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

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In the absence of advanced Solid-Liquid Separation Technologies, coal fines are still being discarded.
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)
Microcel Flotation

![Graph showing recovery and ash content for different flotation methods]

- **Recovery (%)**
- **Ash Content (%)**

- **Release Analysis**
- **Full-Scale Conventional**
- **Laboratory Column**
- **Full-Scale Column**
Microcel at BMA

Center for Advanced Separation Technologies
Cleaner Coal at BMA

![Graph showing ash percentage over time with a target line.]
New Installations in Australia
Microcel In Australia
An Indian Coal

The graph shows the cumulative yield (%) against flotation time (minutes) for different particle sizes (>65 mesh and <65 mesh) when floated separately and together. The graph indicates that:

- Flotation separately results in a higher cumulative yield compared to flotation together.
- The cumulative yield increases with increased flotation time, particularly noticeable for the >65 mesh particles.
- The <65 mesh particles have a higher initial yield compared to the >65 mesh particles.

The data suggests that different particle sizes behave differently during flotation, with >65 mesh particles requiring more flotation time to achieve a similar yield compared to <65 mesh particles.
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 CAST
Fine coal produces lower-ash coal.

Release Analysis
Assam Coal I
- 28 x 100 mesh
- 100 mesh
- 325 mesh

Product Ash (%)

Combustible Recovery (%)
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>
<th>Existing Dewatering</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>Fines Circuits</td>
<td>85.0</td>
<td>14.0</td>
<td>10.5</td>
<td>11325</td>
</tr>
<tr>
<td><strong>Total Plant</strong></td>
<td><strong>637.6</strong></td>
<td><strong>6.2</strong></td>
<td><strong>11.8</strong></td>
<td><strong>12300</strong></td>
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<th>Improved Dewatering</th>
<th>Clean (tph, ar)</th>
<th>Moisture (%, ar)</th>
<th>Ash (%, ar)</th>
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<td>12450</td>
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<tr>
<td>Coarse (1.5x1.6 SG)</td>
<td>25.8</td>
<td>5.0</td>
<td>25.0</td>
<td>10500</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>
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</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>Mb/Mc Ratio</th>
<th>Percent Moisture at Specified Feed Solids Content</th>
</tr>
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<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

[Image of an Advanced Hydrocyclone]

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

[Graph showing mass passing percentage against particle size (microns)]

- Mass Passing (%)
- Particle Size (Microns)

Legend:
- Diamond: 1.25 Apex, 28 PSI
- Square: 1.00 Apex, 30 PSI
- Triangle: 0.75 Apex, 32 PSI
- Circle: 1.00 Apex, 26 PSI (Washed)

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
Energy Policy Act 2005

(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 water slurry;
(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>Solid-Liquid Separation</th>
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<td>Raw Coal Screen</td>
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<td>Basket Centrifuge</td>
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<tr>
<td>Heavy Media Cyclone</td>
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| Intermediate         |                         |                         |
| Hydrocyclone         |                         | Screen-Bowl Centrifuge  |
| Spirals              |                         |                         |

| Fine                 |                         |                         |
| Froth Flotation      |                         | Disc Filter             |
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Microcel at BHP
Typical Ash/Moisture in Product Stream

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<th>Particle Size Class (Mesh)</th>
<th>Ash</th>
<th>Moisture</th>
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<tr>
<td>Plus 28</td>
<td>7.5</td>
<td>5.1</td>
</tr>
<tr>
<td>28 x100</td>
<td>8.8</td>
<td>12.3</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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Percent
Release Analysis
Assam Coal II

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

-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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<tr>
<th>Drying Cycle or Centrifugation Time (sec)</th>
<th>Cake Moisture (wt %)</th>
<th>Air Pressure(^1) Alone</th>
<th>Centrifugal Force(^2) Alone</th>
<th>Centrifugal Force(^2) &amp; Air Pressur(^1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>27.5</td>
<td>24.4</td>
<td>14.2</td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>25.8</td>
<td>22.6</td>
<td>12.9</td>
<td></td>
</tr>
<tr>
<td>120</td>
<td>23.8</td>
<td>21.0</td>
<td>10.6</td>
<td></td>
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\(^1\) 100 kPa of air pressure; \(^2\) 2000 G; \(^3\) 0.45 inch cake thickness.
Semi-continuous unit

Cross Section A-A

0.1 mm Opening
Screen Panel Bars
Feed Inlet
Rotation
Filter Cake

Cake Port
Drain Ports

Pressure Chamber
Cake

Sealing Edge
Scraper
Wedge Bars

Cake Discharge
Drain Discharge

Housing
Pneumatic Cylinder
Air
Timed Rotary Valve
Slurry

Seal

Drive Motor

Center for Advanced Separation Technologies (CAST)
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

<table>
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<tr>
<th>Test Condition</th>
<th>Moisture (%)</th>
<th>Yield (%)</th>
</tr>
</thead>
<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>