Development of a Multipurpose Coke Plant for Synthetic Fuel Production

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Slot Battery
Coke Oven
Zones of a Blast Furnace

Figure 4: The driving force of a blast furnace: the counter current process creates voidage at the indicated areas causing the burden to descend.
Currently there is a shortfall of 5.50 million tons of coke per year in the United States.

Shortfall is being filled by imports, mainly from China and, to a lesser extent, from Japan.

The result is high volatility in coke prices and a general trend to dramatic price increases.

Coke FOB to a Chinese port in January 2004 was priced at $60/ton, but rose to $420/ton in March 2004 and in September 2004 was $220/ton. Estimates in early 2008 of up to $450/ton FOB port.
2005 forecasts indicate that the US will produce 11,500,000 net tons of coke, but will require 17,000,000 net tons for blast furnace, foundry, and related uses.

At present, essentially no Indiana coal is being used for coke production. In 2002, Indiana’s steel industry used an estimated 10.7 million tons of coal.

- 8.1 million tons was used for coke production.
- Most from West Virginia and Virginia.
Goals

- Develop multipurpose Heat Recovery coke plant that maximizes the use of non coking coals (up to 50%).
- Combine the best of recovery and non recovery coke making technology to maximize the value of coke oven gas (COG).
- Produce new value from methane as heating fuel or reducing agent for direct reduction, production of diesel oil, fertilizer, hydrogen.
- Electric power from waste heat gas.
- Reduce carbon footprint by converting CO$_2$ to marketable chemical product.
One metric ton of coal typically produces 600-800 kg of blast-furnace coke and 296-358 m$^3$ of coke oven gas.*

Process Value Streams
Develop model for blending coals in way that maximizes Indiana/Illinois Basin coal percentage (minimizes cost) within constraints

- Maintain acceptable CSR levels
- Produce pyrolysis gas streams at various temperatures that have composition suitable for producing Fischer Tropsch liquids, fertilizer, and bulk hydrogen
- Electricity production

Use the Model to formulate the design for a multipurpose coking facility that maximizes value for the entire process while meeting operating requirements

Continue development of new approach to using nut coke in blast furnace operations that maximizes use of Indiana/Illinois Basin coal
**Coal Price Trends**

### Coking / Steam Differential

#### Graph Details:
- **Source:** C. Gubbins, 2001
- *$84.00 = Coking*
- *$64.00 = Steam*

#### Price Trends:
- **1990:** Steam price starts at a differential of around 40.
- **1992:** Coking price slightly higher than steam.
- **1994:** Coking price rises, while steam price remains relatively stable.
- **1996:** Coking price peaks, then begins to decline.
- **1998:** Price differential narrows significantly.
- **2000:** Steam price begins to rise, while coking price stabilizes.

#### Additional Information:
- 2004 - Pittsburgh Seam Steam Coal - 4th Qr 2004 = $63.50; for 2005 = $64 (Source: Argus Daily News)
## Production Cost Example

<table>
<thead>
<tr>
<th>Blend 1</th>
<th>Blend 2</th>
<th>Cost Difference</th>
<th>Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>60% EHV 40% MVM</td>
<td>30% IN/IL 30% EHV 40% MVM</td>
<td></td>
<td>Coke plant using 2 MTPY coal</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$10/ton</td>
<td>$20M/Yr (2005: $40M/Yr)</td>
</tr>
</tbody>
</table>
Before the coke property called CSR (coke strength after reaction with CO₂) was implemented in the USA during the 1970s, Illinois Basin coal was used extensively at a local steel company in blends as follows.

- For wet charged coke batteries, a blend of 60% Illinois coal and 40% Eastern medium volatile coal was used.
- For preheat coke batteries, a blend of 70% Illinois coal and 30% Eastern medium volatile coal was used.

These blends produced coke with high cold strength properties (stability, hardness, impact resistance, and abrasion resistance). But, the hot strength property, CSR, was poor.

- For small blast furnaces, poor CSR values did not cause operating issues, but as furnace sizes increased dramatically in the late 1970s, issues started to arise with furnace component and wall integrity.
To improve CSR, blends were modified

- 30% Illinois coal, 30% Eastern high volatile coal, and 40% Eastern medium volatile coal for wet charged batteries
- 43% Illinois coal, 25% western Canadian high/medium volatile coal, and 32% Eastern medium volatile coal for preheat charged batteries.
- Optionally, for preheat charged batteries a blend of 43% Illinois coal, 25% western Canadian high/medium volatile coal, and 32% western Canadian medium volatile coal

With increased emphasis on CSR as an operating parameter, the use of Illinois coal was discontinued for production of coke.

Research Results

- Indiana and Illinois coal can be used as part of a blend for production of coke in the Multipurpose Coking Facility currently being developed with properties suitable for use in modern large blast furnaces.
- Reduced costs
- New market for Indiana coal
<table>
<thead>
<tr>
<th>TC1931</th>
<th>TC1933</th>
<th>TC1935</th>
<th>TC1940</th>
<th>TC1941</th>
<th>TC1951</th>
<th>TC1952</th>
<th>TC1953</th>
<th>TC1954</th>
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<tr>
<td>30% III</td>
<td>30% Ind</td>
<td>80% Ind</td>
<td>45% Ind</td>
<td>45% Ind</td>
<td>30% Ind</td>
<td>30% III</td>
<td>20% Ind</td>
<td>20% III</td>
<td>50% Ind</td>
</tr>
<tr>
<td>30% EHV</td>
<td>30% EHV</td>
<td>15% EHV</td>
<td>15% EHV</td>
<td>30% EHV</td>
<td>30% EHV</td>
<td>30% EHV</td>
<td>10% PC</td>
<td>10% PC</td>
<td>50% LVM</td>
</tr>
<tr>
<td>40% EMV</td>
<td>40% EMV</td>
<td>40% EM</td>
<td>40% WCM</td>
<td>40% WCM</td>
<td>40% WCM</td>
<td>40% WCM</td>
<td>30% EHV</td>
<td>30% EHV</td>
<td>40% WCM</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>Moisture (%)</td>
<td>2.94</td>
<td>2.5</td>
<td>4.98</td>
<td>5.15</td>
<td>4.48</td>
<td>4.03</td>
<td>3.29</td>
<td>3.24</td>
<td>3.4</td>
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<tr>
<td>Grind (%,-3.35mm)</td>
<td>97.1</td>
<td>93.3</td>
<td>87.6</td>
<td>90.7</td>
<td>91.1</td>
<td>91.9</td>
<td>92.7</td>
<td>94.6</td>
<td>96.9</td>
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<tr>
<td>Dry oven bulk density (kg/m^3)</td>
<td>792</td>
<td>816</td>
<td>754</td>
<td>801</td>
<td>788</td>
<td>801</td>
<td>804</td>
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<td>805</td>
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<tr>
<td>Max oven wall pressure (kPa)</td>
<td>5.65</td>
<td>6.27</td>
<td>2.55</td>
<td>4.62</td>
<td>3.45</td>
<td>4.07</td>
<td>4.07</td>
<td>3.58</td>
<td>7.23</td>
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<tr>
<td>Coking time (h)</td>
<td>16.87</td>
<td>16.37</td>
<td>16.05</td>
<td>17.13</td>
<td>17.03</td>
<td>17.05</td>
<td>17</td>
<td>16.6</td>
<td>16.1</td>
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<tr>
<td>Stability</td>
<td>61</td>
<td>60</td>
<td>42</td>
<td>58</td>
<td>63</td>
<td>57</td>
<td>61.1</td>
<td>60.5</td>
<td>60.7</td>
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<td>CSR</td>
<td>61</td>
<td>68</td>
<td>24</td>
<td>57</td>
<td>65</td>
<td>65</td>
<td>70</td>
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<td>CRI</td>
<td>30</td>
<td>22</td>
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<td>32</td>
<td>24</td>
<td>21</td>
<td>20</td>
<td>28</td>
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<tr>
<td>Hardness</td>
<td>70</td>
<td>70</td>
<td>51.3</td>
<td>70</td>
<td>68</td>
<td>70</td>
<td>69</td>
<td>68</td>
<td>72</td>
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<tr>
<td>Coke size (mm)</td>
<td>61.73</td>
<td>65.53</td>
<td>70.9</td>
<td>70.74</td>
<td>69.3</td>
<td>62.8</td>
<td>59</td>
<td>61.3</td>
<td>64.2</td>
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<td>Coke yield (%)</td>
<td>73.58</td>
<td>70.15</td>
<td>69.6</td>
<td>73.39</td>
<td>74.6</td>
<td>74.9</td>
<td>76.3</td>
<td>78</td>
<td>76.9</td>
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<tr>
<td>Coke sulfur (%)</td>
<td>0.66</td>
<td>0.93</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coke ash (%)</td>
<td>11.1</td>
<td>8.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
1. Presence of liptinite macerals (Valia and Hooper, 1994) contributes to higher fluid properties;

2. At comparable values of vitrinite reflectance, higher carbon content and lower O/C ratio (Walker et al., 2001);

3. Organic sulfur content correlates with plastic range, suggesting that organic sulfur promotes coking behavior;

4. Lower Block liptinites contribute a considerable amount of long chain, unbranched aliphatics to the overall kerogen composition of the seam. An increased cracking temperature would allow the Lower Block coal to maintain coherency and strength further into the coking process, and may assist plasticity (Walker and Mastalerz).
In a recovery coke oven, typically the coke oven gas has a composition of 58% hydrogen, 26% methane, 5.5% nitrogen, 2.25% acetylene, 2% carbon dioxide, 6% carbon monoxide, and .25% oxygen.

One metric ton of coal typically produces 600-800 kg of blast-furnace coke and 296-358 m³ of coke oven gas.

Source:
Pyrolysis Gas Chromatogram
Indiana Coal Pyrolysis Data

The graph shows the volume percentages of various gases as a function of temperature. The gases include H2, O2, CH4, and CO, with data points for different dates (3-14-08, 3-17-08, and 3-19-08). The x-axis represents temperature in degrees Celsius, ranging from 450 to 850, while the y-axis represents volume percentage, ranging from 0 to 70.

Key observations:
- H2 shows a decrease in volume percentage as temperature increases.
- O2 shows an increase in volume percentage as temperature increases.
- CH4 shows a decrease in volume percentage as temperature increases.
- CO shows a slight increase in volume percentage as temperature increases.

Each date has distinct markers and line styles to differentiate the data points.
Eastern Metallurgical Coal Pyrolysis Data
IN Coal Blending Test Pyrolysis Data

Temperature (C)

Volume %

- H2 3-31-08
- H2 4-3-08
- H2 4-7-08
- O2 3-31-08
- O2 4-3-08
- O2 4-7-08
- CH4 3-31-08
- CH4 4-3-08
- CH4 4-7-08
- CO 3-31-08
- CO 4-3-08
- CO 4-7-08
Blend of 40% Indiana Coal with Eastern Metallurgical Coal

Volume (%) vs Temperature (°C)

- H2
- O2
- CH4
- CO
Blend of 40% Illinois Coal with Eastern Metallurgical Coal

Volume (%) vs Temperature (°C)

- H2
- O2
- CH4
- CO
Slow Pyrolysis Kinetics

\[
\frac{dV}{dt} = \frac{K_0 V_0}{m'} 10^{\left[-\frac{E}{RT} - \frac{K_0 R T^2}{m E} e^{-\left(\frac{E}{RT}\right)}\right]} \quad (1975 \text{ data})
\]  

\[m' = \text{heating rate} = \frac{dT}{dt}\]

\[V = \text{volume of any particular gas released at time } t \text{ (not total volatiles)}\]

\[K_0 = \text{rate constant for release of a particular component, including tar, sec}^{-1}\]

\[E = \text{activation energy kJ/mol}\]

\[R = \text{gas constant, kJ/mol °K}\]

\[m = \text{order of reaction}\]

<table>
<thead>
<tr>
<th>Gas</th>
<th>(K_0)</th>
<th>(E)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(H_2)</td>
<td>20</td>
<td>22.3</td>
</tr>
<tr>
<td>(CH_4)</td>
<td>1.67x10^5</td>
<td>31.0</td>
</tr>
<tr>
<td>(CO_2)</td>
<td>550</td>
<td>19.5</td>
</tr>
<tr>
<td>(CO)</td>
<td>55</td>
<td>18.0</td>
</tr>
</tbody>
</table>

Source: Coal Conversion Technology, Wen, C., Lee, E.
Transportation Issues

Index map of Indiana showing the coal-bearing rocks of the Pennsylvanian System in green, underground coal mines in blue, and surface coal mines in brown.

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CSL Pilot Oven
Thank You!

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