Cleaning and Dewatering of Fine Particles using Hydrophobic-Hydrophilic Separation (HHS) Process

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In the case of coal, ash and moisture must be removed before the coal can be used to make steel or to produce heat used in generating electricity.

As particle size becomes finer, the difficulty of removing ash and moisture increases.

Billions of tons of coal fines have been mined only to be thrown away in impoundments because of a lack of technology.
Lasting Problem

>4 billion tons in impoundments
Modern coal plants can efficiently recover >50 μm solids.

However, ultrafines intentionally discarded due to cleaning and dewatering difficulties.

Deslime cyclones now the most common method for dealing with ultrafines.
Fine Coal Cleaning in US

Liberation vs. Size

Teh, 1987

Nicole, 1991

YIELD, %

CUMULATIVE YIELD, %

PRODUCT ASH, %

CUMULATIVE ASH, %

d_{50}, mm

- ▲ 0.005
- □ 0.012
- △ 0.014
- ● 0.085

0.1 mm Topsize

10 mm Topsize

1mm Topsize
Fine Coal Cleaning in US

Flotation

- 10-100 µm for minerals
- 45-150 µm for coal
Dewatering occurs preferentially in larger capillaries, leading the water in small capillary untouched.

\[
\frac{dV}{dt} = \frac{\pi R^4 \Delta p}{8\eta L}
\]

Mechanical Dewatering

Water removed layer by layer, requires extensive energy

Thermal Drying

\[\Delta G > 0\]
Fine Coal Cleaning in US

**Oil Agglomeration**

- **Otisca Process**
  - Ash content: 1-2%
  - Moisture: 40%

- **Problem**
  - 7-30% of moisture due to adsorption on coal surface
  - Rest occurs as “large globules of water” trapped in agglomerates
  - Hydrophobic particles act as solid surfactants
Transformational Technology

Hydrophobic-Hydrophilic Separation (HHS) Process
Hydrophobic-Hydrophilic Separation (HHS)

- Uses a low-heat-of-vaporization liquid to save energy
- No lower size limit known
- Dry product with very low ash
Bench-Scale Laboratory Tests

HHS Product Quality

- Ash (db)
- Moisture (ar)

HHS semi-continuous bench-top unit results (2011-17), Variable particle size range
Bench-Scale Laboratory Tests

Indian Coal Fines

Combustible Recovery (%) vs. Product Ash (%)

- Release Analysis
- Flotation
- HHS

MRC - Minerals Refining Company

Virginia Tech
Bench-Scale Laboratory Tests

[Graph showing Copper Recovery vs. Copper Grade for different flotation methods and flowrates.]

- **Chalcopyrite-Quartz Separation (12 µm)**
- **HHS Process**
- **Conventional Mechanical Flotation**
- **Flowrate of microbubbles**
- **8 L/kg**
- **16 L/kg**

Tussupbayev et al., 2015

after Yoon et al. (2016)
## Bench-Scale Laboratory Tests

### REE from coal

#### Contained Value in 1 Ton of Material

<table>
<thead>
<tr>
<th>Product</th>
<th>REE Recovery</th>
<th>Additional Coal Recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fine Reject</td>
<td>$20</td>
<td>$60</td>
</tr>
<tr>
<td>Middlings</td>
<td>$40</td>
<td>$40</td>
</tr>
<tr>
<td>Clean Coal</td>
<td>$10</td>
<td>$50</td>
</tr>
<tr>
<td>Feed</td>
<td>$10</td>
<td>$50</td>
</tr>
</tbody>
</table>

**$/ton of Feed**

<table>
<thead>
<tr>
<th>Products</th>
<th>TREE (Ind.) in ppm</th>
<th>REE Distribution(%wt.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Individual</td>
</tr>
<tr>
<td>Cleaner Concentrate</td>
<td>8812.7</td>
<td>37.4</td>
</tr>
<tr>
<td>Cleaner Tails</td>
<td>891.6</td>
<td>11.3</td>
</tr>
<tr>
<td>Scavenger Tails</td>
<td>195.1</td>
<td>51.4</td>
</tr>
<tr>
<td>Feed</td>
<td>356.9</td>
<td>100</td>
</tr>
</tbody>
</table>

\[ D_{80} = 3.9 \, \mu m \]

Honaker et al., 2016
## Proof-of-Concept (POC) Unit

### Proof-of-Concept Demonstration

<table>
<thead>
<tr>
<th>Feed Source</th>
<th>Feed Ash (%)</th>
<th>Product Moisture (%)</th>
<th>Product Ash (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>KY Mine A – PCI/Thermal</td>
<td>67.5</td>
<td>6.8</td>
<td>3.8</td>
</tr>
<tr>
<td>WV Mine B – High Vol Met</td>
<td>53.0</td>
<td>8.5</td>
<td>3.4</td>
</tr>
<tr>
<td>PA Mine C – Thermal Pitt 8</td>
<td>40.4</td>
<td>3.9</td>
<td>4.3</td>
</tr>
<tr>
<td>WV Mine D – High Vol Met</td>
<td>53.6</td>
<td>3.5</td>
<td>3.9</td>
</tr>
<tr>
<td>WV Mine E – High Vol Met</td>
<td>13.7</td>
<td>4.9</td>
<td>5.0</td>
</tr>
<tr>
<td>VA Mine F – Low Vol Met</td>
<td>7.0</td>
<td>3.8</td>
<td>2.1</td>
</tr>
<tr>
<td>WV Mine G – Low Vol Met</td>
<td>10.7</td>
<td>3.8</td>
<td>3.1</td>
</tr>
</tbody>
</table>
Proof-of-Concept Demonstration

Separation Efficiency ($E$)

$$E = R_{\text{organics}} - R_{\text{minerals}}$$
Pilot-Plant Demonstration
- MRC built and operated at one of the largest U.S. coal company’s mining complex in Southwest Virginia.
- The process was installed in Fall 2015, and operated for >1800 hours
- Intrinsically safe operation under N2 blanket
Pilot-Plant Demonstration
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Pilot-Plant Demonstration
Feed: Deslime Cyclone O/F

- ~58% ash
- ~94% water (6% solids)
- ~44 µm x 0

Clean Coal

- Ash = 4.5%
- Moisture (avg.) = 7%

Organic Recovery

- >95%
Summary

- The HHS process can achieve dewatering and cleaning of ultrafine coal simultaneously.
  - There is no lower size limit known

- The HHS process can be a solution to convert *(long-existing)* ultrafine coal waste to a high-value salable product.
  - A wide variety of ultrafine coal waste has been tested successfully to obtain essentially *dry coal with very low ash contents*.

- Following the successful pilot-scale tests, Minerals Refining Company (MRC) is in the process of designing and constructing the first commercial unit.
Acknowledgements

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