ADVANCED COAL CLEANING AND COAL RECOVERY

US-India Coal Working Group Meeting
April 4-5, 2006

by

Roe-Hoan Yoon
Virginia Tech

http://www.castconsort.org
## Separation Processes Used for Coal

<table>
<thead>
<tr>
<th>Size-Size</th>
<th>Solid-Solid</th>
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<td>Coarse</td>
<td>Dense Media Vessel</td>
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<td></td>
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<td>Basket Centrifuges</td>
</tr>
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<td>Sieve Bends</td>
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In the absence of advanced Solid-Liquid Separation Technologies coal fines are still being discarded.

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<td>Coal Spirals</td>
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<td>Ultrafine</td>
<td>Slimes (-325 M)</td>
<td>Froth Flotation</td>
</tr>
</tbody>
</table>
Impoundments

- 3 billion tons of fine coal
  - In 713 impoundments
  - Mostly in Central Appalachia.

- Main cause
  - Lack of appropriate Separation Technologies
    - Solid-Solid (Fine particles)
    - Solid-Liquid (Dewatering)
Application of Advanced Separation Technologies

- Use of advanced separation technologies at Middle Fork
  - Recovered coal
  - Reuse of impoundment
    - No new impoundment
    - No new permits

Then…

…and Now

Center for Advanced Separation Technologies
Microcel Flotation

![Graph showing recovery vs. ash content with data points for different methods: Full-Scale Conventional, Laboratory Column, and Full-Scale Column.](image)

- **Release Analysis**: Graph shows a trend line with data points indicating recovery percentage against ash content.
- **Ash Content (%)**: The x-axis represents ash content, while the y-axis represents recovery percentage.
- **Methods**: Three methods are compared: Full-Scale Conventional, Laboratory Column, and Full-Scale Column.

![Image of a large column](image)
Microcel at BMA
Cleaner Coal at BMA

![Graph showing ash percentage over time](image_url)
New Installations in Australia
Microcel In Australia

Center for Advanced Separation Technologies

CAST
An Indian Coal

Cum. Yield, %

Flotation Time, minutes

Float Separately

Float Together

>65 mesh

<65 mesh

Center for Advanced Separation Technologies
Fine coal produces lower-ash coal.
Fine coal dewatering is costly.

from Hucko, 1990
Advanced Coal Cleaning Technologies at Virginia Tech

- Microcel flotation
- Dewatering
  1. Dewatering aids
     - Licensed to Nalco
     - Pinnacle pond recovery plant
       - Due to completion in July 2006
  2. Hyperbaric centrifuge
     - Licensed to Decantor
     - Pilot-scale tests is ongoing
  3. Hyperbaric horizontal belt filter
     - Pilot-scale tests is ongoing
  4. Dewatering by displacement
     - An engineering company is exploring commercialization potential
  5. Polymer injection system for Screen-bowl centrifuges
     - 18 installations
Dewatering fine coal helps you increase revenue.

<table>
<thead>
<tr>
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<th>Existing Dewatering</th>
<th>Improved Dewatering</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Clean (tph, ar)</td>
<td>Moisture (% ar)</td>
</tr>
<tr>
<td>Coarse (1.50 SG)</td>
<td>552.6</td>
<td>5.0</td>
</tr>
<tr>
<td>Fines Circuits</td>
<td>85.0</td>
<td>14.0</td>
</tr>
<tr>
<td><strong>Total Plant</strong></td>
<td><strong>637.6</strong></td>
<td><strong>6.2</strong></td>
</tr>
</tbody>
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<tr>
<th></th>
<th>Clean (tph, ar)</th>
<th>Moisture (% ar)</th>
<th>Ash (% ar)</th>
<th>Heat (Btu/lb, ar)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse (1.50 SG)</td>
<td>552.6</td>
<td>5.0</td>
<td>12.0</td>
<td>12450</td>
</tr>
<tr>
<td><strong>Coarse (1.5x1.6 SG)</strong></td>
<td><strong>25.8</strong></td>
<td><strong>5.0</strong></td>
<td><strong>25.0</strong></td>
<td><strong>10500</strong></td>
</tr>
<tr>
<td>Fines Circuits</td>
<td>81.2</td>
<td>10.0</td>
<td>11.0</td>
<td>11852</td>
</tr>
<tr>
<td><strong>Total Plant</strong></td>
<td><strong>659.7</strong></td>
<td><strong>5.6</strong></td>
<td><strong>12.4</strong></td>
<td><strong>12300</strong></td>
</tr>
</tbody>
</table>

Tonnage Gain = 659.7 - 637.6 = **22 tph**
Value = 22 ton/hr x $50/ton x 5,000 hr/yr = **$5.5 MM/yr**

*Great Payback! Dump moisture on steam contracts, it’s 100% inert!*
Fine coal cleaning is good for the country.

Results show that dry coal can be obtained without thermal drying.

<table>
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<tr>
<th>$M_b/M_c$ Ratio</th>
<th>Percent Moisture at Specified Feed Solids Content</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5% Solids</td>
</tr>
<tr>
<td>0.5</td>
<td>---</td>
</tr>
<tr>
<td>0.75</td>
<td>---</td>
</tr>
<tr>
<td>1.0</td>
<td>12.5</td>
</tr>
<tr>
<td>1.5</td>
<td>5.5</td>
</tr>
<tr>
<td>2.0</td>
<td>1.4</td>
</tr>
</tbody>
</table>

By decreasing the top size of the coals cleaned from 1.5 inches to 14 mesh, US can double its reserve for compliance coal (DOE report by Cavallero, et al. 1991)
Advanced Hydrocyclone

- 1.25 Apex, 28 PSI
- 1.00 Apex, 30 PSI
- 0.75 Apex, 32 PSI
- 1.00 Apex, 26 PSI (Washed)

Particle Size (Microns) vs. Mass Passing (%)

120 GPM
Electronic Density Tracers

- **Project:**
  - Develop electronic “tags” to monitor performance of density separators.

- **Status:**
  - Tag/antenna system constructed using transponder technology.
  - Automated system accurately detected 98.5% of tracers added, while lower manual count gave a misleading result.
  - Field study indicated potential savings of $1 MM per plant by improving recovery and reducing waste.

- **Applicability:**
  - Coal, Base Metals, Diamond
Flotation Model
Under Laminar Flow Conditions
(Yoon and Mao, JCIS, 1996; Mao and Yoon, IJMP, 1997)

\[ \frac{dN}{dt} = -kN \]

\[ k = \frac{1}{4} S_b P \]

\[ P = P_c P_a (1 - P_d) \]

\[ k = \frac{1}{4} S_b \left[ \frac{3}{2} + \frac{4 \text{Re}^{0.72}}{15} \right] \left( \frac{D_p}{D_b} \right)^2 \exp \left( -\frac{E_1}{E_k} \right) \left[ 1 - \exp \left( -\frac{W_{ad} + E_1}{E_k'} \right) \right] \]
Microcel
Pond recovery at Pinnacle Mine
Wyoming County, WV

- **Pilot-scale tests**
  - **Moisture reduction**
    - From 29% to 16%
  - **Throughput**
    - 2-3 times higher
  - 200 tons/hr plant is being built by Beard Technologies
A Solution for Indian Coal
(1) innovations for existing plants (including mercury removal);
(2) gasification systems;
(3) advanced combustion systems;
(4) turbines for synthesis gas derived from coal;
(5) carbon capture and sequestration research and development;
(6) coal-derived chemicals and transportation fuels;

(7) liquid fuels derived from low rank coal
(8) solid fuels and feedstocks;
(9) advanced coal-related research;
(10) advanced separation technologies; and
(11) fuel cells for the operation of synthesis gas derived from coal.
Simplified Flowsheet

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<th>Size-Size Separation</th>
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<th>Solid-Liquid Separation</th>
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<td></td>
</tr>
<tr>
<td>Raw Coal Screen</td>
<td>Heavy Media Cyclone</td>
<td>Basket Centrifuge</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intermediate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydrocyclone</td>
<td>Spirals</td>
<td>Screen-Bowl Centrifuge</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
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Microcel at BHP
Typical Ash/Moisture in Product Stream

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<tr>
<th>Particle Size Class (Mesh)</th>
<th>Ash</th>
<th>Moisture</th>
</tr>
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<tr>
<td>Plus 28</td>
<td>7.5</td>
<td>5.1</td>
</tr>
<tr>
<td>28 x100</td>
<td>12.3</td>
<td>8.8</td>
</tr>
<tr>
<td>Minus 100</td>
<td>10.8</td>
<td>25.1</td>
</tr>
<tr>
<td>Total</td>
<td>7.9</td>
<td>7.4</td>
</tr>
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</table>
Release Analysis: Assam Coal II

- 100 mesh
- 325 mesh
# Hyperbaric Centrifuge

**Table 60: Effect of Using Compressed Air for the Centrifugal Filtration of a Pittsburgh Coal**  

<table>
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<th>Drying Cycle or Centrifugation Time (sec)</th>
<th>Cake Moisture (wt %)</th>
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<tbody>
<tr>
<td></td>
<td>Air Pressure&lt;sup&gt;1&lt;/sup&gt; Alone</td>
</tr>
<tr>
<td>------------------------------------------</td>
<td>-----------------------</td>
</tr>
<tr>
<td>30</td>
<td>27.5</td>
</tr>
<tr>
<td>60</td>
<td>25.8</td>
</tr>
<tr>
<td>120</td>
<td>23.8</td>
</tr>
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</table>

<sup>1</sup> 100 kPa of air pressure;  
<sup>2</sup> 2000 G;  
<sup>3</sup> 0.45 inch cake thickness.
Dewatering by Displacement (1)

(Liquid butane displaces water from coal surface.)

An engineering company is exploring commercialization potential.
Dewatering Aids (2)

Pinnacle plant flowsheet
(due to completion in January 2006)
Hyperbaric Filter Centrifuge

- **Project:**
  - Develop a pressurized (hyperbaric) filter centrifuge for solid-liquid separation.

- **Status**
  - Pilot-scale unit constructed and tested
  - One test reduced moisture from 11.0% to 1.86%.
  - Flotation product from Moss 3, VA
    - No air: 15.9% moisture
    - 15 sec air: 10.3%
    - 120 sec air: 6.7%

- **US patent issued**
  - 6 international patents applied for

- **Applicability:**
  - fine coal
  - Mineral fines
  - municipal sludge
  - Food
  - others.
Hyperbaric Belt Filter

- **Project:**
  - Development of high efficiency, high pressure belt filter for solid-liquid separation.

- **Status:**
  - Project just beginning, but design and construction of prototype is well underway.
  - Contact with a major equipment producer to further develop, manufacture, and sell the unit.

- **Applicability:**
  - Coal and Minerals, Municipal Waste Sludge, Environmental Applications
Hydrophobic Dewatering

- **Project:**
  - Develop of novel solid-liquid separation process can compete with thermal drying methods.

- **Status:**
  - Process uses recyclable non-polar liquid to displace moisture
  - Bench-scale tests successfully completed with moistures <1%
  - Concept patent issued and new disclosures expected
  - Marketing discussions underway with a major engineering firm

- **Applicability:**
  - Coal and Minerals, Municipal Waste Sludge, Environmental Applications

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<th>Test Condition</th>
<th>Moisture (%)</th>
<th>Yield (%)</th>
</tr>
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<tbody>
<tr>
<td>5 ml P</td>
<td>2.90</td>
<td>89.6</td>
</tr>
<tr>
<td>5 ml P + 1 ml E</td>
<td>2.17</td>
<td>75.5</td>
</tr>
<tr>
<td>5 ml P + 12 ul RU</td>
<td>1.89</td>
<td>74.2</td>
</tr>
<tr>
<td>5 ml P + 12 ul FA</td>
<td>0.67</td>
<td>49.9</td>
</tr>
<tr>
<td>5 ml P + 120 ul O</td>
<td>1.15</td>
<td>14.0</td>
</tr>
</tbody>
</table>