CARBON BASED BRIQUETTES
- A REVIEW

Viktor Myrvåges

NyKoSi Seminar, Trondheim, Oct 22-23 2016
Outline

1. Introduction
2. Briquetting with binders
   - Binders
   - Industrialized pilot plants
   - Laboratory Research
3. Binderless technology
   - Industrialized technology
   - Laboratory Research
4. Briquetting technology
5. Summary
Personal interest in agglomerates
Results from coals with different rank and petrographical composition

SINTEF SIO REACTIVITY RESULTS (R10 CORRECTED)

<table>
<thead>
<tr>
<th>Samples</th>
<th>LD</th>
<th>MD</th>
<th>HD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue Gem</td>
<td>80 - 85</td>
<td>85 - 90</td>
<td></td>
</tr>
<tr>
<td>Peak Downs</td>
<td>95 - 100</td>
<td>95 - 100</td>
<td></td>
</tr>
<tr>
<td>Stasctic</td>
<td>90 - 95</td>
<td>85 - 90</td>
<td></td>
</tr>
</tbody>
</table>
Natural agglomerates

Microphotograph of coal

Microphotographs of reacted samples
1. Introduction
2. Briquetting with binders
   - Binders
   - Industrialized pilot plants
   - Laboratory Research
3. Binderless technology
   - Industrialized technology
   - Laboratory Research
4. Briquetting technology
5. Summary
Briquetting technology
- Binders

- The binder properties:
  - Produces a strong briquette
  - Does not reduce the quality of the carbon material
  - Does not interfere with the use of the carbon
  - Is environmentally acceptable
  - Is economically viable

- The most successful binders have been:
  - Pitch (replaced by Bitumen)
  - Bitumen
  - Lignosulphonates
  - Molasses
  - Starch
  - Binder with lime
  - Resin, styrene and esters
Ancit briquettes

SMOKELESS FUELS / HOT BRIQUETTING / SANDANCIT

- Smokeless briquettes developed as heating fuel in the 1960’s by DSM
- Alsdorf plant using hot briquetting with coking coal and breeze as raw materials
- Temperature at about 500 deg C
- Post hardening step for obtaining desired strength
- Plant shut down after severe fire

- In the 80’s the plant was re-started by Laborlux
- Developed the sandancit briquette
- 50% quartz sand, 50% petcoke with coking coal as binder
- Tested at Kemanord
In the 90’s AIMCOR built a 100,000 tpy briquetting plant in Rotterdam

- Raw materials: green petcoke, coal, quartz sand, lime and a catalyst
- Binder: Coal tar pitch
- C/SiO$_2$ molar ratio: 5:1
- Green briquettes calcined in rotary kiln with sand bed at about 550 deg C
- Poor thermal and mechanical properties
- Industrial test reported high disintegration and fines generation of briquettes
- Plant shut down
AIMCOR Silgro plant

- Principle

1-6: Raw material bins
7-10: Recycle
11: Scales
12: Dryer
13: Screen
14: Crusher
15: Pre-heater
16: Mixer
17: Cooler
18: Roller press
19: Rotary kiln
20: Briquettes
Carbosil

DEVELOPED BY R&D CARBON

- High purity Carbosil briquettes developed for direct UMG-Si production in SAF
- Binder: HT coal tar pitch
- Molar ratio C/SiO$_2$: 5:1
- Co-carbonization process:
  - Green granular carbon and green briquettes
  - 750 deg C
  - Vertical retort

Granular carbon materials co-carbonized with green briquettes in a vertical retort at final temperature at about 750 deg C

Carbon dry aggregate prepared by crushing and screening in a continuous pilot roller crusher and multideck screening machines

Dry aggregate is mixed and pre-heated before mixing in a high intensive propeller mixer

Paste is cooled by water addition to the right temperature before briquetting

Green briquettes co-carbonized in vertical retort in order to obtain desired strength
Carbosil properties

**VS ANCIT AND SILGRO**

- Similar molar ratios of C:SiO$_2$ (5:1)
- Highest density of the Carbosil briquettes
- Highest strength (load strength)
  - Due to intimate mixing of dry aggregate and size control before compression
- Carbosil briquettes are more suitable for UMG-Si production due to lower ratio of non-SiO$_2$ ash components
- Silgro and Sandancit have similar values of loss and dust formation in CO$_2$. Both superior to the Silgro briquettes

### Table I. Comparison of Carbosil with Previous Industrial Briquettes (Ancit and Silgro)

<table>
<thead>
<tr>
<th>Apparent density</th>
<th>kg/dm$^3$</th>
<th>1.49</th>
<th>1.35</th>
<th>1.52</th>
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</thead>
<tbody>
<tr>
<td>Load strength</td>
<td>kg</td>
<td>120</td>
<td>80</td>
<td>140</td>
</tr>
<tr>
<td>Loss in CO$_2$</td>
<td>%</td>
<td>14</td>
<td>18</td>
<td>13</td>
</tr>
<tr>
<td>Dust in CO$_2$</td>
<td>%</td>
<td>11</td>
<td>54</td>
<td>9</td>
</tr>
<tr>
<td>Ratio loss/dust</td>
<td>–</td>
<td>1.2</td>
<td>0.3</td>
<td>1.4</td>
</tr>
<tr>
<td>Volatiles</td>
<td>%</td>
<td>4</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>Non SiO$_2$ ash</td>
<td>%</td>
<td>3</td>
<td>2</td>
<td>0.2</td>
</tr>
</tbody>
</table>
FeSi agglomerates

PATENTED BY OLA RAANESS

• US patent 1998

• Raw Materials
  - Swelling coal (FSI=8-9)
    • Size: < 3 mm
    • Moisture: < 3 wt%
  - Iron slags
    • Size: < 106 μm

• Carbon to Fe ratio (mass): 0.2-1:1.5 (preferred 1:2:1)

• No binders in the laboratory test

• Possible binders: CTP, bitumen
FeSi agglomerates patented by Ola Raaness

LABORATORY TESTS

• Coal to slag weight ratio: 0,8-1,5:1
• Briquetting:
  - Cool pressing
  - Load: 10-20 tonnes
  - Cylindrical briquettes with d = 30 mm
  - Length of green briquettes = 10-15 mm
• Sintering
  - 400-500 deg C for 30 min
  - Alsint crucible with lid in air

PILOT BRIQUETTING PLANT

• Raw materials:
  - Coal size: < 2 mm
  - CTP as binder (6-7 wt%)
• Coal to slag weight ratio: 1,8:1
• Continous roller press
• Sintering:
  - 400 deg C for 10 min
  - Air atmosphere
• Briquettes
  - Pillow shaped
  - Dimension 35x35x20 mm
NEDO – Development of Ferrocoke for use in blast furnaces
- JFE Steel, Nippon Steel and Kobe Steel

• Raw Materials:
  - Weakly caking and non-caking coals
  - Ore
  - Innovative binder from the Hyper Coal process

• Coal / ore ratio: 7:3
• Binder: 5-9 wt%
• Briquetting temperature: 100 – 120 deg C
• Size: 30x25x15 mm
• Calcination in shaft furnace
• Coking temperature: 800 – 1000 deg C
• Briquettes tested at blast furnace (No. 6) at Chiba works
Process flow of the Ferrocoke plant

- Iron ore
- Non-coking coal
- Crusher
- Dryer Pre-heater
- Mixer/kneader
- Forming furnace
- Shaft furnace
- Gas heating, Carbonization/Reduction
- Sintered ore
- Oven coke
- Blast furnace
- Briquetting
- Carbonization
- Stock yard
- Crushing and heating
- Gas recycle

Furnace type: Shaft
Capacity: 30t/d
Location: JFE Steel Corp., East Work (Keihin)
Water resistant briquettes from Turkish lignite

- Coal size: < 3 mm
- Binder: Co-polymer binder Mowilith-VDM
- Briquetting: Hydraulic press
- Pressure: 30 – 60 MPa
- Briquette size: 30 mm diameter
- Addition of molasses increased strength
- Lime did not show any positive influence on the shatter index
Water resistant briquettes from Turkish lignite

- Results

• Compressive strength correlated with increased ratio of bituminous coal due to the higher inherent compressibility of bituminous coal
• Strength increased with addition of binder
Briquetting of coal fines and saw dust
- Centre for Applied Energy Research, University of Kentucky

• Business Case:

• Briquetting process:
  - 90 wt% coal fines, 10 wt% saw dust
  - Diameter: 25.4 mm
  - Load: 4000 lbf
  - Temperature: 22 deg C

• Tests:
  - Compressive strength
  - Water resistance
  - Shatter resistance
  - Attrition index
Briquetting of coal fines and saw dust
- Information

• Equivalent – cost basis
  - Cost 8 USD/nt as the binder application rate
• More than 10 binders evaluated
• Evaluation of binders
  - Best:
    • Guar gum
    • Wheat starch
    • Reax+2 wt% lime
  - Other potentials
    • Black strap molasses
    • Paper sludge
    • Tall oil emulsions
    • Molasses
    • Coal tar

• Coal samples:
  - Bituminous coal rank
  - Coal fines from JRC and Cooke and Sons Mining
  - 20-25 wt% moisture
• Saw dust
  - Mix of three species (or pure species)
    • White Oak
    • Red Oak
    • Poplar
  - Size: < 6.3 mm
### Briquetting of coal fines and saw dust

- Results (Compressive strength, 90wt% coal and 10wt% saw dust)

<table>
<thead>
<tr>
<th>Binder ID</th>
<th>Binder Wt %</th>
<th>Green Strength</th>
<th>1-day Strength</th>
<th>7-day Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peridur 300</td>
<td>0.4</td>
<td>34.3</td>
<td>35.7</td>
<td>189.4</td>
</tr>
<tr>
<td>Western Bentonite</td>
<td>6.7</td>
<td>34.5</td>
<td>35.1</td>
<td>70.9</td>
</tr>
<tr>
<td>Wheat Flour, Wal-Mart</td>
<td>3.4</td>
<td>30.2</td>
<td>37.8</td>
<td>126.1</td>
</tr>
<tr>
<td>Spring Wheat Flour</td>
<td>7.2</td>
<td>42.6</td>
<td>42.5</td>
<td>161.3</td>
</tr>
<tr>
<td>Lavabond</td>
<td>6.7</td>
<td>30.5</td>
<td>40.0</td>
<td>71.0</td>
</tr>
<tr>
<td>Corn Starch</td>
<td>2.9</td>
<td>39.0</td>
<td>51.0</td>
<td>121.2</td>
</tr>
<tr>
<td>Black Strap Molasses</td>
<td>6.4</td>
<td>33.1</td>
<td>37.0</td>
<td>49.9</td>
</tr>
<tr>
<td>Coal Loading Tar</td>
<td>5.0</td>
<td>43.4</td>
<td>39.9</td>
<td>73.6</td>
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<tr>
<td>Paper Sludge</td>
<td>17.8</td>
<td>41.0</td>
<td>29.2</td>
<td>33.8</td>
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<tr>
<td>Lime</td>
<td>8.0</td>
<td>45.6</td>
<td>32.6</td>
<td>67.1</td>
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<tr>
<td>RS-2</td>
<td>4.8</td>
<td>32.8</td>
<td>22.6</td>
<td>23.2</td>
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<tr>
<td>Sodium Silicate</td>
<td>8.0</td>
<td>31.3</td>
<td>68.9</td>
<td>73.6</td>
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<td>Polybond 300G</td>
<td>6.2</td>
<td>30.2</td>
<td>33.7</td>
<td>55.4</td>
</tr>
<tr>
<td>Polybond</td>
<td>9.4</td>
<td>25.7</td>
<td>34.1</td>
<td>45.9</td>
</tr>
<tr>
<td>Guar Gum</td>
<td>1.0</td>
<td>43.7</td>
<td>70.4</td>
<td>142.9</td>
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<tr>
<td>Bleached Softwood pulp</td>
<td>1.5</td>
<td>54.6</td>
<td>35.8</td>
<td>34.4</td>
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<td>Brewex</td>
<td>17.8</td>
<td>41.4</td>
<td>40.7</td>
<td>73.9</td>
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<td>Wheat starch 7</td>
<td>1.0</td>
<td>35.6</td>
<td>37.6</td>
<td>93.2</td>
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<tr>
<td>Wheat starch 6</td>
<td>2.9</td>
<td>45.2</td>
<td>53.6</td>
<td>141.3</td>
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<tr>
<td>Reax</td>
<td>4.8</td>
<td>31.5</td>
<td>34.5</td>
<td>61.1</td>
</tr>
<tr>
<td>Cola Syrup</td>
<td>12.3</td>
<td>33.0</td>
<td>28.5</td>
<td></td>
</tr>
<tr>
<td>Asphalt-SS</td>
<td>4.8</td>
<td>39.2</td>
<td>31.1</td>
<td></td>
</tr>
<tr>
<td>Asphalt-MS</td>
<td>4.8</td>
<td>29.6</td>
<td>26.9</td>
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<tr>
<td>No binder (Control)</td>
<td>0.0</td>
<td>30.9</td>
<td>19.3</td>
<td></td>
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</tbody>
</table>
Briquetting of coal fines and saw dust
- Results (Comparison of physical properties)

<table>
<thead>
<tr>
<th>Binder ID</th>
<th>Binder</th>
<th>Wt %</th>
<th>green Strength</th>
<th>1-day Strength</th>
<th>7-day Strength</th>
<th>Drop Test #drops</th>
<th>H20 resist (lb/CS)</th>
<th>Attrition Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black Strap Molasses*</td>
<td>6.70</td>
<td>91.7</td>
<td>102.4</td>
<td>174.9</td>
<td>17.8</td>
<td>disintegrated</td>
<td>55.5</td>
<td></td>
</tr>
<tr>
<td>Hi-Gluten Wheat Flour</td>
<td>2.90</td>
<td>64.7</td>
<td>78.4</td>
<td>&gt;200</td>
<td>46.8</td>
<td>24.1</td>
<td>67.5</td>
<td></td>
</tr>
<tr>
<td>Guar Gum</td>
<td>1.00</td>
<td>63.6</td>
<td>86.1</td>
<td>&gt;200</td>
<td>51.3</td>
<td>41.7</td>
<td>81.1</td>
<td></td>
</tr>
<tr>
<td>Hi-Starch Wheat Flour</td>
<td>2.89</td>
<td>51.3</td>
<td>61.7</td>
<td>&gt;200</td>
<td>27.3</td>
<td>17.8</td>
<td>56.8</td>
<td></td>
</tr>
<tr>
<td>Corn Starch</td>
<td>2.9</td>
<td>50.4</td>
<td>66.2</td>
<td>169.8</td>
<td>24.8</td>
<td>36.8</td>
<td>46.0</td>
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<tr>
<td>Paper Sludge*</td>
<td>17.90</td>
<td>78.4</td>
<td>83.7</td>
<td>135.8</td>
<td>4.3</td>
<td>85.0</td>
<td>36.0</td>
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<tr>
<td>Wheat starch 6</td>
<td>2.90</td>
<td>58.1</td>
<td>N/A</td>
<td>&gt;200</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control w/ lime only</td>
<td>2.00</td>
<td>57.6</td>
<td>N/A</td>
<td>45.5</td>
<td>1.0</td>
<td>35.9</td>
<td>31.1</td>
<td></td>
</tr>
<tr>
<td>Tall Oil Emulsion</td>
<td>5.3</td>
<td>45.9</td>
<td>38.0</td>
<td>64.4</td>
<td>2.8</td>
<td>42.5</td>
<td>34.1</td>
<td></td>
</tr>
<tr>
<td>Molasses</td>
<td>5.7</td>
<td>55.9</td>
<td>71.4</td>
<td>151.5</td>
<td>9.0</td>
<td>disintegrated</td>
<td>55.2</td>
<td></td>
</tr>
<tr>
<td>Reax</td>
<td>4.3</td>
<td>43.7</td>
<td>89.0</td>
<td>&gt;220</td>
<td>&gt;100</td>
<td>disintegrated</td>
<td>91.1</td>
<td></td>
</tr>
<tr>
<td>Reax &amp; ASPHALT*</td>
<td>2.5 &amp; 1.2</td>
<td>59.6</td>
<td>87.5</td>
<td>195.2</td>
<td>28.0</td>
<td>58.2</td>
<td>50.4</td>
<td></td>
</tr>
</tbody>
</table>

*Note: Results are based on comparison of physical properties. The table includes data for various binders used in briquetting, showing their performance in terms of green and cured strengths, drop test results, and water resistance, along with their attrition indices.
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5. Summary
White Energy Process (BCB) developed by CSIRO

- Binderless Coal Briquetting (BCB) Process using dehydration and compaction
- Upgrading of brown coals
- Establishment of 1 million tonnes per year plant in Kalimantan

Feedstock coal
- High moisture coal
- Coal fines

Upgraded high energy coal briquettes

Sub-bituminous coal example

Indonesia
Approx. 4,400 Kcals/kg GAR

PRB Coal
Approx. 8,400 Btu/lb GAR

Approx. 6,100 Kcals/kg GAR

Approx. 11,350 Btu/lb GAR

* GAR = Gross As Received
White Energy Process (BCB) developed by CSIRO

• Coal crushed to < 3mm
• Flash dried to moisture level 7-8 wt%
• Compacted and briquetted, creating tight bonds between coal particles and eliminating nearly all voids
• Patented briquetting machines by Komarek
• Briquettes cooled to enable handling and storage
• Resulting in a higher density, higher energy briquette with low permeability and reduces propensity towards spontaneous combustion
South-African prime coking and blend coking coals

- Coking coals with high proportions of vitrinite
- Bonding mainly created by deformation and consolidation of vitrinite
- Weathering (oxidation) has an adverse effect on the suitability of coal for binderless briquetting
- Coal size: < 2 mm
- Ash: 10 wt%

Petrographic properties of Samples A and B coal

<table>
<thead>
<tr>
<th>Colliery</th>
<th>% Vitrine</th>
<th>% Liptinite</th>
<th>% Reactive inertinite</th>
<th>% Inert inertinite</th>
<th>% Total inertinite</th>
<th>% Reactives</th>
<th>$\bar{R}$%</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample A</td>
<td>91</td>
<td>1</td>
<td>1</td>
<td>7</td>
<td>8</td>
<td>93</td>
<td>1.26</td>
<td>Medium rank B</td>
</tr>
<tr>
<td>Sample B</td>
<td>86</td>
<td>6</td>
<td>3</td>
<td>5</td>
<td>8</td>
<td>95</td>
<td>0.72</td>
<td>Medium rank C</td>
</tr>
</tbody>
</table>

Note: Maceral analysis — percentage by volume, mineral matter-free basis (mmf).
South-African coking coals
- Process and results

• Pillow shaped briquettes: 40 x 19 x 13 mm
• Maximum pressure: 17 MPa
• Komarek B-100A roll type briquetting machine

Fig. 2. Compressive strength of briquettes against superficial moisture content of the Sample A.

Fig. 4. Plot of the mean dry and wet compressive strengths of briquettes against feed moisture content of Sample B.
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Briquetting Technology
- Generalized Flowsheet

- Size preparation: Correct size distribution
  - Coal size: < 2 mm
- Moisture control
  - Optimal moisture for optimal properties
- Mixing coal and binder
- Briquetting process
- Condition the mixture if needed
- Post formation treatment:
  - Heating, sintering
  - Cooling
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5. Summary
# Summary

<table>
<thead>
<tr>
<th>Project name or inventor</th>
<th>Main application</th>
<th>Binder</th>
<th>SiO$_2$/Fe$_3$O$_4$</th>
<th>Carbon RM</th>
<th>Sintering</th>
<th>Test scale</th>
<th>Properties evaluated</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbosil</td>
<td>High pure Si production</td>
<td>Coal pitch</td>
<td>C:SiO$_2$=1(W)</td>
<td>Char, pet coke</td>
<td>750 °C</td>
<td>Pilot</td>
<td>Load strength, Apparent density, Thermal stability, CO$_2$ reactivity</td>
<td>HMS on use of pitch</td>
</tr>
<tr>
<td>Silgro</td>
<td>Si production</td>
<td>Coal pitch</td>
<td>C:SiO$_2$=1(W)</td>
<td>Pel coke, Coking coal</td>
<td>550 °C</td>
<td>Full size plant</td>
<td>Load strength, Apparent density, Thermal and mechanical stability</td>
<td>MSD on use of pitch, Thermal stability low, Loss in fines</td>
</tr>
<tr>
<td>Fesil agglomerates by Raaness</td>
<td>Fesil production</td>
<td>Coal pitch</td>
<td>C:Fe$_2$O$_4$=1.8(W)</td>
<td>Swelling coal, FSI=8-9</td>
<td>400 °C</td>
<td>Pilot</td>
<td>Thermal and mechanical stability, SiO reactivity</td>
<td>MSD on use of pitch</td>
</tr>
<tr>
<td>Water-resistant briquettes from Turkish lignite</td>
<td>Power plant</td>
<td>Copolymer</td>
<td>Molasses</td>
<td>Lignite and bituminous</td>
<td>No</td>
<td>Laboratory</td>
<td>Compressive strength, Shatter index, Weathering test</td>
<td>Binder cost, Thermal stability unknown n</td>
</tr>
<tr>
<td>Coal fines and sawdust</td>
<td>Power plant</td>
<td>Guar gum, Wheat starch, Reax + lime</td>
<td>No</td>
<td>Bituminous coal and saw dust (10%)</td>
<td>No</td>
<td>Laboratory</td>
<td>Compressive strength, Shatter index, Water resistance, Attrition index</td>
<td>Binder cost $8/ton, Thermal stability unknown n</td>
</tr>
<tr>
<td>White Energy Process</td>
<td>Thermal coal, Metallurgical coal fines</td>
<td>No</td>
<td>No</td>
<td>Low ranker coal, Sub-bituminous coal, Lignite</td>
<td>No</td>
<td>1 million tonne per annum</td>
<td>Mechanical stability, Thermal values</td>
<td>Thermal stability unknown n</td>
</tr>
<tr>
<td>South African coking coal</td>
<td>Power plant</td>
<td>No</td>
<td>No</td>
<td>Prime coking and blend coking coals</td>
<td>No</td>
<td>Laboratory</td>
<td>Compressive strength, Water resistance (with compressive strength)</td>
<td>Thermal stability unknown n</td>
</tr>
</tbody>
</table>
ADVANCED MATERIALS
SHAPING THE FUTURE