“Natural Gas and the Impact on Pulverized Coal Injection in Blast Furnace Operations”

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Topics

• Latest results on use of natural gas in NAFTA blast furnace operations,

• Progress with “co-injection” of natural gas and coal injection in NAFTA BF operations,

• Limits of coke replacement with injectants in BF operation,

• Global prospects for increased use of natural gas
Decreasing Natural gas Prices Promote Increased Use of Blast Furnace Natural Gas Injection

• Mainly a USA phenomena:
In the US, gas prices have decoupled from oil prices.
Blast Furnace Natural Gas Injection

• Lower natural gas prices lead to increased injection of natural gas in blast furnaces,

• In 2013, all but 1 of 29 of NAFTA blast furnaces are injecting gas while 45% are co-injecting with gas and PCI, while one coal injection system (to serve 2 BF’s) remains idle

• Natural gas is cheaper than coal at many but not all BF sites; continued use of coal maximizes total coke replacement
## NAFTA Blast Furnace Reductant Rates

- **Weighted (by Production Rate) Averages of Reductants by AISI BF’s**

<table>
<thead>
<tr>
<th></th>
<th>Hot Metal Production, M tonnes</th>
<th># of Operating BF’s</th>
<th>Coke</th>
<th>Lump Nut Total</th>
<th>Reductant Usage, kg/tHM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Coal</td>
</tr>
<tr>
<td>1990</td>
<td>55.55</td>
<td>60</td>
<td>454</td>
<td>1</td>
<td>455</td>
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<tr>
<td>1995</td>
<td>61.00</td>
<td>51</td>
<td>402</td>
<td>8</td>
<td>410</td>
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<tr>
<td>2001</td>
<td>51.92</td>
<td>45</td>
<td>395</td>
<td>24</td>
<td>419</td>
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<tr>
<td>2004</td>
<td>52.75</td>
<td>38</td>
<td>366</td>
<td>26</td>
<td>392</td>
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<tr>
<td>2007</td>
<td>47.85</td>
<td>35</td>
<td>377</td>
<td>28</td>
<td>405</td>
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<tr>
<td>2008</td>
<td>44.80</td>
<td>35</td>
<td>379</td>
<td>29</td>
<td>408</td>
</tr>
<tr>
<td>2010</td>
<td>41.80</td>
<td>33</td>
<td>376</td>
<td>32</td>
<td>409</td>
</tr>
<tr>
<td>2011</td>
<td>43.70</td>
<td>32</td>
<td>364</td>
<td>36</td>
<td>400</td>
</tr>
<tr>
<td>2012</td>
<td>44.10</td>
<td>32</td>
<td>364</td>
<td>34</td>
<td>398</td>
</tr>
<tr>
<td>2013</td>
<td>33.10</td>
<td>29</td>
<td>362</td>
<td>31</td>
<td>394</td>
</tr>
</tbody>
</table>

* *9 months*
Limits of BF Natural Gas Injection:

- Replacement ratios of BF injectants:
  - (Kg of coke replaced per kg of injectant)
  - Natural gas  1.3 – 1.4
  - Fuel oil  1.1 – 1.2
  - Coal  0.9 - 1.0

- Natural gas suppresses raceway (combustion zone) flame temperature more than oil or coal
Limits of BF Natural Gas Injection

• Typical BF Raceway Flame Temperatures Range from 3400 F to 4000 F,

• Research by Gas Research Institute/Charles Rivers Associates showed that smaller BF’s could operate at 3100 – 3400 F range,

• Increased oxygen enrichment can restore flame temperature but upper limit of oxygen enrichment set by BF top temperature as well as practical limits: cost of O2, excess hot metal production,

• Typical NG injection limit: 100 to 125 kg/ton of hot metal
# Examples of NAFTA BF Gas Injection Only Practices

<table>
<thead>
<tr>
<th>BF</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hearth Dia. (m)</td>
<td>9.2</td>
<td>10.7</td>
<td>10.7</td>
<td>10.9</td>
<td>9.0</td>
</tr>
<tr>
<td>Production, (tons/day)</td>
<td>5844</td>
<td>6612</td>
<td>6428</td>
<td>6364</td>
<td>4461</td>
</tr>
<tr>
<td>(tons/day/M3)</td>
<td>3.9</td>
<td>2.7</td>
<td>2.4</td>
<td>2.4</td>
<td>2.9</td>
</tr>
<tr>
<td>Coke Rate, kg/T</td>
<td>370</td>
<td>409</td>
<td>365</td>
<td>349</td>
<td>397</td>
</tr>
<tr>
<td>Gas Rate, Kg/T</td>
<td>115</td>
<td>91</td>
<td>99</td>
<td>107</td>
<td>95</td>
</tr>
<tr>
<td>Coal Rate kg/T</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Oxygen, % of Blast</td>
<td>33.1</td>
<td>30.0</td>
<td>25.6</td>
<td>25.9</td>
<td>27.4</td>
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<tr>
<td>Flame Temp, C</td>
<td>1852</td>
<td>2027</td>
<td>1827</td>
<td>1819</td>
<td>1804</td>
</tr>
<tr>
<td>F</td>
<td>3366</td>
<td>3681</td>
<td>3321</td>
<td>3306</td>
<td>3279</td>
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</table>
Examples of NAFTA BF Gas Coal Co -Injection Practices

<table>
<thead>
<tr>
<th>BF</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>J</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hearth Dia. (m)</td>
<td>10.2</td>
<td>8.5</td>
<td>13.7</td>
<td>9.2</td>
<td>9.7</td>
<td>11.7</td>
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<tr>
<td>Production, (tons/day)</td>
<td>4585</td>
<td>3446</td>
<td>8234</td>
<td>5764</td>
<td>5831</td>
<td>7332</td>
</tr>
<tr>
<td>(tons/day/M3)</td>
<td>2.2</td>
<td>2.2</td>
<td>2.0</td>
<td>3.2</td>
<td>2.5</td>
<td>2.3</td>
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<tr>
<td>Coke Rate, kg/T</td>
<td>428</td>
<td>376</td>
<td>336</td>
<td>357</td>
<td>422</td>
<td>345</td>
</tr>
<tr>
<td>Gas Rate, Kg/T</td>
<td>37</td>
<td>23</td>
<td>30</td>
<td>70</td>
<td>71</td>
<td>34</td>
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<tr>
<td>Coal Rate kg/T</td>
<td>71</td>
<td>111</td>
<td>151</td>
<td>83</td>
<td>5</td>
<td>144</td>
</tr>
<tr>
<td>Oxygen, % of Blast</td>
<td>25.7</td>
<td>24.3</td>
<td>26.3</td>
<td>30.9</td>
<td>25.7</td>
<td>26.6</td>
</tr>
<tr>
<td>Flame Temp, C</td>
<td>2096</td>
<td>2092</td>
<td>2133</td>
<td>2091</td>
<td>1932</td>
<td>2160</td>
</tr>
<tr>
<td>F</td>
<td>3805</td>
<td>3798</td>
<td>3871</td>
<td>3796</td>
<td>3279</td>
<td>3920</td>
</tr>
</tbody>
</table>
Global prospects for increased use of natural gas
Global shale gas reserves for 2012 (trillion cubic meters)

- 36.1 China;
- 24.4 U.S;
- 21.9 Argentina;
- 19.3 Mexico;
- 13.7 South Africa;
- 11.6 Australia;
- 11.0 Canada;
- 8.2 Libya;
- 6.5 Algeria
- 6.4 Brazil;
- 5.3 Poland.
Global shale gas basins, top reserve holders

- Canada 11.0
- U.S. 24.4
- Mexico 19.3
- Argentina 21.9
- Poland 5.3
- Libya 8.2
- Algeria 6.5
- Brazil 6.4
- China 36.1
- Australia 11.2
- South Africa 13.7

Assessed basins:
- With resource estimate
- Without resource estimate

Source: EIA based on Advanced Resources International Inc data, BP

Reuters graphic/Catherine Trevethan
Challenges to global shale gas production

- Major environment risks:
  - Water consumption during the hydraulic fracturing process
  - Effects on bio diversity
  - Channeling away from agriculture uses
  - Treatment and disposal of Waste Water
  - Proper secure storage on site
  - Infrastructure to recycle or treatment for discharge or reuse
  - Groundwater Contamination from fracturing fluid
  - Accidentals spills
  - Leakages
  - Higher scale leading to higher risks

- Some wells at least in China could be more complex and deeper. Economics for drilling these wells have not been clearly established
Challenges to global shale gas production

- Gas prices have fallen in US but in ROW it remain linked to oil indexed prices. It does not appear that it will follow the US path very soon,
- In the US, gas prices have decoupled from oil prices... .. . but what about other regions?
- In Europe, it is a mix of oil indexed gas prices (from Statoil and Gazprom) and some hub prices from Qatar mirroring current spot prices. But the average gas prices remain very high. In the medium term, this is unlikely to change.
Challenges to global shale gas production

- In China gas prices remain stubbornly linked to oil indexed prices despite pressure from buyers. There is talk about reforming these to reflect the current spot prices but it could take a number of years before shale gas imports and local shale gas production to start before prices align to market levels in the US.

- In Brazil, the situation is no different from Europe and China.

- Key Point – In USA landowners control mineral and gas ownership; elsewhere globally the State controls mineral and energy resources
Challenges to global shale gas production

- In the US at least, the ready gas pipeline and distribution infrastructure was available. Therefore it has been possible to increase gas supplies relatively easily.

- In other regions like India, Brazil, Indonesia, Mexico the pipeline infrastructure is underdeveloped. Meeting the large growing production would require building new pipeline infrastructure which is inherently very capital intensive and potentially slow with burdens of permitting process.
Forecast of shale gas production up to 2035 (cu mt)*

- USA
- China
- Canada
- Australia
- India
- Indonesia
- Russia
- Mexico
- Argentina
- Poland
- Brazil

* Golden Rules Scenario
Thank You for Your Attention!

Special Acknowledgement to Hatch for use of material in slides 4, 13-18
Appendix - slides from 2012 presentation
Impact of Blast Furnace Process Improvements on Met Coke Demand

Global Trends in BF Operations That Reduce Met Coke Demand:

• Concentrate Production in Largest, Most Efficient Furnaces,
• Incremental Increases in Injection of Coal, Gas, Plastics, other reductants,
• Improvements in Sinter, Pellet Properties

- Declining iron ore grades will increase BF slag volumes and coke rates

Overall: expect 3-5% decrease in specific coke consumption over 5 year period
Gas Based Shaft Furnace Direct Reduction

• Now economically feasible in USA,
• Nucor building 2.5 MTPY DRI plant in Louisiana to ship DRI to existing EAF plants; planning second plant;
• SeverstalNA has been planning DRI plant,
• Other EAF flat rolled mini mills studying gas based DRI projects
Gas Based Shaft Furnace Direct Reduction

• **Major initial impact:**

  elimination of imported merchant pig iron (Brazil, Russia, Ukraine)

  No further expansion of coal based DRI, hot metal or pig iron nugget projects in USA,

  IDI, Mesabi Nugget plants will continue but further plants less likely
Alternate Steelmaking Production Route: EAF Steelmaking based on Ore Based Metallics

- Gas Based Shaft Furnace Direct Reduction -

  Longer range impact:

- Shift towards DRI/EAF steel production route:
  - Continued expansion by current EAF flat rolled steel companies: e.g. expansion at Severstal Columbus helped Severstal divest BF/BOF plants
  - Switch to DRI/EAF steel production by current BF/BOF producers: less likely due to capital constraints
Prospect for Large Scale Smelting Reduction to Replace Blast Furnace Ironmaking,

- Objectives: eliminate coke, sinter, pellet facilities with hot metal process to feed existing BOF steel plants
<table>
<thead>
<tr>
<th>Process Type</th>
<th>Large Scale Options</th>
<th>Small Scale Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blast Furnace</td>
<td>Fastmelt, Redsmelt</td>
<td>Romelt, AusIron, Tecnored</td>
</tr>
<tr>
<td>Cupola</td>
<td>AISI, DIOS</td>
<td></td>
</tr>
<tr>
<td>OxyCup</td>
<td></td>
<td>Romelt, AusIron, Tecnored</td>
</tr>
<tr>
<td>Coke</td>
<td>coal-based</td>
<td></td>
</tr>
<tr>
<td>Reduction</td>
<td>Pellets/lump, fines</td>
<td>Pellets/lump, fines</td>
</tr>
<tr>
<td>Mini-Blast Furnace</td>
<td>Corex, IDI</td>
<td>ITmk3</td>
</tr>
<tr>
<td>Blast Furnace</td>
<td>Large scale Finex</td>
<td></td>
</tr>
<tr>
<td>HiSmelt</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CCF/HiSmelt</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Prospect for Large Scale Smelting Reduction to Replace Blast Furnace Ironmaking,

- Corex, Finex processes only ones to reach commercial status:
  global production < 10 MTPY

Corex, Finex processes have very high capital costs; high operating costs; adopted in niche situations only
Conclusions

- NAFTA met coke demand decreasing due to:
  - increased BF natural gas injection
  - expansion of EAF flat rolled minimills, now being fed by gas based DRI plants

Globally, BF/BOF steelmaking will remain dominant but specific coke consumption will decrease with increased scale, injection rates and burden property improvements.

Smelting reduction processes will have limited impact globally in next 5 years.