Kumtor gold mine

- Tested on Kumtor gold mine data for comparison of eco-efficiency between a regrind ball mill and an IsaMill.
- In October 2005, Kumtor commissioned a 2.6 MW IsaMill to fine grind leach feed to increase gold liberation and recovery. A period of refurbishment for the regrind ball mill provided an opportunity for an industrial scale comparison of the IsaMill and the regrind ball mill.

Results – Direct and Indirect energy consumption



Overall, there was almost a 15% decrease in the direct energy consumption when IsaMill was installed to replace the ball mill in regrind duty. A significant reduction (almost 40%) of indirect energy was achieved when the regrind ball mill was replaced by the IsaMill.

Results – Contribution of energy from comminution equipment

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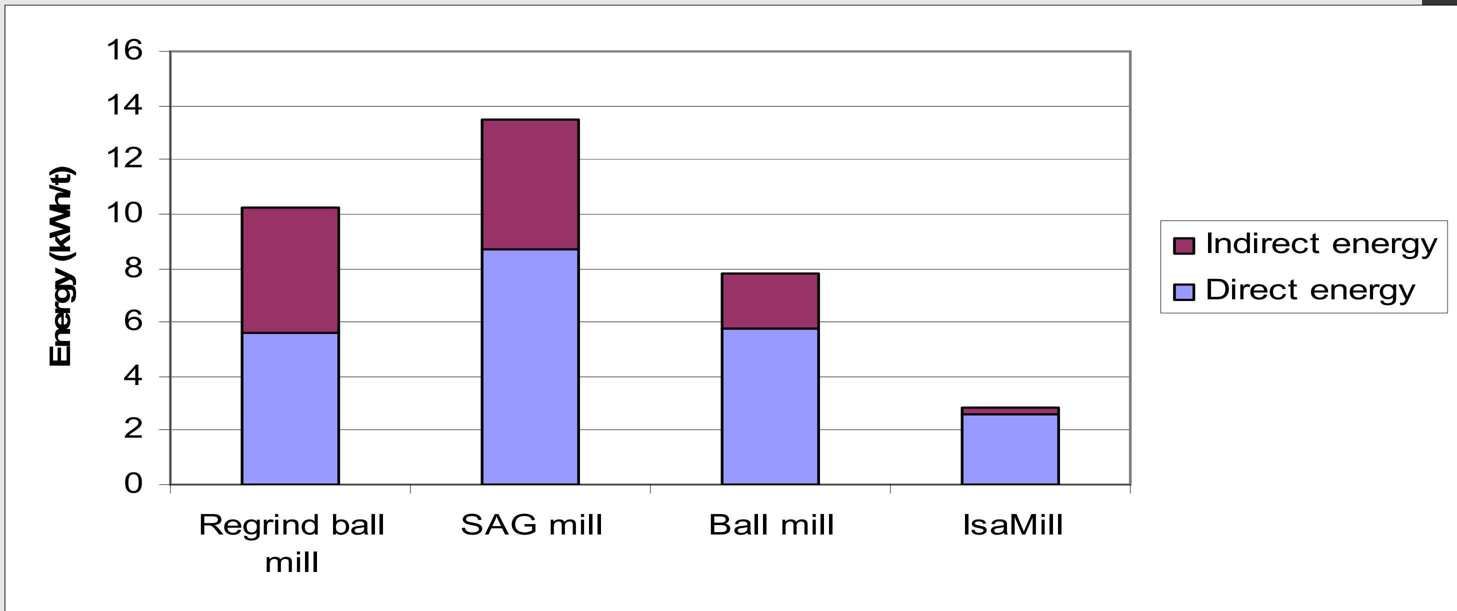
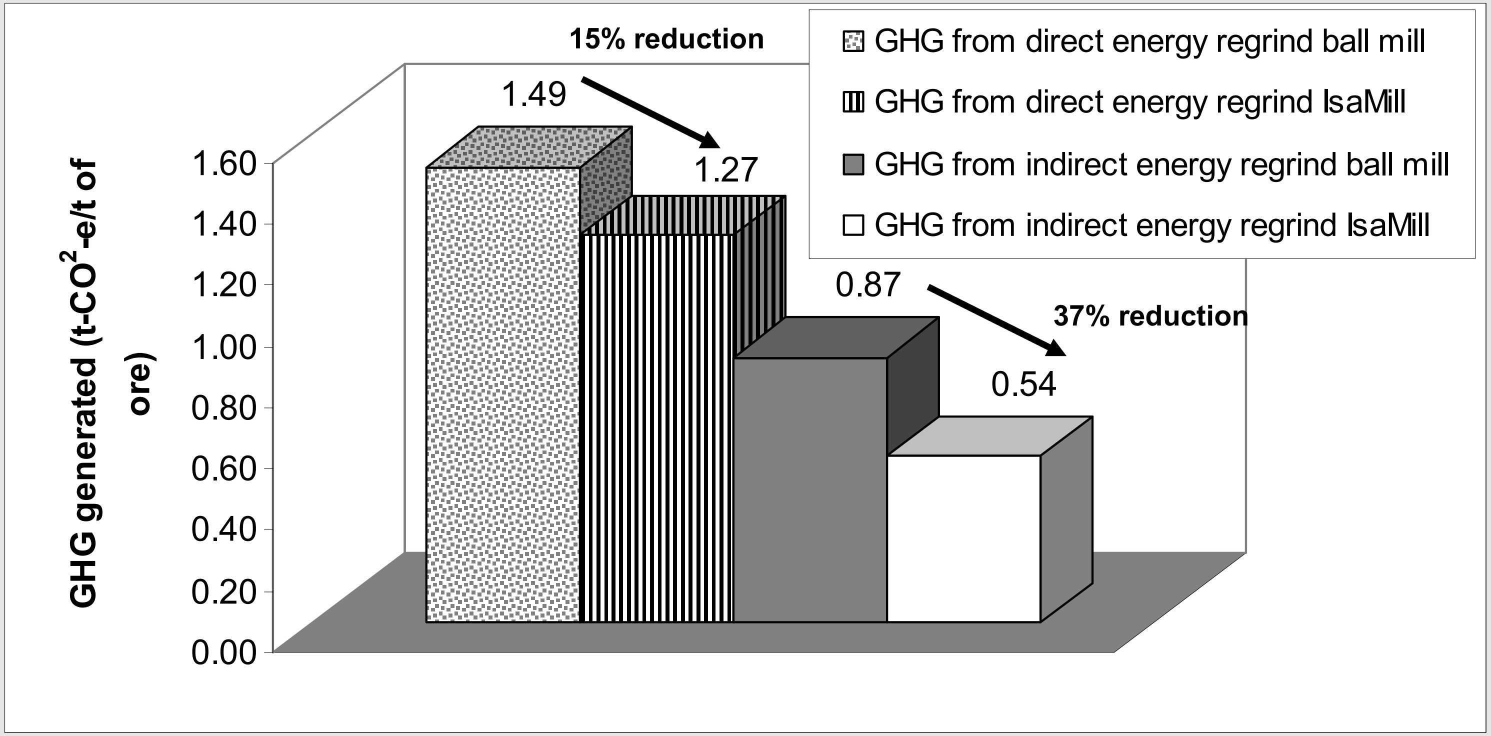


SAG mill consumes the largest portion (about 38%) of electricity energy used followed by the regrind ball mill while the IsaMill consumes the smallest portion (only about 2%) of indirect energy in the comminution process.

Results – Impact of energy on environment (GHG generation)



GHG generated from the regrind ball mill operation was found to be much higher than the IsaMill operation.

Conclusions

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- The traditional Bond approach has been tested against a wide range of comminution devices and found to be reasonably adequate for rod and ball mill circuits but not for any of the other devices.
- The traditional efficiency assessments only consider energy consumed as electricity. In fact, substantial GHG are generated in the manufacture of media and liner and in material transport and classification within comminution circuits.
- This work has developed a series of evaluation criteria which can be used to:
  - provide a fair comparison between different comminution devices and circuits
  - take account of energy and GHG production other than direct electricity consumption
  - provide a more fundamental evaluation of efficiency by comparison with energy required for single particle breakage for AG and SAG mills as well as crushers

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