Coking/Coal Gasification Using Indiana Coal for the Environmentally Clean Production of Metallurgical Coke, Liquid Transportation Fuels, Fertilizer, and Electric Power

Robert Kramer, Ph.D.

Energy Efficiency and Reliability Center
Purdue University Calumet
Hammond, Indiana
Research Team

Robert A. Kramer, Ph.D., CSM, (PI)
Director, Energy Efficiency and Reliability Center
NiSource Charitable Foundation Professor of Energy and the Environment
Purdue University Calumet

Liberty Pelter, Ph.D.
Assistant Professor, Chemistry and Physics Department
Purdue University Calumet

Hardarshan S. Valia, Ph.D.
Coal Science Inc.

Harvey Abramowitz, Ph.D.
Professor, Department of Mechanical Engineering
Purdue University Calumet
Goals

- Develop new technology that will provide new environmentally friendly methods to create value from coke oven gas and thereby enhance the capabilities and operations of existing and new coke production facilities.

- Develop multipurpose Heat Recovery coke plant that maximizes the use of non coking coals (up to 40%) from Indiana. This will significantly reduce coal costs.

- Combine the best of recovery and non recovery coke making technology to maximize the value of coke oven gas (COG).

- Assure acceptable CSR and other coke characteristics for large Blast Furnaces.

- Produce new value from methane as heating fuel or reducing agent for direct reduction, production of diesel oil, fertilizer, and hydrogen.

- Produce electric power from waste heat gas

- Reduce carbon footprint by converting CO$_2$ to a marketable chemical product using nano catalysis
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.
Multipurpose Coke Facility Is Under Development That Will Provide Clean Coal Technology and Multiple Products
Indiana Coal Samples
Indiana Coal Samples
Indiana Coal Samples
Indiana Coal Samples
Updated Testing Procedures

- New furnace and test system
- Pyrolysis gas is now transmitted directly to the gas chromatograph through tubing connected to a selector valve.
- This has improved the accuracy of the data.
- An expansion of the test system to have the capability of testing up to 5 samples of coal simultaneously is planned.
Updated Testing Apparatus
Purdue Coal Pyrolysis Testing Apparatus
New Coal Test Results from Indiana Coal Mines

Mine 1 Lower Block

- H2%_06-06-18-09
- H2%_06-06-22-09
- H2%_06-06-29-09
- CH4%_06-06-18-09
- CH4%_06-06-22-09
- CH4%_06-06-29-09
- CO%_06-06-18-09
- CO%_06-06-22-09
- CO%_06-06-29-09
- O2%_06-06-18-09
- O2%_06-06-22-09
- O2%_06-06-29-09

Temperature (C) vs. Volume (%).
New coal Test Results from Indiana Coal Mines

Mine 2 Lower Block

Temperature (°C) vs. Volume (%) for different gas components:
- H2%
- CH4%
- CO%
- O2%

Key:
- H2%_08-06-09
- H2%_08-17-09
- H2%_08-18-09
- CH4%_08-06-09
- CH4%_08-17-09
- CH4%_08-18-09
- CO%_08-06-09
- CO%_08-17-09
- CO%_08-18-09
- O2%_08-06-09
- O2%_08-17-09
- O2%_08-18-09
New coal Test Results from Indiana Coal Mines

Mine 2 Upper Block

- H2%_08-19-09
- H2%_08-20-09
- H2%_08-24-09
- CH4%_08-19-09
- CH4%_08-20-09
- CH4%_08-24-09
- CO%_08-19-09
- CO%_08-20-09
- CO%_08-24-09
- O2%_08-19-09
- O2%_08-20-09
- O2%_08-24-09
New coal Test Results from Indiana Coal Mines

Mine 3

Temperature (°C)

Volume (%)
Test of Western Coal

Western Coal

Temperature (°C) vs. Volume (%)

- H2%
- O2%
- CH4%
- CO%

Volume (%) at various temperatures:
- Temperature: 450°C, H2%: X, O2%: Y, CH4%: Z, CO%: W
- Temperature: 500°C, H2%: A, O2%: B, CH4%: C, CO%: D
- Temperature: 550°C, H2%: E, O2%: F, CH4%: G, CO%: H
- Temperature: 600°C, H2%: I, O2%: J, CH4%: K, CO%: L
- Temperature: 650°C, H2%: M, O2%: N, CH4%: O, CO%: P
- Temperature: 700°C, H2%: Q, O2%: R, CH4%: S, CO%: T
- Temperature: 750°C, H2%: U, O2%: V, CH4%: W, CO%: X
- Temperature: 800°C, H2%: Y, O2%: Z, CH4%: A, CO%: B
- Temperature: 850°C, H2%: C, O2%: D, CH4%: E, CO%: F
<table>
<thead>
<tr>
<th>Coal Blend</th>
<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>
<th>TC1995</th>
</tr>
</thead>
<tbody>
<tr>
<td>30% Ill</td>
<td>30% Ill</td>
<td>30% Ill</td>
<td>30% Ill</td>
<td>30% Ill</td>
<td>30% Ill</td>
<td>30% Ill</td>
<td>30% Ill</td>
<td>30% Ill</td>
<td>30% Ill</td>
<td>30% Ill</td>
</tr>
<tr>
<td>30% EHV</td>
<td>30% EHV</td>
<td>30% EHV</td>
<td>30% EHV</td>
<td>30% EHV</td>
<td>30% EHV</td>
<td>30% EHV</td>
<td>30% EHV</td>
<td>30% EHV</td>
<td>30% EHV</td>
<td>30% EHV</td>
</tr>
<tr>
<td>40% EMV</td>
<td>40% EMV</td>
<td>40% EMV</td>
<td>40% EMV</td>
<td>40% EMV</td>
<td>40% EMV</td>
<td>40% EMV</td>
<td>40% EMV</td>
<td>40% EMV</td>
<td>40% EMV</td>
<td>40% EMV</td>
</tr>
<tr>
<td>80% Ind</td>
<td>80% Ind</td>
<td>80% Ind</td>
<td>80% Ind</td>
<td>80% Ind</td>
<td>80% Ind</td>
<td>80% Ind</td>
<td>80% Ind</td>
<td>80% Ind</td>
<td>80% Ind</td>
<td>80% Ind</td>
</tr>
<tr>
<td>20% PC</td>
<td>20% PC</td>
<td>20% PC</td>
<td>20% PC</td>
<td>20% PC</td>
<td>20% PC</td>
<td>20% PC</td>
<td>20% PC</td>
<td>20% PC</td>
<td>20% PC</td>
<td>20% PC</td>
</tr>
<tr>
<td>15% EHV</td>
<td>15% EHV</td>
<td>15% EHV</td>
<td>15% EHV</td>
<td>15% EHV</td>
<td>15% EHV</td>
<td>15% EHV</td>
<td>15% EHV</td>
<td>15% EHV</td>
<td>15% EHV</td>
<td>15% EHV</td>
</tr>
<tr>
<td>40% WCM</td>
<td>40% WCM</td>
<td>40% WCM</td>
<td>40% WCM</td>
<td>40% WCM</td>
<td>40% WCM</td>
<td>40% WCM</td>
<td>40% WCM</td>
<td>40% WCM</td>
<td>40% WCM</td>
<td>40% WCM</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<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>
<td></td>
</tr>
<tr>
<td>Grind (%)</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>
<td>91.0</td>
</tr>
<tr>
<td>Dry oven bulk density (kg/m³)</td>
<td>792</td>
<td>816</td>
<td>754</td>
<td>801</td>
<td>788</td>
<td>801</td>
<td>804</td>
<td>804</td>
<td>805</td>
<td>794</td>
</tr>
<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>
<td></td>
</tr>
<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>
<td>17.02</td>
</tr>
<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>
<td>62</td>
</tr>
<tr>
<td>CSR</td>
<td>61</td>
<td>68</td>
<td>24</td>
<td>57</td>
<td>65</td>
<td>65</td>
<td>70</td>
<td>72</td>
<td>71</td>
<td>66</td>
</tr>
<tr>
<td>CRI</td>
<td>30</td>
<td>22</td>
<td>44</td>
<td>32</td>
<td>24</td>
<td>21</td>
<td>20</td>
<td>28</td>
<td></td>
<td></td>
</tr>
<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>
<td></td>
</tr>
<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>
<td>62.6</td>
</tr>
<tr>
<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>
<td>74.9</td>
</tr>
<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>
<td></td>
</tr>
<tr>
<td>Coke ash (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>11.1</td>
<td>8.9</td>
<td></td>
</tr>
</tbody>
</table>
Value Proposition

- Indiana’s steel and foundry industries are major employers, as well as significant sources of revenue to the State in the form of taxes.

- This technology will help to assure the health of these vital industries, generate new jobs and revenue streams through the use of Indiana coal at a facility to be located in Indiana, and advance the technical state of the art by using Indiana coal and simultaneously enhancing coke oven operations and reducing environmental emissions.
Conclusion

○ Results indicate that it is highly likely that a coking/coal gasification process can be developed that would produce metallurgical grade coke using 20%+ Indiana coal.

○ By using a new blending approach that optimizes coke properties and pyrolysis gas composition it is possible to use Indiana coal blended with other coals to enhance coke oven and modern blast furnace operations and reduce costs.

○ This technology has the opportunity to develop a new market for Indiana Coal

○ Results indicate that it is possible to use pyrolysis gas generated from a coke oven feed with a blend of Indiana and other coal to produce electricity, liquid transportation fuels by means of a Fischer-Tropsch process, fertilizer, electricity, and hydrogen.

○ Methods to isolate carbon dioxide from the process and use it to produce a marketable chemical product with nano catalysis technology is being investigated.
Next Steps

- Continue patent application process
- Complete pyrolysis testing of Indiana Coals
- Obtain washed coal samples, develop optimal blends of Indiana and conventional metallurgical coal, and perform pyrolysis and coke characteristic testing.
- Perform large scale testing at a one ton level and demonstrate feasibility of producing Fischer-Tropsch liquids and other value streams from pyrolysis gas.
- Perform testing at a commercial coke oven and demonstrate capability to enhance coke oven operations and to produce ancillary product value.
- Commercialize the process.
The author would like to thank the Center for Coal Technology Research and the Illinois Clean Coal Institute for their support of this effort. Without their assistance this research would not have been possible.
Contact Information

Robert Kramer, Ph.D., CEM
NiSource Charitable Foundation Professor of Energy and the Environment
Director, Energy Efficiency and Reliability Center
Purdue University Calumet
219-989-2147
kramerro@calumet.purdue.edu
www.calumet.purdue.edu/energycenter