Ore Sorting Technologies and Applications in the Coal

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Cleaning Coal at the Speed of Light

- Hand sorting was historically a common practice for ores and coal.
- First radiometric sorter in 1946.
- Photometric sorter developed in 1952 was the basis of the first commercial sorters in uranium.
- Around 35 ore sorters worldwide in 1990.
- Estimated 300 plus/minus sorters in 2009.

*Mineral Separation Technologies, Inc.*
Typical Sorting Process

- Process involves the following sequential steps:
  - Particle Presentation
  - Particle Examination
  - Data Analysis
  - Particle Separation

* Tomra Sorting Solutions
Ore Sorting

- Achieves a separation using a sensor, computer and air jets.
- Sensors are:
  - Optical
  - X-Ray
  - Electromagnetic
  - Infrared
  - Lazer
- Multiple sensors can be used.
- 450 air nozzles on a 2 meter wide unit.
- Particle sizes from 100 x 10 mm
- Particle surface can be moist.
Sorting Quartz Pebbles (100 x 20 mm)

- Feed stream on chute
- Nozzle bar
- Trajectory of ejected material
- Trajectory of accepted material

* Tomra Sorting Solutions
Sorter Capacity

\[ Q = W \times D_p \times V \times \beta \]

\[ M = \rho \times Q \]

- \( M \) = mass flow rate
- \( Q \) = volumetric flow
- \( W \) = machine width
- \( D_p \) = particle diameter
- \( V \) = belt velocity
- \( \beta \) = packing (<\( \pi/6 \)°)

Theoretical Capacity (TPH per foot of width per 10 ft/sec velocity)

- SG=1.3
- SG=1.6
- SG=1.9
- SG=2.2
- SG=2.5

15 tph/m

5 tph/m
Typical Sorting Capacity & Operating Cost

*Tomra Sorting Solutions (February 2013 report)
### Ore Sorting Applications

<table>
<thead>
<tr>
<th>COMMODITY</th>
<th>INDUSTRIAL MINERALS</th>
<th>BASE &amp; Fe METALS</th>
<th>FUEL/ENERGY</th>
<th>PRECIOUS METALS</th>
<th>DIAMONDS &amp; GEMS</th>
<th>METAL SLAG</th>
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<tbody>
<tr>
<td>Calcite</td>
<td>Copper</td>
<td>Coal</td>
<td>Gold</td>
<td>Diamonds</td>
<td>Stainless steel</td>
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<tr>
<td>Quartz</td>
<td>Zinc</td>
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<td>Platinum</td>
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<table>
<thead>
<tr>
<th>SENSOR TECHNOLOGY</th>
<th>COLOR XRT</th>
<th>XRT COLOR NIR</th>
<th>XRT RM</th>
<th>XRT COLOR XRF NIR</th>
<th>COLOR XRF NIR</th>
<th>XRT XRF</th>
<th>XRF EM</th>
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</tbody>
</table>

* Tomra Sorting Solutions, 2014
X-Ray Transmission

- X-rays are transmitted through materials at varying degrees according to atomic density.
- Lambert’s Law:
  \[ I_{\text{det}} = I_o e^{-\mu(\lambda) \rho d} \]
  - \( \rho \) = particle density
  - \( d \) = particle size
  - \( \mu(\lambda) \) = mass adsorption coefficient

- Mass adsorption coefficient is specific to the elements within the solid mass.
The transmission of a single energy wave is strongly influenced by particle size.

To provide separations over a range of particle sizes:
- a dual energy x-ray can be applied.
- Combination of x-ray and a lazer for size detection.

Subjecting a composite particle having a range of sizes to a high and low energy x-ray results in transmission curves.
Dual Energy XRT Separations

*De Jong and Harbeck (2005)
X-Ray Image of U.S. Bituminous Coal
Dual Energy XRT Sorting

- Representative samples of the material needed by sorted are subjected to XRT analysis based on the calibration curve.

- The image generated is divided into pixels and the pixels colored according to the location above or below the calibration curve.

- Selection criteria is established based on the % of pixels colored in blue or red.

*H. Strydom, 2010*
60 x 20 mm Anthracite

Primary goal was to avoid wet-based process due to a highly fractured and friable coal and limited water supply.

Very difficult washability characteristics.

Tomra Sorting Solutions test facility in Wedel, Germany

Tests conducted at a throughput capacity of 70 tph

Three SG cutpoint test settings evaluated.
Partition Curves

Rougher, Setting 2

Cleaner, Setting 2

Partition Number vs Mean Density for different particle sizes: 30 X 60 mm, 20 X 30 mm, 20 X 60 mm.
Feed Ash = 68.01%

<table>
<thead>
<tr>
<th>Density Cutpoint Setting</th>
<th>Size Fraction</th>
<th>Product Yield %</th>
<th>Product Ash %</th>
<th>Organic Efficiency %</th>
<th>Product Bypass %</th>
<th>Reject Bypass %</th>
<th>Ep</th>
<th>Sp. Gr. Cutpoint</th>
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</thead>
<tbody>
<tr>
<td>Setting 1</td>
<td>30 x 60 mm</td>
<td>13.10</td>
<td>13.81</td>
<td>97.04</td>
<td>0</td>
<td>0</td>
<td>0.065</td>
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<td>20 x 30 mm</td>
<td>13.45</td>
<td>17.10</td>
<td>61.14</td>
<td>4.23</td>
<td>1.41</td>
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<td></td>
<td>20 x 60 mm</td>
<td>13.72</td>
<td>16.53</td>
<td>65.33</td>
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<td>18.19</td>
<td>16.99</td>
<td>90.96</td>
<td>0</td>
<td>0</td>
<td>0.07</td>
<td>1.97</td>
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<tr>
<td></td>
<td>20 x 30 mm</td>
<td>20.02</td>
<td>22.45</td>
<td>71.51</td>
<td>3.05</td>
<td>3.29</td>
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<td>20 x 60 mm</td>
<td>20.12</td>
<td>21.65</td>
<td>80.48</td>
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<td>1.94</td>
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<tr>
<td>Setting 3</td>
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<td>24.55</td>
<td>24.98</td>
<td>90.93</td>
<td>6.17</td>
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<td>20 x 30 mm</td>
<td>28.75</td>
<td>30.1</td>
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</tbody>
</table>

Rougher stage ejected the low density particles due to the low weight percent in the lower specific gravity fractions.
Cleaner Performance Results

Feed Ash = 68.01%

<table>
<thead>
<tr>
<th>Density Cutpoint Setting</th>
<th>Size Fraction</th>
<th>Product Yield %</th>
<th>Product Ash %</th>
<th>Organic Efficiency %</th>
<th>Product Bypass %</th>
<th>Reject Bypass %</th>
<th>Ep</th>
<th>Sp. Gr. Cutpoint</th>
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</thead>
<tbody>
<tr>
<td>Setting 1</td>
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<td>13.81</td>
<td>100</td>
<td>0</td>
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<td>2.09</td>
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<tr>
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<td>20 x 30 mm</td>
<td>92.69</td>
<td>12.38</td>
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<td>14.92</td>
<td>0.105</td>
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<tr>
<td></td>
<td>20 x 60 mm</td>
<td>94.19</td>
<td>12.69</td>
<td>99.15</td>
<td>0.93</td>
<td>15.32</td>
<td>0.105</td>
<td>2.25</td>
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<tr>
<td>Setting 2</td>
<td>30 x 60 mm</td>
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<td>16.99</td>
<td>100</td>
<td>0</td>
<td>0</td>
<td>0.02</td>
<td>2.09</td>
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<tr>
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<td>20 x 30 mm</td>
<td>88.95</td>
<td>15.46</td>
<td>99.94</td>
<td>0.96</td>
<td>11.39</td>
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<td>20 x 60 mm</td>
<td>90.65</td>
<td>15.61</td>
<td>99.62</td>
<td>0.85</td>
<td>11.67</td>
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<tr>
<td>Setting 3</td>
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<td>90.05</td>
<td>21.97</td>
<td>98.95</td>
<td>0</td>
<td>17.59</td>
<td>0.125</td>
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<tr>
<td></td>
<td>20 x 30 mm</td>
<td>81.98</td>
<td>20.24</td>
<td>98.77</td>
<td>1.73</td>
<td>13.26</td>
<td>0.075</td>
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<td></td>
<td>20 x 60 mm</td>
<td>84.01</td>
<td>20.52</td>
<td>98.86</td>
<td>1.44</td>
<td>14.15</td>
<td>0.085</td>
<td>2.23</td>
</tr>
</tbody>
</table>

- Cleaner stage ejected the higher density particles from the rougher stage product.
Cleaner stage ejected the higher density particles from the rougher stage product.
In some cases, ROM coal is directly shipped to utilities and possibility blended to achieve an expectable feedstock.

Variability due to mining conditions typically results in more or less rock in the ROM coal.

Sorter units provide a high capacity, low expense option to achieve a more consistent quality which positively impacts:

- Pulverizer & boiler downtime
- Boiler efficiency
- Emissions
- Waste handling costs, etc.
Utility Feedstock Upgrading

- 500 tph ROM coal
- ROM material = 40% ash; 9,400 Btu/lb
- Coal Value = $10/ton
- $5,000/hr value
- 6000 hrs/yr operation
- $30 million annual revenue

### Feedstock Parameters
- Feed Rate
- Size Analysis
- Size-by-Size Washability

### Model Parameters
- Screen Aperture
- Screen Open Area
- Screen Mass Loading

### Output Values
- Product Ash
- Energy Recovery

### Parameter Table

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Price</td>
<td>$50 / ton</td>
</tr>
<tr>
<td>Heat Content Specification</td>
<td>12,500 Btu/lb</td>
</tr>
<tr>
<td>Ash Content Specification</td>
<td>12.5%</td>
</tr>
<tr>
<td>Heat Adjustment</td>
<td>$0.40 per 100 Btu/lb above or below specification</td>
</tr>
<tr>
<td>Ash Adjustment</td>
<td>$1.00 per 1.0% ash above or below specification</td>
</tr>
<tr>
<td>Sales Related Costs</td>
<td>$2.50</td>
</tr>
</tbody>
</table>
- Revenue Increase to $9500/hr (vs. $5,000/hr) using Sorting only.
- $26 million annual revenue improvement

Source: Dr. Aaron Noble, Virginia Tech (assumed $0.50/ton CAPEX & OPEX)
- ROM material contains a significant quantity of liberated rock.
- Operator can reject this material at the mine site to reduce haulage costs.
- Haulage costs were assumed to be fixed at $0.30 per ton-mile.
- Primary output parameter was the net savings between a sorting and no-sorting case.
- Source: Aaron Noble, VT

- 1.6 SG and 1-inch screen provided the superior performance.
- Break even point occurs in less than 5 mile haulage distance.
Efficient separations can be achieved using ore sorting technologies on particles as fine as 6 mm (1/4-inch).

Fast processing speeds and advancement in sensor technologies have enhanced selectivity and increased throughput capacities.

Operating costs mainly controlled by the volume of material in the feed that needs to be ejected. Typically in the range of $0.50 to $1.00 per ton.
Conclusions

- Applications include the removal of low grade, valueless rock prior to haulage and direct fuel upgrading for utilities.
- Dual energy XRT sorting provided an excellent separation performance when treating anthracite coal with poor cleanability characteristics.
- Probable error values obtained in our study are similar to those previously reported in publications.

*Mineral Separation Technologies, Inc.*