DEVELOPMENT OF THE COMMINUTION 'ENERGY CURVE'

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ABSTRACT

The ability to rank individual mines by comminution energy intensity in an international database was identified as a priority by the Coalition for Energy-Efficient Comminution in 2012 (Napier-Munn, Drinkwater, & Ballantyne, 2012). Providing a tool to compare the comminution energy intensity of a mine against the industry distribution will incentivise an improvement in energy productivity. It is acknowledged that there is a tendency for the mining industry to avoid benchmarking operational performance because of the inherent variability in geology, mining technique and process design at different mines internationally. Therefore, any tool must be simple to understand, comprehensive in nature and flexible in application. Allowing a number of measures for energy intensity to be included in the analysis (e.g. energy per rock milled or metal produced) will provide a fairer comparison between sites.

The cost curve format widely published by financial organisations has been used to visualise the variability in processing energy intensity across the industry. The applications of energy curves are many and varied. It can be used to map the position of the mine as production progresses with year-on-year analysis. Circuit design proposals can be compared to assess the position of the mine on the energy curve when operational. Operational efficiency improvements can be mapped on the curves to visually assess the magnitude of reductions achievable through various strategies. The efficiency with which the various comminution devices achieve size reduction can be mapped down a circuit to identify opportunities for improvement and the magnitude of achievable gains.

This technique allows the current position of the mine to be identified, providing operators with the insight to achieve best practice and move their operation down the energy curve to a more productive and efficient location. A major outcome from the recent 2014 CEEC workshop was to increase the number of mines in the study to greater than 50% of the copper and gold production internationally, while also extending the methodology to other commodities such as platinum and nickel.

KEYWORDS

Comminution, Energy, Energy curves

INTRODUCTION

The recent downturn in global commodity prices has resulted in increased pressure to decrease production costs and improve productivity. Curry, Ismay, and Jameson (2014) found that for an average mining operation, between 43 and 45 per cent of the total enterprise operating costs were incurred by the mill. Comminution is also the most energy intensive process within mining, with an average gold or copper producing mine consuming 36% of its energy through rock breakage processes (Ballantyne, Powell & Tiang, 2012). The energy consumed through rock comminution is therefore a major focus of mining companies because it is a large operating cost, a good predictor of productivity and a significant environmental indicator. To address this significant problem, the first step is to quantify comminution energy intensity and use this to identify improvement opportunities.

METHOD

The energy curve methodology is becoming well established (Ballantyne & Powell, 2014). A substantial, sophisticated database is methodically used to visualize the variability of energy consumed through comminution for mines internationally. An example of the kind of data that has been collected is available on the CEEC website; this also provides you the opportunity to engage in the process by supplying your information and receiving your position on the curves. Each mine is presented as bar in the graph where the width is proportional to the mine's production and the height is related to a measure of comminution energy intensity. The right-hand vertical axis represents a basic attempt to provide a monetary value for the energy consumption by using a figure of 22c/kWh, although the authors acknowledge that this figure can vary dramatically regionally and internationally. A suite of four curves can be used to cover the full range of energy intensity metrics and indicate potential remedial action (see Figure 1):

Bond Intensity Bond work index (BWi) and operating work index (OWi) are both presented in this energy curve to show the influence of rock hardness (h) on comminution energy consumption. The differential between a mine's position on the BWi and OWi curves can also be used as an estimate of the comminution circuit performance relative to other mine's with similar rock hardness.

SSE Intensity The size specific energy (SSE) presents the energy required to generate new material finer than 75 µm (with units of kWh/t-75µm). A mine's position on this energy curve is determined from a combination of rock hardness and circuit efficiency (h + c). This graph is where the benefit of different circuit configurations or the addition of novel comminution devices may be best visualized.

Tonne Intensity This energy curve presents the range in specific energy (kWh/t) intensity of the mines in the database. This energy curve adds the dependence of grind size (s) to the previous two variables (h + c + s). Mines that process ores with complex mineralogy requiring fine grinding, will be expected to be positioned on the high side of this curve.

Grade Intensity Metal specific comminution energy is presented in the final energy curve. The poly-metallic nature of the database required production to be normalized using copper equivalent production to convert other commodities to the equivalent revenue generated by copper production (Ballantyne, Mainza, & Powell, 2015). The major contributor to a mines position on this energy curve is grade (g) but the other parameters also contribute (h + c + s + g). The energy benefit of pre-concentration strategies will be best visualized on this graph.

The flexibility of the energy curves increases the applicability of the approach to a wide range of problems. The baseline position of an operation can be mapped on the curves to compare to other operations and identify where improvements could be made. Subsequently, methods such as Bond, Morrell or SSE could be used to pinpoint specific efficiency improvements down the circuit. Additionally circuit design options can be visualized in relation to energy consumption and the performance of a specific circuit over time can be assessed with year-on-year analysis. All these techniques simply require the operator to determine the position of the mine after calculating energy intensity for each of the curves.

RESULTS

The energy curves were first published by Ballantyne and Powell (2014) and have subsequently been further developed with input from CEEC participants. This input has resulted in a substantial increase in the number of mines in the database as well as the proportion of global production that are covered by those mines. Figure 1 clearly shows the development in the suite of energy curves since the previous publication. Most noticeably, the magnitude of material milled and metal production that is contained within the database has more than doubled. This development has not dramatically changed the shape of the energy curves, but instead has resulted in increased definition and granularity in the data.

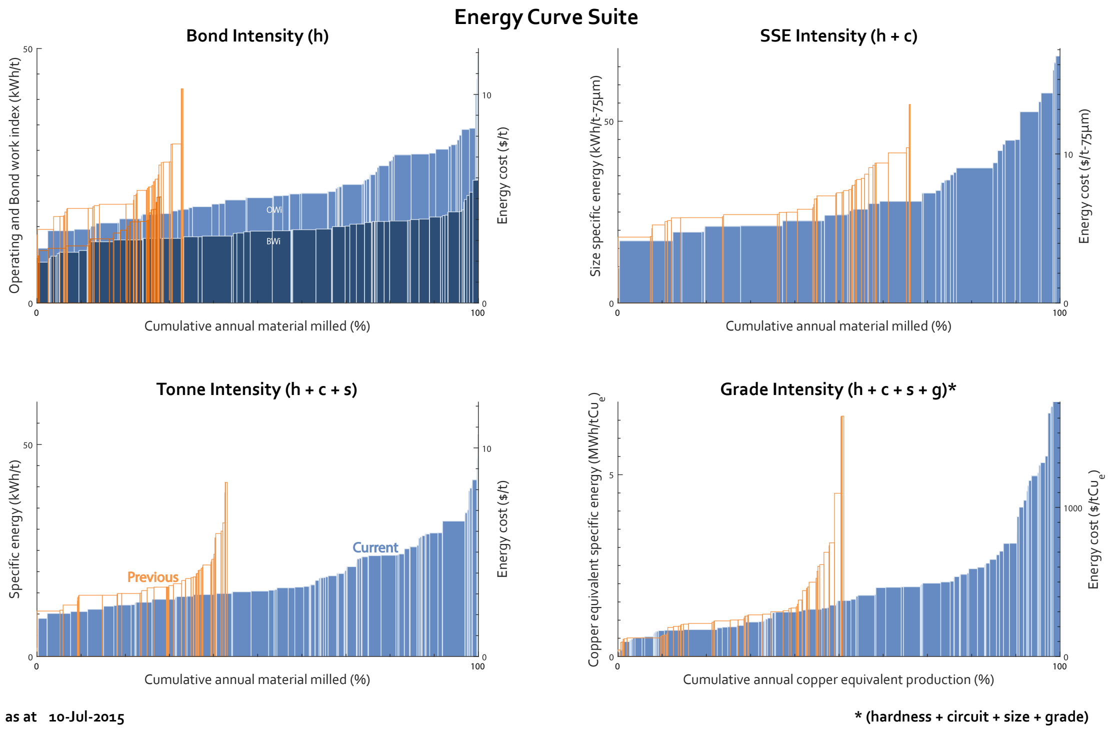

Figure 1 - Development in the suit of energy curves since the first publication by Ballantyne and Powell (2014) (represented by orange lines).

As at the date of publication, the energy curve database covered 117 mines across a broad portfolio of commodities (see Figure 2). Copper and gold mines were represented disproportionately (80%) as these are the commodities that were targeted in the early development of the energy curves. The energy curves accurately represents 40% of global copper production, approximately one fifth of global gold, molybdenum, lead, zinc and silver production, and a small proportion of global platinum, nickel and iron production. Although almost half the mines were gold producers, the proportion of global production represented less than half that of copper and even smaller than zinc. This is due to the highly diverse nature of gold production in comparison to these other commodities. This was also reflected in the proportion of rock throughput in the database which was predominately copper producing mines.

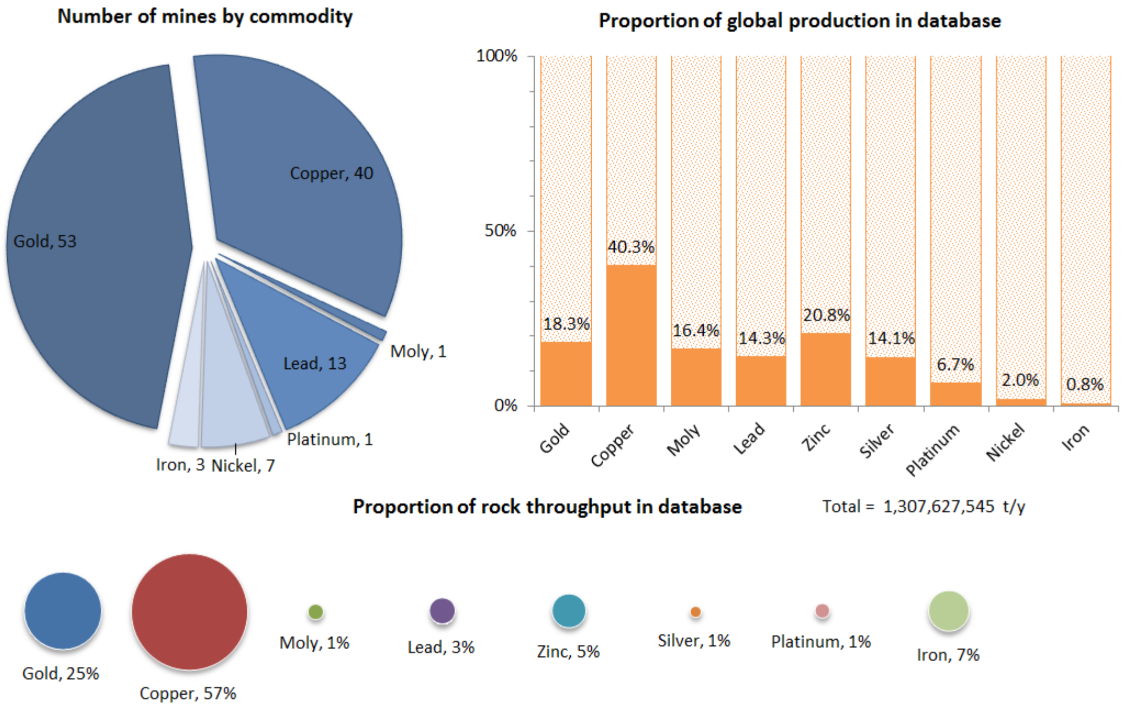

Figure 2 - Energy curve database size and make up.

DISCUSSION

The granularity of the data used to construct the energy curves allows an analysis of the proportion of energy consumed by the different equipment within a comminution circuit. Figure 3 shows the breakdown of energy by equipment if the whole database were considered one database treating the full 1.3 Gt/y. The database contains 1.14 GW of primary milling and 1.29 GW of secondary milling; 94% of the total comminution power. The next biggest consumers were 40 MW for HPGR and 49 MW for tertiary grinding. The split of power between primary and secondary milling is of particular interest, especially for the design and operation of the ubiquitous SABC circuit.

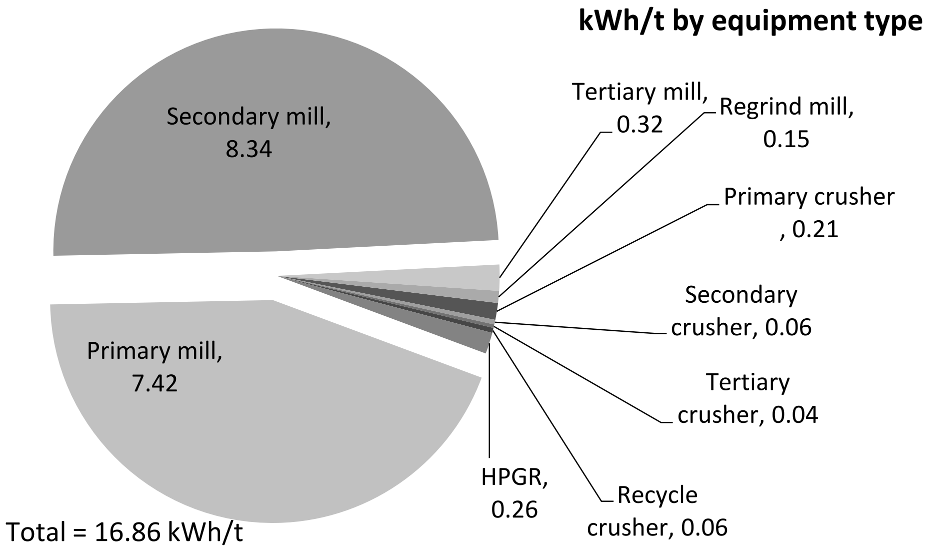

Figure 3 - Proportion of specific energy consumed presented by equipment type in the database.

Figure 4 displays the relationship between primary and secondary milling specific energy consumption. There is significant scatter in this relationship, but it appears to be evenly distributed around the parity line. Further analysis is required to assess the impact of factors such as the relationship between impact and abrasion rock competence, transfer particle size between primary and secondary milling, final grind size, throughput and circuit type. It is also likely the equipment design methodology (e.g. SMC, SAGDesign, etc.) employed will also be a factor in this power ratio. The power split between primary and secondary milling is also likely to influence the total circuit efficiency.

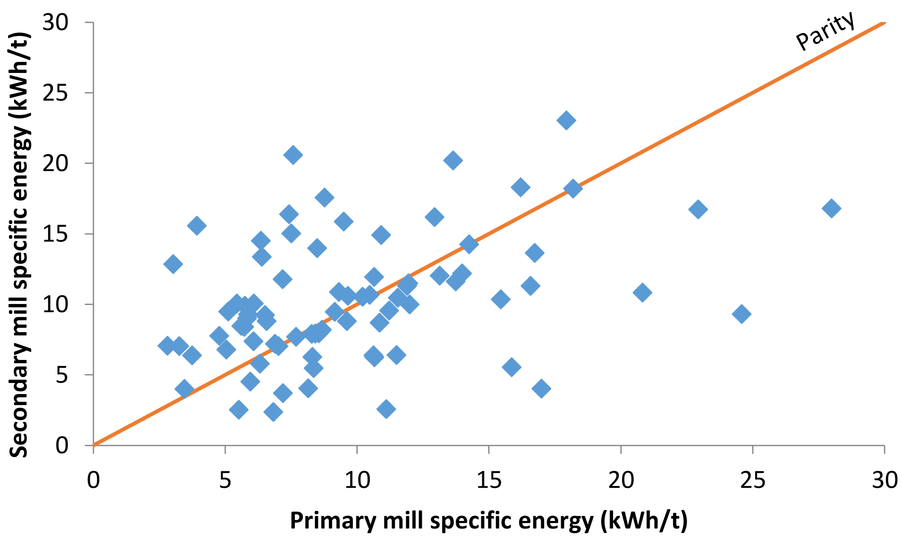

Figure 4 - Relationship between total and primary mill specific energy

The tonne intensity energy curve has also been used as another method to show the proportion of primary milling power in relation to total circuit specific energy (see Figure 5). As elucidated above, the position of a mine on the tonne intensity energy curve is dependent on three factors: rock hardness, circuit efficiency and grind size. Visually, there does not appear to be any clear correlation between position on the curve and the proportion of energy consumed by the primary mill. However, another factor is introduced by analysing this relationship using the energy curves, and that is that the circuit throughput has a large effect on what is viewed visually. However, this is not a contributing factor in this case as when the power ratio is mapped as a function of total circuit power, no relationship was observed.

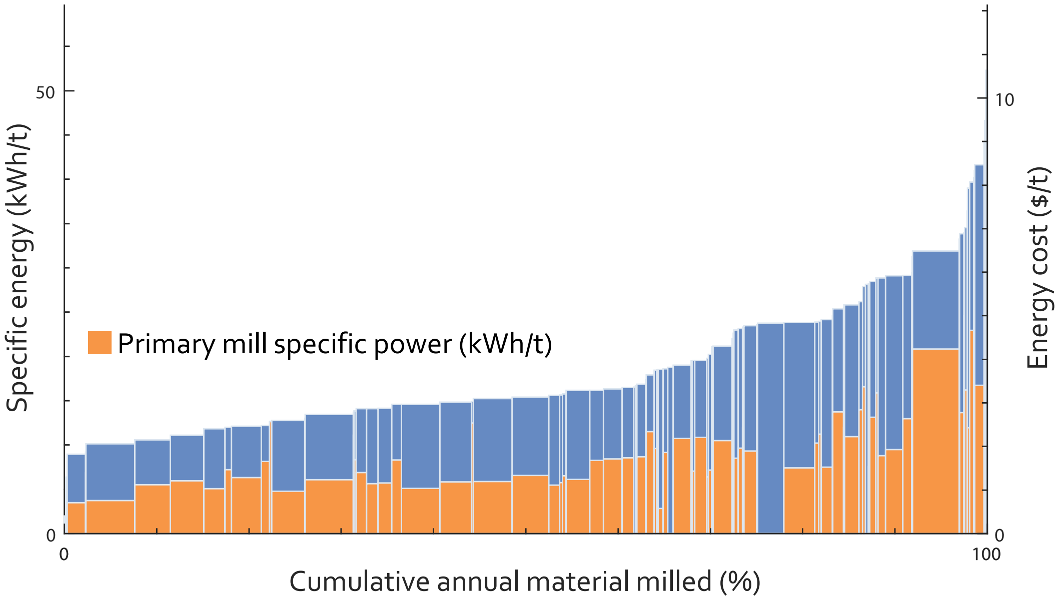

Figure 5 - Tonne intensity energy curve with the proportion contribution of the primary mill highlighted.

Engaging with the energy curve methodology enables operations to identify improvement opportunities and clearly convey the value that can be added by achieving best practice. The Bond method for assessing energy efficiency can be visualised on the Bond intensity energy curve (Bartholomew, McIvor & Arafat, 2014). The 95% confidence limits predicted by the Morrell method can be plotted on the tonne intensity energy curve to identify the expected range of energy consumption (Morrell, 2004). Alternatively, without any laboratory measurement of rock competence, the Size Specific Energy (SSE) can be calculated for each individual comminution devices; identifying underperformance and improvement potential (Ballantyne, Mainza & Powell, 2015). These three techniques address circuit energy efficiency, however, the suite of energy curves can also be used as a diagnostic tool to identify where the most value is likely to be achieved. For instance, if a mine is low on the tonne intensity curve, but high on the grade intensity curve, strategies such as Grade Engineering® may present a greater opportunity to add value.

CONCLUSION

The benefits of engaging with the energy curve are the ability to assess the performance of an operation in relation to its peers. The energy curve database and methodology are presented in this paper to show the development that has occurred with the support of CEEC. The database which underlies the energy curves has more than doubled in terms of metal production as well as material milled. It has expanded from two to eight commodities and there exists a possibility to extend further into coal, aggregate and concrete processing. As mines continue to engage in this process and add their mine's performance data, the energy curves are going to evolve and grow. As the data becomes more comprehensive and granular, the ability to assess 'best practice' will be increased. Additionally, the database can be partitioned to allow greater analysis of parameters such as circuit type, mining style, recovery method and mineralogy.

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