ECONOMICS AND TECHNICAL FEATURES OF PRECONCENTRATION USING SORTING

BO R. ARVIDSON

ABSTRACT

Computer-controlled machine sorting may have a dramatic effect on overall economics of a mine operation. Radiometric, photometric, and conductivity/magnetic sorters have been used for many years and new developments will be reported. Application examples with economics will be given. Sorting underground is shown to be particularly attractive, but machine sorting would be profitable in most cases based on savings in transportation and milling/beneficiation costs only.

Ore Sorters (North America) Inc. - USA
ECONOMICS AND TECHNICAL FEATURES OF PRECONCENTRATION USING SORTING

ABSTRACT

Computer-controlled machine sorting may have a dramatic effect on overall economics of a mine operation. Radiometric, photometric, and conductivity/magnetic sorters have been used for many years and new developments will be reported.

Application examples with economics will be given. Sorting underground is shown to be particularly attractive, but machine sorting would be profitable in most cases based on savings in transportation and milling/beneficiation costs only.

INTRODUCTION

If an ore can be preconcentrated at a low cost it is like finding a high-grade one. No doubt, the ore grade is the most important factor in determining the economic feasibility of a deposit. Even a good grade can be made even better using various sorter technologies as we will show in this paper. All feasibility studies of ores should take into the consideration the possibility of preconcentration.

Preconcentration should be applied as early as possible in the process. It could mean at the mine site, even underground. Sometimes that is not possible, but reduction in crushing and/or grinding costs often provide enough basis for using some form of preconcentration.

There are several sorter technologies available today.
technical aspects that need to be considered in order to evaluate physical preconcentration of a natural raw material.

SORTER FEED CHARACTERISTICS

To enable preconcentration in large particle sizes it is necessary that the valuable elements are occurring in some more concentrated form than the particles to be eliminated. Typically, if the desired element is found in veins, layers or brecciated mineralizations there are good possibilities for sorting. Ores with pebbly composition could also be candidates.

There is a common misconception that there is no use for a sorter for massive ores. However there are at least three sorter applications even for such ores:

1. Sorting of development ore.
2. Massive ores boundaries. It often happens that some ore is left at the extremes to avoid dilution.
3. Pillars from room-and-pillar mining. Dilution, due to backfill, can be coarse sortable rock.

There are a couple more common misconceptions:

1. "The mineral(s) must be liberated in the coarse sizes." This is not normally required. The main purpose for preconcentration is to eliminate of as much barren waste as possible early in the handling of the ore. Composite rock particles (and liberated minerals) will go to further processing.

There are indeed some cases when complete liberation of the
valuable element is required, for example, when a very white limestone for filler purposes is wanted.

2. "As the sorter equipment is relatively capital intensive it is necessary to keep it in continuous operation". It might be true for some low-value materials, but that is not the rule. One underground mine operates a sorter one shift a day, six days a week, and it is indeed profitable.

Once it has been established that there might be suitable geological/mineralogical conditions for sorting, simple tests with a few representative pieces of (barren) waste and ore rock will verify if there are sufficient physical differences to enable sorting with the presently available technologies. If affirmative, the next step in most cases is to process a bulk sample.

With regards to particle size, the ideal ratio of top size to the bottom size in a fraction is 2:1. It may be as large as 3:1 for small particles.

For radiometric and conductivity/magnetic sorting the smallest practical particle size is 25 mm (1 inch), while for the standard photometric laser sorter it is 20 mm (3/4 inch), sometimes 12 mm (1/2 inch). Maximum size is 120 to 140 mm, sometimes 150 mm.

There are both dry and wet (i.e., washed ore) applications for all high-capacity sorting cases (1-5).
For some ores, combination sorting might yield the best performance, e.g. radiometric and photometric, conductivity and photometric. If gold is mineralized in quartz veins as well as associated with sulfides, a sorter with both photometric and conductivity simultaneous sorting would recover the gold in one step even though there are two kinds of mineralization.

Combination sorters using radiometric and photometric sorting have been used for several years, and recently a third sensing mode was added (3).

SORTER TECHNOLOGIES

Definitions

Sorting is normally defined as the process of identifying certain physical or chemical characteristics of individual rock particles which, based on often complex information, are affected by a sorting mechanism that physically changes positions or trajectories of selected particles.

Basic Sorter Subsystems: All automated machine sorters consist of four basic subsystems as follows:

1. Rock presentation
2. Sensing
3. Electronic processing
4. Rock separation

In the following, the subsystems for sorters used for coarse rocks applications will be reviewed, i.e. x-ray diamond sorters are not included.
Rock Presentation: For sorters requiring rocks in single files to be passed through the sensing systems, the feed presentation consists of more elaborate conveying components than for the sorter that accepts randomly positioned rock particles, i.e., the photometric sorter. For a more detailed review, see References.

Sensing: The radiometric sorter (M17) has scintillation detectors (called scints) housed in a drawer beneath the main belt (under a slide plate).

Electromagnetic detectors are used in the conductivity-magnetic sorters in a similar position as the scints. The signals from the detectors are processed electronically and a value for each rock is stored in the processor.

After progressing through the sensing zone, the rocks move over the end of the conveyor. In free flight, they pass between a light source and bank of photosensitive diodes. Rock size and shape as well as location are fed to the processor and stored.

Photometric sorters use a rapidly scanning laser beam (1,2) or a video camera, measuring the level of reflectivity in small increments over the rock particle surfaces.

Electronic Processing: The processor receives all input data, evaluates them and makes a decision as to whether a specific rock particle is to be classified as useful or reject material. An appropriate blast pattern is then sent to the rock separator air blast mechanism.
Rock Separation: Air jet nozzles are directed to provide an adequate blast on selected rock particles with regard to the number of nozzles and the blast duration (based on rock size and shape). Affected particles will be deflected from the normal trajectory path and two products can be collected on either side of a splitter.

APPLICATION EXAMPLES

Magnesite Applications

Cryptocrystalline magnesite ores are excellent candidates for photometric sorting. The white or yellowish white magnesite rocks can be easily recognized and sorted from serpentine and dunite which are colored from brown and grey to black as well as lighter colored soapstone.

A total of 8 sorters are processing three size fractions at the Grecian Magnesite plant near Thessaloniki in Greece. Another major magnesite producer will soon install a sorter.

Even small size producers are now considering machine sorters and our first example is generated for one such company, see Appendix 1. As can be seen, even in countries with half the labor cost, compared to the example, machine sorting would be more economical (and more reliable) than handsorting.

Limestone Applications

There are several similarities between limestone and magnesite applications. The valuable constituent is white and the waste is colored. It is possible to produce cement raw material feed from very low-grade limestone and in many cases the quality
can be upgraded to high-brightness filler or lime process feed. The blue laser has advanced the possibilities in this area.

The largest limestone sorter applications are in Finland, where three sorters in each of two plants are producing cement raw materials, white filler feed and wollastonite process feed. The economics are similar as in Example 1. Labor costs are higher and sorter operating costs are lower in Finland, though.

Pb-Zn Ore Applications

Many complex sulfide ores of Cu-Pb-Zn or Pb-Zn types respond well to sorting and several potentials are being explored presently. Example 2, Appendix 2, is based on extensive operation with a full size M16 photometric sorter in a mine which is using a room-and-pillar method to extract a massive sulfide ore with a host rock mainly consisting of marble.

Precious Metals Applications

Radiometric Sorting: By far, the greatest present sorter application for metal ores is the preconcentration of gold-bearing reef in South Africa. About 14 sorters for such purpose are in operation, most of them the Model M17 radiometric sorter. Typical performance is almost doubling the grade of 94% recovery.

Photometric Sorting: Some valuable heavy minerals are present in quartz veins, e.g. gold, cassiterite and wolframite. Such veins are found as intrusions in country rock, which exhibit reflective properties different from the quartz. Therefore, photometric sorting can recover the quartz vein material selectively and hence improve the metal grade before more expensive milling and
further processing. Several Ml6 sorters have been used in such applications at the Mt. Carbine wolframite mine in Australia (4).

Several potential gold ores can be made viable or more economical using photometric sorting. Table Nos. 1-3 show recent examples. A nearly five-fold upgrading is possible according to results shown in Table 2 at a recovery of 92.8%. The example in Table No. 3 was used to illustrate the economics for modest upgrading, in this case only 33% (5). At a gold price of $350/oz the net revenue would be $11 million per year, which would pay off a sorter installation in 2 months.

Low-grade complex ore can also be upgraded as well as several waste dumps. Even medium grade ores can be enhanced to high grade.

Conductivity Sorting: Many minerals are relatively good conductors. Sometimes gold and silver are mineralized in close association with conductive sulfides and can be concentrated by sorting. For a silver ore example, Table 4, underground sorting could practically double the plant metal output for a small investment compared to the cost of enlarging or driving additional hoisting shafts, increasing hoisting capacity, raising mill capacity, transportation from mine to mill, etc.

A few gold ores show excellent response to conductivity sorting with recoveries at 99+%.

Magnetic Sorting: The same technique used in conductivity sorting can be used for magnetic sorting. One example is shown in Table 7. In this case, the barren country rock (diabase)
contains pyrrhotite, ilmenite and probably minor amount of magnetite. With a PERMROLL magnetic separator, the performance was very similar in sizes down to 1/4 inch (6mm) (5). Based on these results, an economic example, Appendix 3, was constructed. The revenue increase could be as high as $30 million per year.

Uranium Ore Applications

Radiometric sorters have been used for over 25 years to preconcentrate uranium ores. Even today such sorters are used for various ores as well as marginal stockpiles.

Copper Ore Applications

Some copper ores respond sufficiently well to conductivity sorting to make it profitable to use this technology. The first such installation is in India (5). An extensive evaluation has recently been completed that indicate that several ore bodies can be effectively preconcentrated. An estimate shows that the entire preconcentration plant could be paid off in one year.

Other Applications

Several industrial mineral and coal applications do exist for which machine sorting are or have been used in full industrial scale:

- Talc, feldspar, pegmatite (spodumene in feldspar/quartz matrix), quartz pebbles, phosphate, and coal (lignite).

CONCLUSIONS

Machine sorting when it is technically applicable, is shown to be economically attractive for a wide range of ore types. In
to be economically attractive for a wide range of ore types. In countries with low labor costs it is often advantageous to use automated machine sorting, even at wages in the range of $3 to $5 per day.

In addition to improved economics it is often possible to enhance ore reserves by processing lower-grade deposits, extend the particle size range to smaller sizes for preconcentration, recovering marginal grade materials at mine boundaries, development ores and pillars from room-and-pillar mines. Reducing transportation costs per unit of finished product can make small remote ore bodies feasible for exploitation.

In several recent major studies of metal ores for which the final grades were achieved by flotation it was found that the metal values that were lost in the sorter process did not cause an overall reduction in metals recovered compared to a standard flotation, process without preconcentration. Therefore a sorter process should not necessarily be penalized according to the recoveries in a feasibility study.

The most sophisticated machine sorters have now been used for a decade at tremendous benefit for the progressive companies that make full use of computerized sorter technology. As these machine are proven highly reliable, there are many good reasons for a company to explore the potential of using preconcentration to reduce overall costs and improve productivity. Ore sorting is no longer only one of the last options to turn around an unprofitable operation, it can also be applied to make a good opera-
REFERENCES


Table 1. Photometric Sorting Result with North American Gold Ore

**EXAMPLE 2**

<table>
<thead>
<tr>
<th>Size Fraction</th>
<th>Product</th>
<th>Wt Dist</th>
<th>Grade Au</th>
<th>Au Dist</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/4-2</td>
<td>Accept</td>
<td>31.0</td>
<td>55.5</td>
<td>90.2</td>
</tr>
<tr>
<td></td>
<td>Reject</td>
<td>57.2</td>
<td>0.93</td>
<td>2.8</td>
</tr>
<tr>
<td></td>
<td>Head</td>
<td>88.2</td>
<td>20.1</td>
<td>93.0</td>
</tr>
<tr>
<td>2-4</td>
<td>Accept</td>
<td>4.3</td>
<td>28.2</td>
<td>6.5</td>
</tr>
<tr>
<td></td>
<td>Reject</td>
<td>7.5</td>
<td>1.4</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>Head</td>
<td>11.8</td>
<td>11.2</td>
<td>96.7</td>
</tr>
<tr>
<td>3/4-4</td>
<td>Accept</td>
<td>35.3</td>
<td>52.2</td>
<td>96.7</td>
</tr>
<tr>
<td></td>
<td>Reject</td>
<td>64.7</td>
<td>0.99</td>
<td>3.3</td>
</tr>
<tr>
<td></td>
<td>Head</td>
<td>100.0</td>
<td>19.1</td>
<td>100.0</td>
</tr>
</tbody>
</table>

-3/4 not analyzed

Table 4. Conductivity Sorting Result with North American Silver Ore

<table>
<thead>
<tr>
<th>Size Fraction 1-3 Inch (25-75 MM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product</td>
</tr>
<tr>
<td>---------------------------------</td>
</tr>
<tr>
<td>Accept</td>
</tr>
<tr>
<td>Reject</td>
</tr>
<tr>
<td>Head</td>
</tr>
</tbody>
</table>

Note: Waste dilution in actual operation is close to 2:1 hence the accept fraction would be approx. 33 wt %.
<table>
<thead>
<tr>
<th>Size Fraction</th>
<th>Wt Distrib %</th>
<th>Grade Au g/t</th>
<th>Au Distrib %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accept</td>
<td>3.14</td>
<td>26.0</td>
<td>18.8</td>
</tr>
<tr>
<td>Reject</td>
<td>2.77</td>
<td>1.2</td>
<td>0.6</td>
</tr>
<tr>
<td>Head</td>
<td>5.91</td>
<td>14.2</td>
<td>19.4</td>
</tr>
<tr>
<td>2-4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accept</td>
<td>16.41</td>
<td>19.6</td>
<td>74.0</td>
</tr>
<tr>
<td>Reject</td>
<td>32.58</td>
<td>0.3</td>
<td>2.4</td>
</tr>
<tr>
<td>Head</td>
<td>48.99</td>
<td>6.8</td>
<td>76.4</td>
</tr>
<tr>
<td>4-6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accept</td>
<td>18.39</td>
<td>0.8</td>
<td>3.5</td>
</tr>
<tr>
<td>Reject</td>
<td>26.69</td>
<td>0.1</td>
<td>0.8</td>
</tr>
<tr>
<td>Head</td>
<td>45.08</td>
<td>0.4</td>
<td>4.3</td>
</tr>
<tr>
<td>1-6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accept</td>
<td>37.93</td>
<td>11.0</td>
<td>96.3</td>
</tr>
<tr>
<td>(Total Sample) Reject</td>
<td>62.07</td>
<td>0.3</td>
<td>3.7</td>
</tr>
<tr>
<td>Head</td>
<td>100.00</td>
<td>4.3</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Alternatively:

<table>
<thead>
<tr>
<th>Size Fraction</th>
<th>Wt Distrib %</th>
<th>Grade Au g/t</th>
<th>Au Distrib %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accept</td>
<td>19.55</td>
<td>20.6</td>
<td>92.8</td>
</tr>
<tr>
<td>Reject*</td>
<td>80.45</td>
<td>0.4</td>
<td>7.2</td>
</tr>
<tr>
<td>Head</td>
<td>100.00</td>
<td>4.3</td>
<td>100.0</td>
</tr>
</tbody>
</table>

*Incl. 4-6 inch fraction, that is rejecting +4-inch fraction as waste
## Table 3. Photometric Sorting Result with Australian Gold Ore

**EXAMPLE 4**

<table>
<thead>
<tr>
<th>Size Fraction</th>
<th>Wt Distrib %</th>
<th>Grade Au g/t</th>
<th>Au Dist %</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Inch</strong></td>
<td><strong>Product</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1/2 - 1</td>
<td>Accept 12.58</td>
<td>9.77</td>
<td>15.84</td>
</tr>
<tr>
<td></td>
<td>Reject 4.42</td>
<td>0.89</td>
<td>0.51</td>
</tr>
<tr>
<td></td>
<td>Head 17.00</td>
<td>7.46</td>
<td>16.35</td>
</tr>
<tr>
<td>1 - 2</td>
<td>Accept 13.40</td>
<td>10.36</td>
<td>17.89</td>
</tr>
<tr>
<td></td>
<td>Reject 6.60</td>
<td>0.88</td>
<td>0.75</td>
</tr>
<tr>
<td></td>
<td>Head 20.00</td>
<td>7.23</td>
<td>18.64</td>
</tr>
<tr>
<td>2 - 5</td>
<td>Accept 28.17</td>
<td>10.41</td>
<td>37.79</td>
</tr>
<tr>
<td></td>
<td>Reject 15.85</td>
<td>0.87</td>
<td>1.78</td>
</tr>
<tr>
<td></td>
<td>Head 44.02</td>
<td>6.97</td>
<td></td>
</tr>
<tr>
<td>- 1/2</td>
<td></td>
<td>18.98</td>
<td>10.40</td>
</tr>
<tr>
<td><strong>Total Head</strong></td>
<td></td>
<td>100.00</td>
<td>7.76</td>
</tr>
<tr>
<td><strong>Total Accept and Fines</strong></td>
<td></td>
<td>73.13</td>
<td>10.29</td>
</tr>
<tr>
<td><strong>Total Reject</strong></td>
<td></td>
<td>26.87</td>
<td>0.88</td>
</tr>
</tbody>
</table>
Appendix 1

ECONOMIC EVALUATION

EXAMPLE 1

Mine: Magnesite, grade 30 – 40%, mining rate: 700,000 tons/yr

Preconcentration: Photometric sorters, PERMROLL separators

Handsorter feed capacity for 30-60mm: 6 ton/person/shift and
60-120mm: 12 ton/person/shift

Cost $30 per day/person

Sorter operating cost $0.50/ton feed

Complete M16 sorter plant: $1,000,000

Complete M28 + PERMROLL plant: $900,000

Transportation costs and recoveries in +30mm fraction assumed to be similar as for handsorting.

Comparative Costs for +30mm

Hand sorting 30-60mm: 54 people in 2 shift, 5 days/week, 48 weeks/year $5.47/ton

60-120mm, half the cost: $5.74/ton

M/16 Sorter: One sorter 1/2 time 30-60mm (22 hrs/day, 6 days/wk)

1/2 time 60-120mm

Capital cost/year (10 yrs. 9%) $155,820, 50% $77,900

Total cost per ton feed

30-60mm $1.01

60-120mm $0.79

Costs for 10-30mm

Handsorting is uneconomical and inefficient.

Presently going to stockpiles.

PERMROLL + sorter plant: Capital cost/year $140,240

Operating cost per ton $0.60

Total cost per ton $1.40

Machine sorting/separation even of the fine rock size fraction is more economical than handsorting the coarsest size fraction.
EXAMPLE 2

Mine: Pb-Zn, grade approx. 7 and 2% respectively.

Mining rate: 40,000 t/month, in mountain side, aerial tramway

Preconcentration: M16 photometric sorter. Rejection rate 40% of feed. 96% metal recovery.


Gain of additional ore at mine front compensates for 4% loss through sorter process.

Sorter operating cost $0.50/ton.

Feed preparation cost $2.00/ton.

Sorter feed 8,000 t/month (1 shift/day).

Backfill material a bonus so no extra cost for transporting reject. Total investment approximately $1 million.

Preconcentration Costs.

Mining costs (increased production)

\[0.4 \times 8,000 \times 6 = 19,200/\text{month}\]

Sorter plant capital cost

\[= 21,247/\text{month}\]

Operating costs 8 x $0.50

\[= 4,000/\text{month}\]

Feed prep & transportation 2 x 8,000

\[= 16,000/\text{month}\]

Total

\[= 60,447/\text{month}\]

Revenue

Additional metal production:

\[0.4 \times 8,000 \times 30 \times 0.90 = 96,000/\text{month}\]

Net Revenue

\[= 35,553/\text{month}\]

\[= 426,636/\text{year}\]

plus the value of added backfill material, which will be used for recovery of high-grade pillars left after room-and-pillar mining.
ECONOMIC EVALUATION

EXAMPLE 3

Mine: Gold 5.4 g/ton, underground. Original mining rate 3,500 TPD

Preconcentration: MI9 magnetic mode sorter + PERMROLL. Waste reject 40%, 96.4% recovery

Gold price assumed to be $11.25/g

Assuming that the mining rate can be accelerated at a marginal mining cost of $15/ton, the net revenue for the mine can be enhanced. Assume coarse waste disposal cost $0.35/ton.

Replacing the rejected waste with ore translates to 66.7% increase in mining rate, i.e. 5,835 TPD.

Cost Increase

Mining cost per day would increase

$35,025

Preconcentration cost 4.56 x 2335: $10,648

Coarse waste disposal 0.35 x 2335: $817

Final concentration handling $500

Total cost increase $46,990

Revenue Increase

2335 x 5.4 x 11.25 x 0.964 x 0.94 $128,540

Net Revenue Increase $81,550/d or $27 million/year