Total Ore Processing Integration and Management

12th Quarterly Technical Progress Report
01 April - 30 June 2006

written by
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Abstract

This report outlines the technical progress achieved for project DE-FC26-03NT41785 (Total Ore Processing Integration and Management) during the period 01 April through 30 June 2006.

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Work in Progress: Minntac Mine

A third generation model of the Minntac Mine was developed that includes qualitative and quantitative ore characteristics that impact processing in addition to the usual grade data. The quantitative characteristics are A Factor, grind characteristics (six-minute grind), Davis Tube silica, Davis Tube iron, and total iron. Geological layer is incorporated qualitatively, but was not utilized in the development of the ore control block model.

Attempts to include data from the blasthole drill performance monitors into the model have not been successful, and remain an action item that will be recommended for future development. Information technology incompatibilities have been major hurdles to enhancing the flow of necessary information from exploration to mining to processing on a real-time basis. The major difficulty in following the movement of ore during the ore segregation tests is at the mining face itself.

Work in Progress: Hibtac Mine

Average annual mill production since 1977 has been estimated and compared to the average normalized energy draw by the crushers and by the autogenous mills, and also to powder factor. Since each average incorporates data from an entire calendar year, the effects of seasonal cycles are presumably balanced.

With some exceptions that appear related to factors at the edge of the envelope of economic mining, as the energy required by crushing increases, the energy required by grinding decreases significantly. This is true only for some of the ore, generally that for which the powder facter was the highest and the production and production rate were the lowest.

Future Work

This is that final quarterly technical report, so no future work is being planned for this project.

Dissemination and Outreach

No dissemination or outreach were conducted during the reporting period.

Introduction

This twelfth quarterly report discusses the activities of the project team during the period 1 April through 30 June 2006.

Work in Progress

Minntac Mine

A third generation model of the Minntac Mine was developed that includes qualitative and quantitative ore characteristics that impact processing in addition to the usual grade data. The quantitative characteristics are A Factor, grind characteristics (six-minute grind), Davis Tube silica, Davis Tube iron, and total iron. Geological layer is incorporated qualitatively, but was not utilized in the development of the ore control block model. The blocks are generated using an inverse distance squared relationship between the exploration hole locations and the blocks, which are currently set at 50 by 50 by 20 feet in size to match the bench height in use at Minntac Mine.

Attempts to include data from the blasthole drill performance monitors into the model have not been successful, and remain an action item that will be recommended for future development. Information technology incompatibilities have been major hurdles to enhancing the flow of necessary information from exploration to mining to processing on a real-time basis.

The major difficulty in following the movement of ore during the ore segregation tests is at the mining face itself. The locations where the shovels work are recorded intermittently, preventing precise measurement at the beginning of how much ore is mined from which face, and where that face actually is in relation to the block model. In addition, the direction of shovel advance must be inferred indirectly. One solution would be to survey each active mining face daily, but a better one would be to monitor shovel location with a GPS system. This would permit more exact ore tracking and better correlation to loading position and tons produced. It also would allow the blocks in the ore control model to be decreased in size, increasing the resolution of the pass-through information. Presently, ore movement must be extracted from the Pit to Crusher report, combined with the Summary Mine Indicated Analysis and the shovel location report. They do not always correlate well, for various reasons including incorrect entry of source and destination codes. Ease of use, ease of data transfer, and robustness of the several independent record-keeping systems are the most important information technology characteristics that prevent completion of the TOPIM protocol.

Nevertheless, the third generation mine block model (created with the MineSight® software package) can be used to compare empirically predicted ore movement, ore movement based on the new model, and data flow from the mill. The block model is sectioned along the designated ore movement locations and current mining benches, then plotted and crosschecked against the delivered ore to the crusher (Figure 1).

Fundamental to this process was the development of flowcharts of the Minntac Mine production process, as shown in Figure 2. This flowchart incorporates the type and location of all sources of data regarding the ore and its transformation into pellets ready for shipment. It differs from many of the charts relied on by Minntac Mine personnel in that it is a total overview of the mine and the concentrator. Adding the agglomerator to this chart would be advantageous.

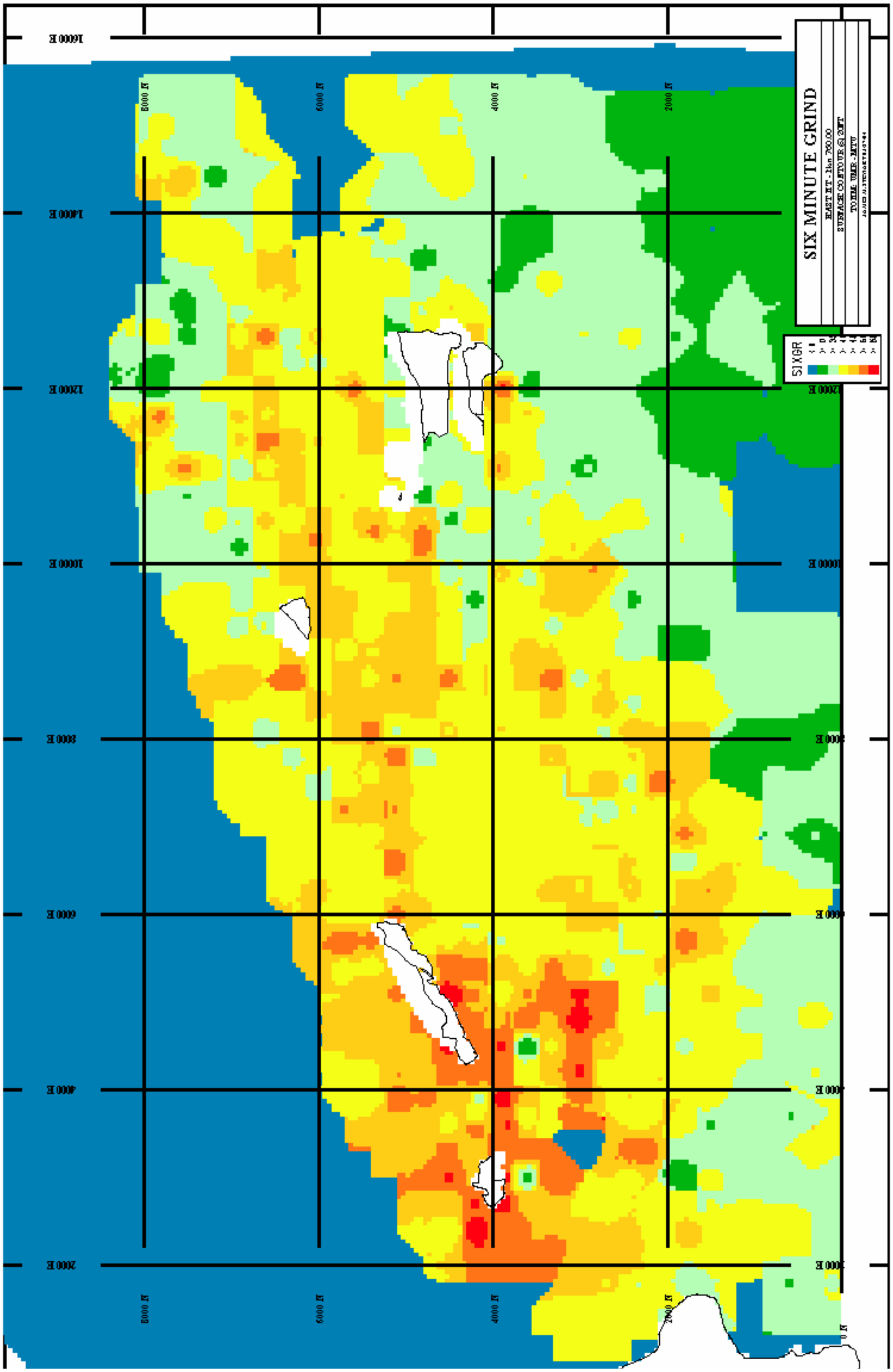

Figure 1. Plan view of variations in six-minute grind at a constant elevation in the East Pit, from the third-generation Minntac Mine block model.

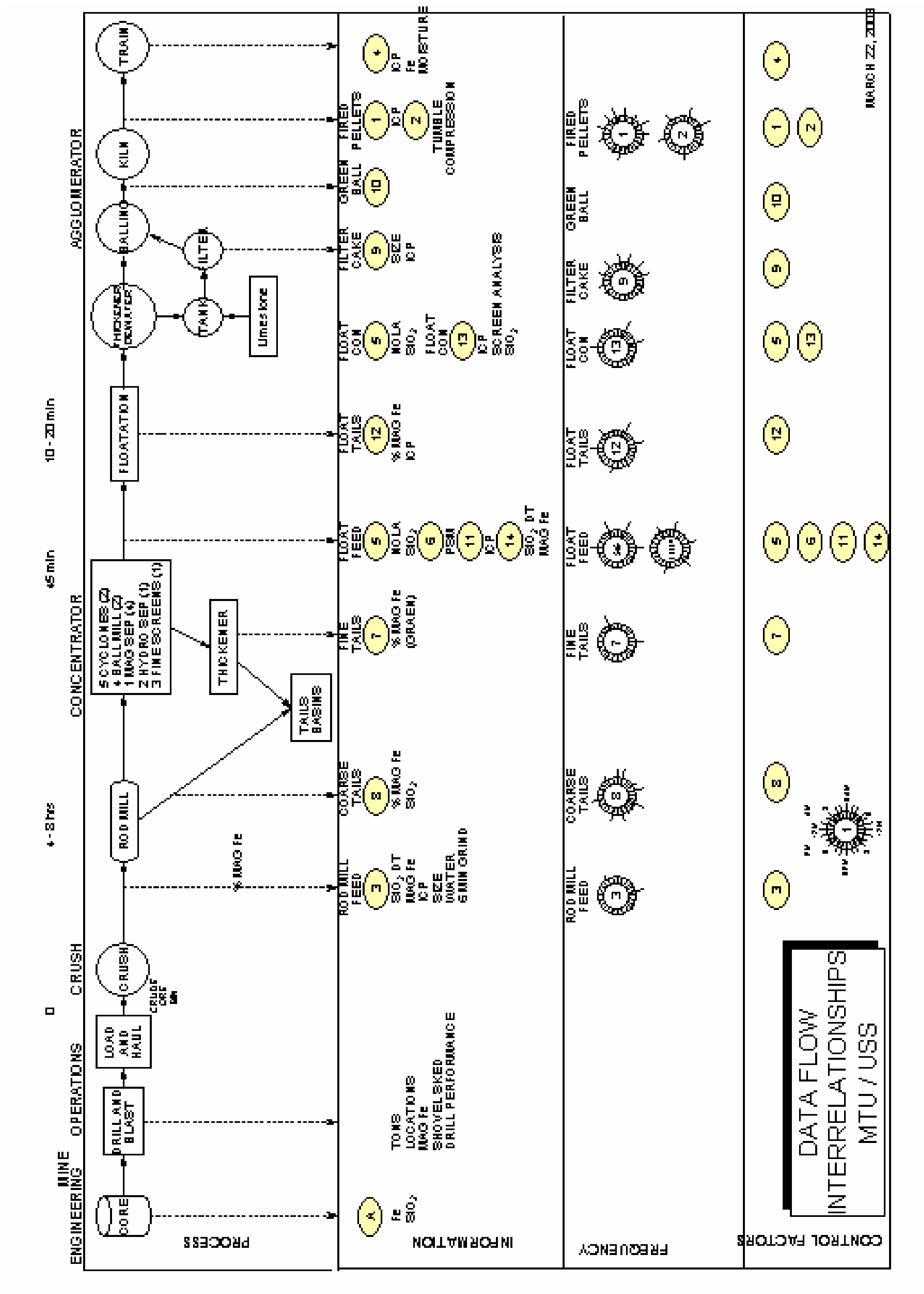

Figure 2. The flowchart developed for the Minntac Mine to show data sources and their relationships to the mining, concentrating, and agglomerating process.

Hibtac Mine

Average annual mill production since 1977 has been estimated and compared in the figures below to the average normalized energy draw by the crushers and by the autogenous mills, and also to powder factor. Since each average incorporates data from an entire calendar year, the effects of seasonal cycles are presumably balanced. Figure 3 illustrates the basic trends visible in time-series plots of the data.

The powder factor has increased steadily since 1989, with a spike in 1996 and a potential jump underway this year (Figure 3A). Mill total production and production rate have reached a plateau from which they are falling slightly (Figure 3B). If iron pellet production is increasing at the same time, this would indicate increasing energy efficiency. Crushing energy requirements have increased to a plateau reminiscent of the production figures, while grinding energy is almost a mirror-image of the crushing energy curve (Figure 3C). Grinding energy is much greater than crushing energy, but the very close correspondence at even this relatively coarse scale indicates a tight correlation; in other words, as the energy required by crushing increases, the energy required by grinding decreases 100-fold. The trick is to induce this behavior to happen repeatedly, and it appears that Hibtac Mine is being successful at doing this. Several aspects of the data set (others are discussed below) confirm that the performance of the autogenous grinding mills controls the performance of the circuits.

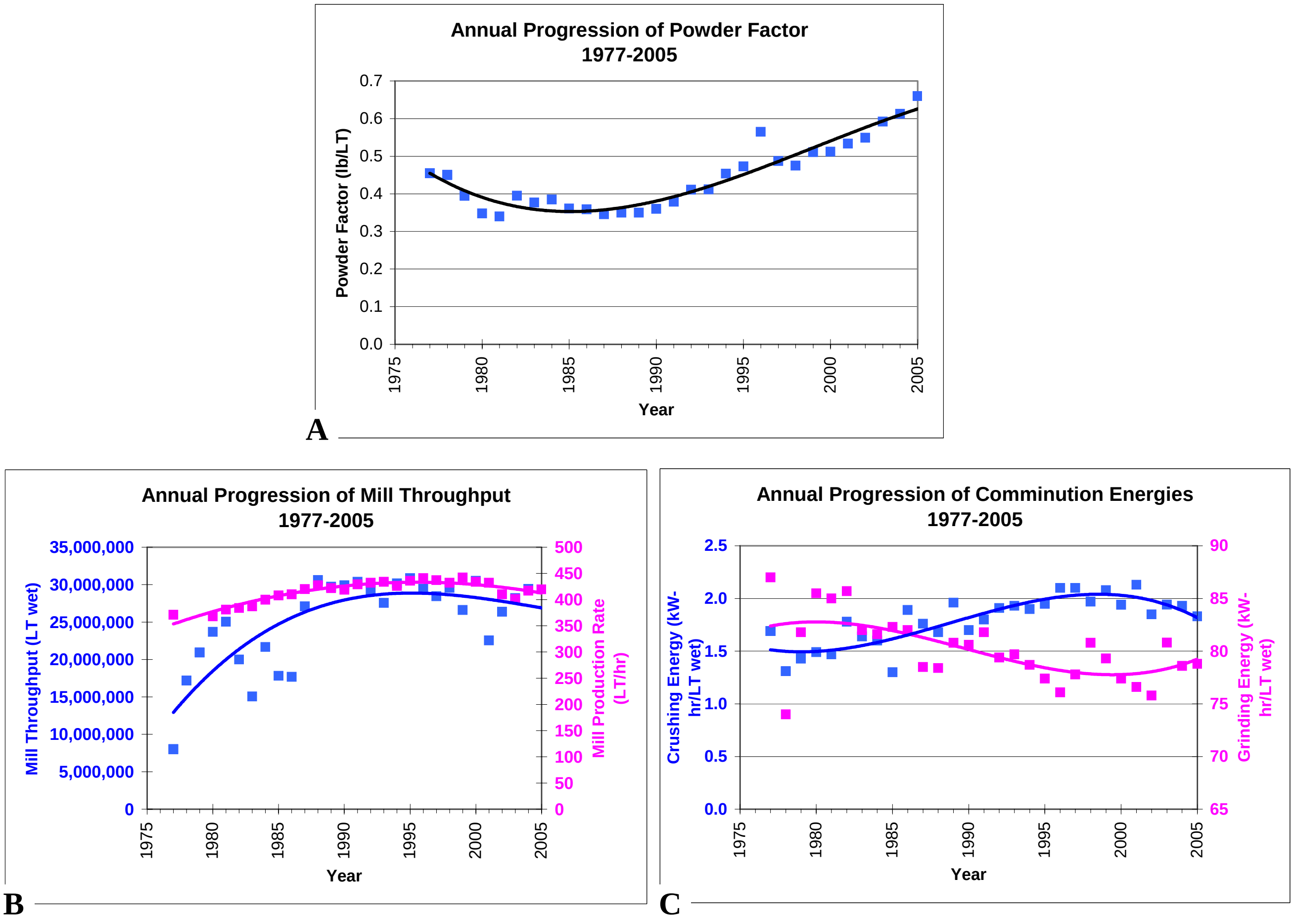

Figure 3. Average annual powder factor and mill production data for Hibtac Mine since 1977, showing several correlated trends.

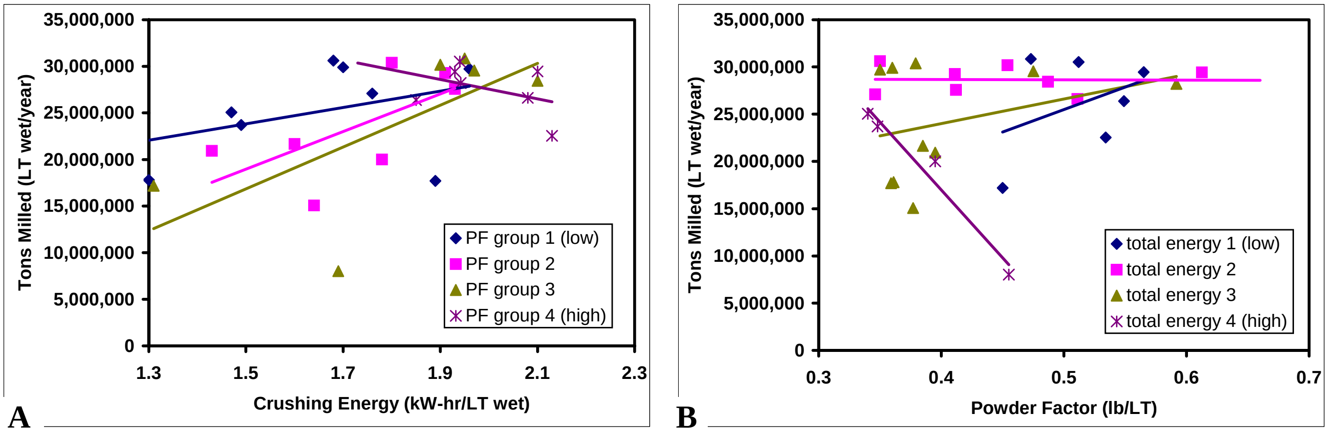

Figure 4. Some basic relationships among average annual mill production data for Hibtac Mine.

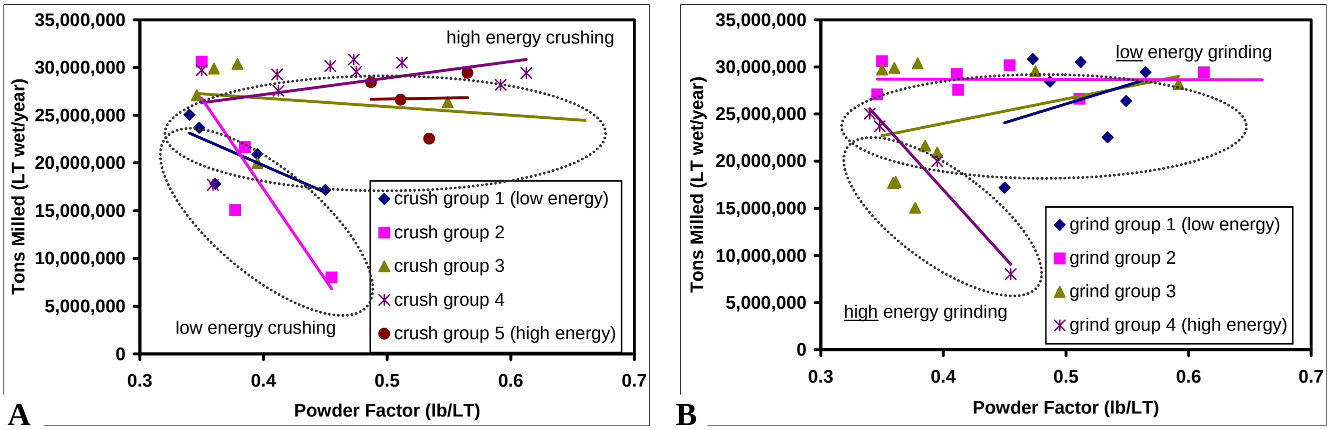

Figure 5. Total production of the mill as a function of powder factor, when crushing energy (A) and grinding energy (B) are taken into account.

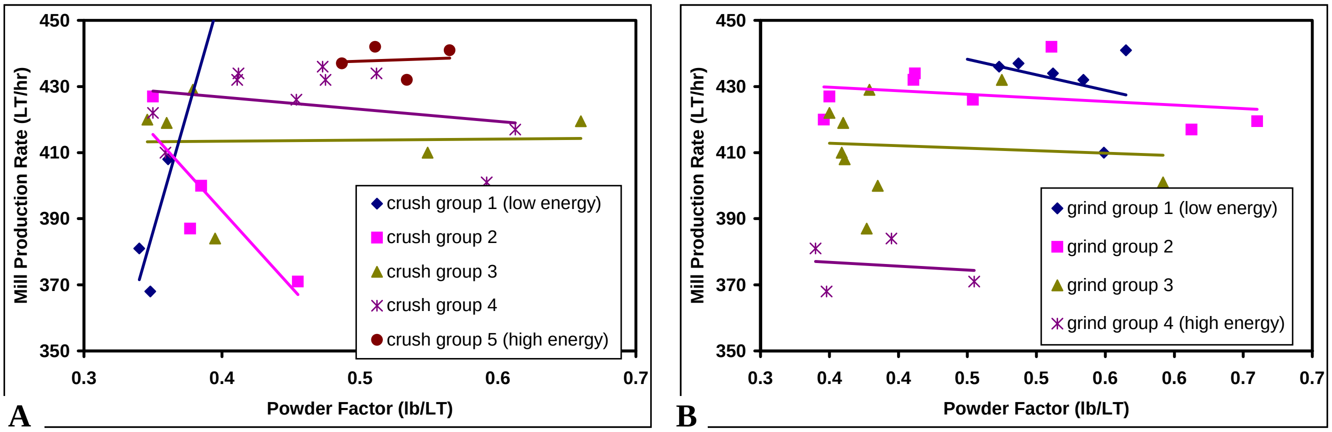

Figure 6. Mill production rate as a function of powder factor, when crushing energy (A) and grinding energy (B) are taken into account.

Bear in mind that these charts do not explicitly take account of the changing stripping ratio and geologic trends that the mine has experienced since 1977. These factors undoubtedly affect the data shown, but are not quantified in these charts. The behavior attributed below to changes in powder factor, crushing energy, and grinding energy is actually due to changes in these factors, but since they are not included in this data set, the energy data serve as proxies.

Figure 4A shows that more tons of ore pass through the mill when the powder factor is highest, and that crushing energy is negatively correlated with production totals for the highest powder factors. For all other powder factors, crushing energy correlates positively with production totals. In other words, the greater the portion of total energy that is devoted to crushing, even though this is an apparently minor component, the higher are the resulting production totals. Figure 5 (discussed below) supports this relationship and explores further the trends seen in Figure 4B. The energy required to grind the ore is 97%-98% of the total energy draw of the mill.

Figure 5A shows that tons produced is affected by powder factor only below a crushing energy of approximately 1.77 kW-hr/long ton (wet). When crushing energy exceeds that threshold, powder factor appears to be irrelevant to the amount of iron produced. Figure 5B shows that production is negatively affected by powder factor above a grinding energy of approximately 81 kW-hr/long ton (wet). In other words, the higher the powder factor used in the difficult regions of the mine, the lower the tons produced. This is likely a case of parallel effects rather than of direct cause and effect, so conclusions about energy control should not be drawn too quickly from this.

To restate, Figures 4 and 5 show that low energy requirements for crushing correlate with high energy requirements for grinding. Since the energy needs for grinding are 36-63 times that for crushing, more efficient crushing is strongly leveraged in the total energy balance. Moreover, the high crushing energy / low grinding energy points are those with higher production totals and production rates (Figures 6 and 7), and are essentially independent of the powder factor used to fragment the ore. Perhaps this is due to the relation of the mean size of the “grains” of iron and matrix minerals in the ore to the mean input and output sizes of the grinding circuits, and to the toughness of their inter-crystal bonding. The differences between this relationship in the difficult ores and in the more easily processed ores may be instructive for diagnostic algorithms for mill operation.

Figure 6 shows how the factors that control crushing and grinding energy requirements also affect the relationship between powder factor and the mill’s production rate. The production rate of the mill is affected by the powder factor only when the energy required for crushing is below a certain threshold (~1.7 kW-hr/LT wet). Mill production rate is slightly negatively affected by powder factor at all levels of grinding energy, and since grinding energy is so much greater than crushing energy, that is the overwhelming trend.

Figure 7 reverses the perspective on these same data, illustrating more clearly the effects that powder factor has on mill production rate. Mill production rate correlates positively with the energy required to crush the ore (Figure 7 A). In fact, production rate becomes increasingly more sensitive to crushing energy as powder factor increases, but only until it exceeds about 0.50 lb/ton, at which point crushing energy becomes less important. Grinding energy and mill production rate are negatively correlated, on the other hand, but a difference in sensitivity of production rate with respect to grinding energy is again slightly evident for the highest powder factors.

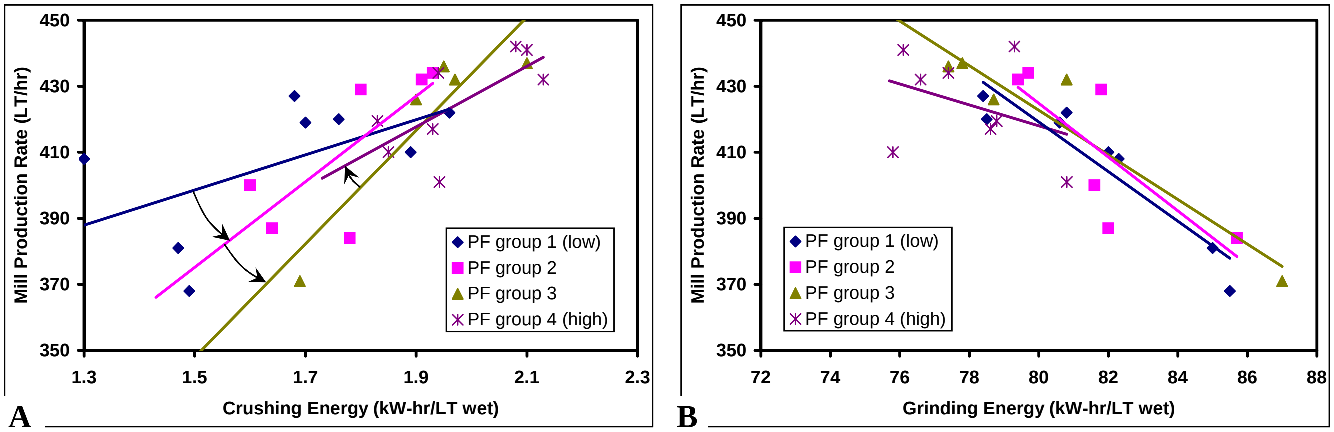

Figure 7. Mill production rate as a function of crushing energy (A) and grinding energy (B) when powder factor is taken into account.

In conclusion, with some exceptions that appear related to factors at the edge of the envelope of economic mining, as the energy required by crushing increases, the energy required by grinding decreases significantly. This is true only for some of the ore, generally that for which the powder facter was the highest and the production and production rate were the lowest.

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