Shenwu’s Innovative Smelting Technology via Rotary Hearth Furnace

2nd INDIA INTERNATIONAL DRI SUMMIT
1ST AUG, 2014
HOTEL LE MERIDIEN, NEW DELHI
**Introduction**

Established in 1999, with a registered capital of RMB 360 million.

Our aim: to be energy saving and low carbon technology solution provider for global fossil fuel consumption market, and specialize in the research, development and marketing of industrial energy-saving & emission-reduction technology and resource comprehensive technology.

Qualifications:
- class A design qualification for chemical industries;
- class A design qualification for metallurgical industries;
- class A qualification for furnace & kiln industries;
- class A engineering consulting qualification,
- foreign project contracting qualification,
- design license for special equipment (pressure vessel and pressure pipeline)
- 138 national patents granted, 151 patents under application.

Current status: Shenwu has 9 subsidiaries, over 3300 employees and total assets of RMB 7.9 billion until now. The order value of energy saving project in 2013 reaches RMB 5.6 billion.

• **Establishment & Growth**

- **1995**
  - Beijing Shenwu Nozzle Technology Co., Ltd established in Z-park.

- **1999**
  - Burner type regenerative combustion technology invented firstly in China.

- **2004**
  - Solely acquire Beijing Huafu Engineering Co. Ltd, and get access to the petrochemical energy-saving market

- **2005**
  - Solely acquire Jiangsu Metallurgical Design Institute Co. Ltd.
  - Hubei Shenwu Company (core energy-saving equipment manufacture center of constructed with an investment of RMB 300 million.

- **2007**
  - Shenwu energy conservation and atmospheric haze control lab (land area: 100 mu) constructed with an investment of RMB 500 million.

- **2009**
  - Strategic investor introduced, and private placement completed.
  - Domestic reorganization completed, group management frame established, and shareholding system reconstruction achieved.

- **2010**
  - Acquired listed company Tianli Group
Regenerative high temperature air combustion technology

Application in various Business Sectors

- Non-ferrous metal technology
- Equipment manufacture
- Solid wastes comprehensive treatment
- Industrial, civil, thermal boilers
- Petroleum refining, petrochemical, coal chemical
- Building materials (ceramic, glass)
- Iron & Steel Technology
Shenwu Core Technology

World first-generation combustion technology

World second-generation combustion technology

World third-generation combustion technology: Regenerative high temperature air combustion technology

- Chamber heat utilization ratio < 55%
- Chamber heat utilization ratio < 65%
- System heat utilization ratio < 93%
- Chamber heat utilization ratio ≥ 86%
- System heat utilization ratio ≥ 94%

Advantages of the 3rd-generation combustion technology

- Improved heat utilization ratio of various reactors;
- Increased reaction temperature of various reactors;
- Reduced fuel grade and quality;
- Beneficial to achieve the low-carbon and low-nitrogen combustion, and reduce pollution.
Combined with the self-innovated HTAC technology, Shenwu Corp. has made breakthrough in efficiency, energy consumption and reduction technology via RHF direct reduction iron-making technology. We posses a number of national patents in technology to treat various types of mineral resources and thus we can realize:

- The processing and utilization of low grade ore like high phosphorus oolitic hematite, magnetite, refractory lean ore, limonite, siderite etc.
- The metallurgical iron bearing solid wastes from steel plant like BF-BOF, DRI sludge, HSM scale, flue gas extraction system and oxide scale, slimes.
- The comprehensive utilization of complex ore resources, such as V-Ti magnetite ore.
- The extraction and recovery of non-ferrous metals from Lateritic-nickel ore.
- The processing and comprehensive utilization of metallurgical slag such as nickel and copper slag, and sulfuric acid slag.
Low rank Coal
Biomass
Urban and industrial waste
Waste Organics

Direct Reduction via Regenerative RHF
Gas Smelter
Iron
Liquid iron
Iron Grain

Low rank lean ore, High P ore,
Refractory ore
Metallurgical solid waste
V - Ti magnetite
Lateriticnickel ore
Non-ferrous metallurgical slag

Research Route of RHF
Regenerative pyrolysis of medium and low temperature of rotating bed
Coke oven gas
Tar
Carbon-bearing solid

Carbon-bearing pellet

Sand
Coke Oven Dust
Coke Oven Gas
Carbon-bearing solid
Shape of RHF

- Regenerative burner
- Flue
- Distributer
- Discharging screw
- Hearth support part
- Hearth driving part
- Hearth
Internal View of RHF
Description of RHF Process

Process of RHF technology: the Raw material, Carbon and Additive combined into a pellet, then put directly into the rotary hearth furnace through distributor. More than 85% iron of the furnace burden will be restored into metalized pellet through the process of preheating and reduction.
Shenwu’s RHF expands the processing domain to refractory ore, complex associated ore, and metallurgic dust and solid waste.

<table>
<thead>
<tr>
<th>Item</th>
<th>Size (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central Diameter</td>
<td>8000</td>
</tr>
<tr>
<td>External Diameter</td>
<td>10000</td>
</tr>
<tr>
<td>Internal Diameter</td>
<td>6000</td>
</tr>
<tr>
<td>Width</td>
<td>2000</td>
</tr>
<tr>
<td>Height</td>
<td>1300</td>
</tr>
</tbody>
</table>

Shenwu’s Pilot-Plant - 24,000 tpy RHF
Shenwu RHF Pilot-Plant won the national appraisal of scientific and technological achievements
The inferior resources such as low grade refractory ore, complex & associated ore, and metallurgic dust can be processed by RHF

Energy-saving and environment-friendly

Demonstration effect to the market development and promotion

The technology reaches the world-leading level
(1) High Phosphorus Oolitic Hematite

**Existing High Phosphorus Oolitic Iron Ore Dephosphorizing Technology**

- **Beneficiating Method**
  - High gradient magnetic separation, flotation
  - Selective acid leaching
  - Ultrasonic wave acid leaching
  - Chloridizing roasting-acid leaching

- **Chemical Method**
  - Reduction roasting - Magnetic separation - Reverse flotation method
  - Direct reduction-Magnetic separation

- **Microbial Method**
  - Natural separation of slag-iron

- **Smelting**
  - Beneficiation-metallurgy

- **The 3rd Generation Grained Iron Method**
(1) High Phosphorus Oolitic Hematite

Inspection of effect and influence of coal type, dosage and additive

Inspection of the influence of process, fitness and magnetic field intensity to the separation effect

1st Stage Magnetic Separation

2nd Stage Magnetic Separation

Iron Powder

Tailings

1st Stage Grinding

2nd Stage Grinding

RHF

Green Pellet

Metalized Pellet

Drying

Agglomeration

Mixing

Burdening

Additive

Dried Ore

Coal Powder

Binder

Lump Coal

Grinding

Drying

Mineral powder

Cooling
1. Chemical Analysis of Raw Ore

<table>
<thead>
<tr>
<th>Ore</th>
<th>TFe</th>
<th>FeO</th>
<th>SiO2</th>
<th>Al₂O₃</th>
<th>CaO</th>
<th>MgO</th>
<th>K₂O</th>
<th>Na₂O</th>
<th>S</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>46.03</td>
<td>2.91</td>
<td>16.5</td>
<td>3.07</td>
<td>2.5</td>
<td>3.4</td>
<td>0.13</td>
<td>0.046</td>
<td>0.012</td>
<td>0.92</td>
</tr>
<tr>
<td>B</td>
<td>51.00</td>
<td>1.86</td>
<td>12.09</td>
<td>5.8</td>
<td>3.48</td>
<td>0.63</td>
<td>0.24</td>
<td>0.063</td>
<td>0.023</td>
<td>0.71</td>
</tr>
</tbody>
</table>

2. Industrial Analysis of Reducing Coal

<table>
<thead>
<tr>
<th>Content (%)</th>
<th>Mad</th>
<th>Aad</th>
<th>Vad</th>
<th>FCad</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.98</td>
<td>38.78</td>
<td>12.92</td>
<td>47.32</td>
</tr>
</tbody>
</table>

3. Other auxiliary materials:
   1) Limestone
   2) Dephosphorization agent
   3) Bentonite, Organic Binder
The productivity and recycling rate of metalized iron powder compared with raw ore:

<table>
<thead>
<tr>
<th>Minerals</th>
<th>Productivity</th>
<th>Fe Grade</th>
<th>Fe Recovery</th>
<th>P Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mineral A</td>
<td>41.65</td>
<td>91.37</td>
<td>83.51</td>
<td>0.12</td>
</tr>
<tr>
<td>Mineral B</td>
<td>47.81</td>
<td>92.33</td>
<td>87.79</td>
<td>0.14</td>
</tr>
</tbody>
</table>

Chemical analysis of metalized iron powder:

<table>
<thead>
<tr>
<th>Minerals</th>
<th>TFe</th>
<th>MFe</th>
<th>SiO₂</th>
<th>Al₂O₃</th>
<th>CaO</th>
<th>MgO</th>
<th>P</th>
<th>S</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mineral A</td>
<td>91.37</td>
<td>89.05</td>
<td>0.43</td>
<td>0.64</td>
<td>1.35</td>
<td>0.83</td>
<td>0.12</td>
<td>0.02</td>
<td>0.12</td>
</tr>
<tr>
<td>Mineral B</td>
<td>92.33</td>
<td>91.17</td>
<td>2.14</td>
<td>0.88</td>
<td>1.15</td>
<td>1.34</td>
<td>0.14</td>
<td>0.04</td>
<td>0.06</td>
</tr>
</tbody>
</table>
Separation Mechanism Analysis

Product SEM Analysis

(SEM analysis picture of reduced product)

Product SEM Analysis (Low content of P)
Briquetting test of metalized iron powder with the iron grade of 92.33%: the density of the briquette is over 4.7 kg/m³. The briquette will not crumble when fall down to the cement floor from 2 meters high, thus it can satisfy the need of shipping of steelmaking fork lift.
(2) Iron bearing Steel Plant Solid Waste (BFD)

- Additive
- Reducing Agent
- Dust, Iron Sheet

Raw material treatment

RHF direct reduction

DRI

Blast Furnace etc.

Magnetic Separation

Iron Powder

Briquetting

Iron Briquette

Exhaust Gas

Heat transfer

Dedusting

Zn, Pb etc.

Discharge

Tailings
(2) Iron bearing Steel Plant Solid Waste (PFD)

Direct Reduction Process for Dust via RHF

- Power Supply
- Proportion Bin
- Crusher for Coal
- Mixer
- Grinder
- Pelletizer
- Vibrating Sieve
- Dryer for Green Pellet
- Bag Collector
- Heat Exchanger
- Exhaught Gas
- Vibrating Sieve
- Cooling Tank
- Induced Draft Fan
- Chimney
- Conveyor
- Truck

Recovery of Zn, Pb, K, Na
Ingredients of Green Pellet (Iron Sheet, Coal Powder, Binder)

<table>
<thead>
<tr>
<th>Scheme</th>
<th>TFe</th>
<th>MFe</th>
<th>Metallization rate (%)</th>
<th>Carbon Residue (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>81.74</td>
<td>68.07</td>
<td>83.27</td>
<td>0.64</td>
</tr>
<tr>
<td>2</td>
<td>90.11</td>
<td>76.60</td>
<td>85.01</td>
<td>0.30</td>
</tr>
<tr>
<td>3</td>
<td>92.22</td>
<td>83.17</td>
<td>90.19</td>
<td>0.44</td>
</tr>
</tbody>
</table>

Ingredients of Metalized Pellets

<table>
<thead>
<tr>
<th>Elements</th>
<th>TFe</th>
<th>MFe</th>
<th>C</th>
<th>CaO</th>
<th>MgO</th>
<th>SiO₂</th>
<th>Al₂O₃</th>
<th>S</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Content (%)</td>
<td>92.22</td>
<td>83.17</td>
<td>0.44</td>
<td>0.93</td>
<td>0.50</td>
<td>0.95</td>
<td>0.44</td>
<td>0.14</td>
<td>0.02</td>
</tr>
</tbody>
</table>

Product quality after magnetic separation

<table>
<thead>
<tr>
<th>Product Name</th>
<th>Productivity (%)</th>
<th>Tfe (%)</th>
<th>MFe (%)</th>
<th>Grade (%)</th>
<th>Recovery (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron Powder</td>
<td>93.08</td>
<td>94.97</td>
<td>94.60</td>
<td>99.61</td>
<td>99.04</td>
</tr>
<tr>
<td>Tailings</td>
<td>6.92</td>
<td>12.36</td>
<td>3.74</td>
<td>30.26</td>
<td>0.96</td>
</tr>
<tr>
<td>DRI</td>
<td>100.00</td>
<td>89.25</td>
<td>88.31</td>
<td>98.95</td>
<td>100.00</td>
</tr>
</tbody>
</table>
1. The analysis of raw material and reduction products

<table>
<thead>
<tr>
<th>Elements</th>
<th>TFe (%)</th>
<th>K₂O (%)</th>
<th>Na₂O (%)</th>
<th>Pb (%)</th>
<th>Zn (%)</th>
<th>Metallization rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw Material</td>
<td>43.04</td>
<td>2.14</td>
<td>0.25</td>
<td>0.12</td>
<td>0.47</td>
<td>-----</td>
</tr>
<tr>
<td>(Mixture)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DRI</td>
<td>67.48</td>
<td>0.13</td>
<td>0.043</td>
<td>&lt;0.05</td>
<td>&lt;0.02</td>
<td>95.38</td>
</tr>
</tbody>
</table>

2. Distribution rate of K, Na, Pb, Zn before and after reduction (%)

<table>
<thead>
<tr>
<th></th>
<th>Combination Dust</th>
<th>Reduction Products</th>
<th>Bag Filter</th>
</tr>
</thead>
<tbody>
<tr>
<td>K</td>
<td>100.00</td>
<td>3.84</td>
<td>96.16</td>
</tr>
<tr>
<td>Na</td>
<td>100.00</td>
<td>9.81</td>
<td>90.19</td>
</tr>
<tr>
<td>Pb</td>
<td>100.00</td>
<td>&lt;25</td>
<td>&gt;75</td>
</tr>
<tr>
<td>Zn</td>
<td>100.00</td>
<td>&lt;3.23</td>
<td>&gt;96</td>
</tr>
</tbody>
</table>
We have cooperated with top 500 world company- Sha Steel to build a joint venture which have operated a 300,000tpy line, and still three lines to implement. Compared with below 60% metallization rate of Posco, Ma’anshan Steel, Shenwu’s technology can get above 85% metallization rate. And another advantage is that Shenwu’s treatment capacity can reach up to 300,000-800,000tpy.
Signing Ceremony for Sha-Steel 300,000 TPY of Metallurgical Dust DR Project
Feedstock specs of RHF direct reduction for 300000 TPA dust and slurry at ShaSteel.

<table>
<thead>
<tr>
<th>Raw material</th>
<th>TFe</th>
<th>SiO₂</th>
<th>Al₂O₃</th>
<th>P</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concentrate fines</td>
<td>66.80</td>
<td>3</td>
<td>1</td>
<td>0.005</td>
<td>0.03</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Coal type</th>
<th>Ash</th>
<th>S</th>
<th>Volatile</th>
<th>Fc</th>
<th>Moisture %</th>
<th>Grades mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reducing coal</td>
<td>11.61</td>
<td>0.58</td>
<td>6.86</td>
<td>80.63</td>
<td>18</td>
<td>&lt;20</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>No</th>
<th>Raw material</th>
<th>TFe</th>
<th>FC</th>
<th>FeO</th>
<th>CaO</th>
<th>MgO</th>
<th>SiO₂</th>
<th>Al₂O₃</th>
<th>K₂O</th>
<th>Na₂O</th>
<th>ZnO</th>
<th>P₂O₅</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Hongfa steel-making dust</td>
<td>35.09</td>
<td>5.56</td>
<td>25.71</td>
<td>8.96</td>
<td>5.9</td>
<td>6.08</td>
<td>1.21</td>
<td>1.07</td>
<td>2.48</td>
<td>4.5</td>
<td>0.12</td>
<td>0.88</td>
</tr>
<tr>
<td>2</td>
<td>Hongfa iron-making dust</td>
<td>36.73</td>
<td>32.23</td>
<td>15.74</td>
<td>4.74</td>
<td>0.74</td>
<td>5.58</td>
<td>2.06</td>
<td>0.35</td>
<td>0.41</td>
<td>3.5</td>
<td>0.13</td>
<td>0.55</td>
</tr>
<tr>
<td>3</td>
<td>Huasheng iron-making dust</td>
<td>30.43</td>
<td>24.06</td>
<td>13.04</td>
<td>4.86</td>
<td>0.92</td>
<td>6.24</td>
<td>2.32</td>
<td>0.26</td>
<td>0.8</td>
<td>3.5</td>
<td>0.09</td>
<td>0.79</td>
</tr>
<tr>
<td>4</td>
<td>Rongsheng steel-making dust</td>
<td>34.99</td>
<td>5.61</td>
<td>15</td>
<td>10.74</td>
<td>2.74</td>
<td>4.41</td>
<td>0.49</td>
<td>0.37</td>
<td>0.89</td>
<td>3.5</td>
<td>0.14</td>
<td>0.28</td>
</tr>
<tr>
<td>5</td>
<td>Slurry of blast furnace</td>
<td>33.83</td>
<td>0.88</td>
<td>14.5</td>
<td>3.74</td>
<td>0.62</td>
<td>6.73</td>
<td>2.31</td>
<td>1.1</td>
<td>0.91</td>
<td>2.4</td>
<td>0.17</td>
<td>6.18</td>
</tr>
</tbody>
</table>
Field Data of the RHF of Sha-Steel Co.

Raw material: the zinc-bearing dust from blast furnace

The field mixture and DRI ingredients analysis

<table>
<thead>
<tr>
<th>Category</th>
<th>TFe</th>
<th>MFe</th>
<th>FeO</th>
<th>SiO$_2$</th>
<th>CaO</th>
<th>MgO</th>
<th>Al$_2$O$_3$</th>
<th>Zn</th>
<th>P</th>
<th>S</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mixture</td>
<td>46.26</td>
<td>0</td>
<td>8.67</td>
<td>4.46</td>
<td>1.96</td>
<td>0.51</td>
<td>1.85</td>
<td>1.33</td>
<td>0.004</td>
<td>0.338</td>
<td>17.41</td>
</tr>
<tr>
<td>DRI</td>
<td>67.90</td>
<td>58.28</td>
<td>15.30</td>
<td>17.40</td>
<td>4.11</td>
<td>1.37</td>
<td>6.23</td>
<td>0.27</td>
<td>Trace</td>
<td>0.502</td>
<td>4.86</td>
</tr>
</tbody>
</table>

DRI metalized rate: **85% - 93%**

The grade of ZnO-bearing slag from bag filter: **72% - 78%**

Metalized pellet

ZnO powder
<table>
<thead>
<tr>
<th>No</th>
<th>Energy Source</th>
<th>Unit of Measurement</th>
<th>Consumption</th>
<th>Conversion Factor</th>
<th>Standard Coal Equivalent in kgce</th>
<th>Energy Consumption GJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>LD GAS</td>
<td>m³</td>
<td>1245</td>
<td>0.205</td>
<td>255.23</td>
<td>7.40</td>
</tr>
<tr>
<td>2</td>
<td>ELECTRICITY</td>
<td>kWh</td>
<td>129</td>
<td>0.1229</td>
<td>15.85</td>
<td>0.46</td>
</tr>
<tr>
<td>3</td>
<td>COMP. AIR</td>
<td>m³</td>
<td>32</td>
<td>0.04</td>
<td>1.28</td>
<td>0.04</td>
</tr>
<tr>
<td>4</td>
<td>N2</td>
<td>m³</td>
<td>25</td>
<td>0.4</td>
<td>10.00</td>
<td>0.29</td>
</tr>
<tr>
<td>5</td>
<td>MAKEUP WATER</td>
<td>m³</td>
<td>1.22</td>
<td>0.0857</td>
<td>0.10</td>
<td>0.00</td>
</tr>
<tr>
<td>6</td>
<td>STEAM @1.6MPa</td>
<td>kg</td>
<td>-720</td>
<td>0.103</td>
<td>-74.16</td>
<td>-2.17</td>
</tr>
<tr>
<td>7</td>
<td>CARBON (CONTAINED IN RAW MATERIALS)</td>
<td>kg</td>
<td>220</td>
<td>0.7143</td>
<td>157.15</td>
<td>4.6</td>
</tr>
<tr>
<td></td>
<td>TOTAL</td>
<td></td>
<td></td>
<td></td>
<td>365.45</td>
<td>10.62 (2.53 Gcal)</td>
</tr>
</tbody>
</table>
Industrialization – Sha-Steel

General view of Sha-Steel RHF project 30
RHF of Sha-Steel is currently adopting the whole solid waste continuous operation, and the metallization rate is above 85%. The content of zinc of ZnO dust removed by bag collector is over of 65%. Both of the situations have reached advanced level.

Metalized pellet

ZnO dust collected from heat recovery boiler

ZnO dust collected by bag collector
(3) V-Ti Magnetic Ore

- Mineral Powder
  - Drying
  - Dried Mine
- Lump Coal
  - Grinding
  - Coal Powder
  - Proportion
  - Mixed Material
  - Pelletizing
  - Drying
  - Ore and Coal Combination Pellet
- Binder

- Iron Grain
- Magnetic Separation
- Crushing
- Vanadium Slag

- Casting
  - Vanadium Slag
  - Vanadium Extraction
  - Molten Iron
  - Cast iron
  - Iron Briquette

- Desulfurizer
  - Desulfuration
  - Desulfurized Molten Iron
  - Desulfurized Slag

- Metallized Pellet
  - RHF
  - Slag
  - Electric furnace
  - Vanadium Iron
  - Cooling agent

- Crashing
  - Molten Iron
  - Cast iron
(3) V-Ti Magnetic Ore

### Original Ore Ingredients

<table>
<thead>
<tr>
<th>Elements</th>
<th>TFe</th>
<th>SiO₂</th>
<th>Al₂O₃</th>
<th>CaO</th>
<th>MgO</th>
<th>V₂O₅</th>
<th>TiO₂</th>
<th>S</th>
<th>P</th>
<th>MnO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Content (%)</td>
<td>57.18</td>
<td>1.16</td>
<td>2.69</td>
<td>0.16</td>
<td>1.98</td>
<td>0.65</td>
<td>12.94</td>
<td>0.03</td>
<td>0.01</td>
<td>0.51</td>
</tr>
</tbody>
</table>

### RHF pilot test results

Metallization rate is 80.5%, smelted vanadium reduction rate is 71%, iron recycling rate >90%, vanadium recycling rate is 67%.

<table>
<thead>
<tr>
<th></th>
<th>Fe</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>V</th>
<th>Ti</th>
</tr>
</thead>
<tbody>
<tr>
<td>Molten Iron</td>
<td>95.00</td>
<td>1.20</td>
<td>0.05</td>
<td>0.07</td>
<td>0.011</td>
<td>0.032</td>
<td>0.04</td>
<td>0.09</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>TFe</th>
<th>TiO₂</th>
<th>FeO</th>
<th>SiO₂</th>
<th>CaO</th>
<th>MgO</th>
<th>Al₂O₃</th>
<th>V₂O₅</th>
</tr>
</thead>
<tbody>
<tr>
<td>Titanium Slag</td>
<td>3.93</td>
<td>53.39</td>
<td>0.56</td>
<td>7.27</td>
<td>2.13</td>
<td>10.34</td>
<td>17.93</td>
<td>0.45</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>TFe</th>
<th>MFe</th>
<th>V₂O₅</th>
<th>CaO</th>
<th>SiO₂</th>
<th>MgO</th>
<th>Al₂O₃</th>
<th>TiO₂</th>
<th>P₂O₅</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vanadium Slag</td>
<td>44.27</td>
<td>16.03</td>
<td>7.93</td>
<td>1.05</td>
<td>25.84</td>
<td>5.10</td>
<td>4.19</td>
<td>3.53</td>
<td>0.011</td>
</tr>
</tbody>
</table>
Industrialization – Pan-Steel

RHF of Pan-Steel Group for 100,000 TPY of V-Ti Magnetite DR Project

It is a world breakthrough, for Ti iron –making is a world problem.

For processing vanadium titano-magnetite, rated production is 100,000tpy. External diameter 19.5m, width of hearth 5m, got into operation in 2009.
Signing Ceremony for Pan-Steel 100,000 TPY of V-Ti Magnetic DR Project
(5) Laterite-nickel Ore

Laterite Ore → RHF Direct Reduction → Metalized Pellet

- Gas Smelter: Ferronickel
- Electric Smelter: Ferronickel
- Magnetic Separation: Ferronickel Powder → Ferronickel Briquette
- Magnetic Separation: Ferronickel Powder → Ferronickel Briquette
- Magnetic Separation: Ferronickel Powder → Ferronickel Briquette

- Gas Smelter: Ferronickel
- Electric Smelter: Ferronickel
(5) Laterite-Nickel Ore

- Underground Feed Bin
- Dryer
- Dust Collection
- Crushing
- Laterite, Limestone, Coal
- Batch Bin
- Mixing
- Pelletizer
- Chimney
- ID Fan
- Deduster
- Heat Exchanger
- Dryer
- RHF
- Smelting Separation Furnace
- Ferronickel
- Slag
- Heatpacking
### Case 1: Pilot Test Result of 1.51% Laterite-nickel Ore

#### 4. Metallized Pellet
(1330°C for the highest reaction temperature; 42min in each zone of RHF)

<table>
<thead>
<tr>
<th>Elements</th>
<th>TFe</th>
<th>MFe</th>
<th>Ni</th>
<th>SiO₂</th>
<th>Al₂O₃</th>
<th>CaO</th>
<th>MgO</th>
<th>C</th>
<th>Metallization Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Content (%)</td>
<td>21.71</td>
<td>15.78</td>
<td>1.81</td>
<td>34.57</td>
<td>5.13</td>
<td>9.1</td>
<td>17.12</td>
<td>3.61</td>
<td>72.73</td>
</tr>
</tbody>
</table>

#### 5. Ferronickel

<table>
<thead>
<tr>
<th>Elements</th>
<th>Ni</th>
<th>Si</th>
<th>S</th>
<th>P</th>
<th>C</th>
<th>Cr</th>
<th>Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Content (%)</td>
<td>14.612</td>
<td>0.119</td>
<td>0.07</td>
<td>0.058</td>
<td>0.577</td>
<td>0.046</td>
<td>84.76</td>
</tr>
</tbody>
</table>

Recovery: Ni 95%, Fe 50%

#### 6. Slag

<table>
<thead>
<tr>
<th>Elements</th>
<th>TFe</th>
<th>FeO</th>
<th>Ni</th>
<th>SiO₂</th>
<th>Al₂O₃</th>
<th>CaO</th>
<th>MgO</th>
<th>C</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Content (%)</td>
<td>12.12</td>
<td>14.67</td>
<td>0.077</td>
<td>37.58</td>
<td>12.975</td>
<td>8.82</td>
<td>17.7</td>
<td>0.035</td>
<td>0.23</td>
</tr>
</tbody>
</table>
# Case 2: Basic Test Result Of 3 Typical Laterite Ores

## Tab 1. Contents of Laterite-nickel Ore

<table>
<thead>
<tr>
<th>Content</th>
<th>TFe</th>
<th>FeO</th>
<th>Ni</th>
<th>CaO</th>
<th>MgO</th>
<th>SiO(_2)</th>
<th>Al(_2)O(_3)</th>
<th>S</th>
<th>P</th>
<th>Cr(_2)O(_3)</th>
<th>K(_2)O</th>
<th>Na(_2)O</th>
<th>Ignition Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>1#</td>
<td>39.40</td>
<td>1.44</td>
<td>1.40</td>
<td>0.51</td>
<td>2.77</td>
<td>14.63</td>
<td>6.43</td>
<td>0.01</td>
<td>&lt;0.001</td>
<td>1.06</td>
<td>0.082</td>
<td>0.054</td>
<td>11.96</td>
</tr>
<tr>
<td>2#</td>
<td>20.13</td>
<td>1.8</td>
<td>1.73</td>
<td>0.72</td>
<td>12.40</td>
<td>35.23</td>
<td>4.23</td>
<td>0.006</td>
<td>&lt;0.001</td>
<td>0.6</td>
<td>0.08</td>
<td>0.054</td>
<td>9.36</td>
</tr>
<tr>
<td>3#</td>
<td>17.12</td>
<td>1.28</td>
<td>1.88</td>
<td>0.33</td>
<td>13.96</td>
<td>36.29</td>
<td>2.99</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>0.23</td>
<td>0.06</td>
<td>0.06</td>
<td>11.33</td>
</tr>
</tbody>
</table>

## Tab 2. Industrial Analysis of Reducing Coal

<table>
<thead>
<tr>
<th>Coal</th>
<th>Fixed Carbon</th>
<th>Ash</th>
<th>Volatile</th>
<th>Moisture</th>
<th>S</th>
<th>Calorific Value (J/kg)</th>
<th>Ash Fusion Point (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>48.30</td>
<td>2.82</td>
<td>43.70</td>
<td>5.17</td>
<td>0.53</td>
<td>28.87</td>
<td>DT 1177  ST 1193 HT 1299 FT 1361</td>
</tr>
<tr>
<td>B</td>
<td>51.60</td>
<td>4.24</td>
<td>39.51</td>
<td>4.65</td>
<td>0.67</td>
<td>29.94</td>
<td>DT 1151 ST 1166 HT 1206 FT 1283</td>
</tr>
</tbody>
</table>

## Tab 3. Chemical Analysis of Limestone

<table>
<thead>
<tr>
<th>CaO</th>
<th>TFe</th>
<th>MgO</th>
<th>SiO(_2)</th>
<th>Al(_2)O(_3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50.4</td>
<td>0.2</td>
<td>1.63</td>
<td>3.45</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>
### Case 2: Basic Test Result Of 3 Typical Laterite Ores

<table>
<thead>
<tr>
<th>SN</th>
<th>C/O</th>
<th>Limestone</th>
<th>Roasting Temperature &amp; Time</th>
<th>Productivity</th>
<th>Grade of Ni</th>
<th>Recovery of Ni</th>
<th>Recovery of Fe</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1#</td>
<td>0.8</td>
<td>10%</td>
<td>1200°C 30min</td>
<td>23.19</td>
<td>6.58</td>
<td>97.63</td>
<td>48.98</td>
<td>With Coal A, recovery of Ni &gt;96%, grade of Ni 7.5%</td>
</tr>
<tr>
<td>2#</td>
<td>1.0</td>
<td>5%</td>
<td>1250°C 30min</td>
<td>14.57</td>
<td>11.42</td>
<td>95.51</td>
<td>63.00</td>
<td>With Coal A, recovery of Ni &gt;93.79%, grade of Ni 12.11%</td>
</tr>
<tr>
<td>3#</td>
<td>1.6</td>
<td>10%</td>
<td>1200°C 30min</td>
<td>12.52</td>
<td>16.22</td>
<td>96.72</td>
<td>53.92</td>
<td>With Coal A, recovery of Ni ~97%, grade of Ni 13.3%</td>
</tr>
</tbody>
</table>

**Conclusion**

1. To the raw material of laterite ore in limonite ore bed, the reduction of nickel can be controlled. Generally, the Ni grade of ferronickel is higher than 6%;
2. The recovery of Ni can be up to 96% by using Gas Smelter.
Ferronickel from Gas Smelter at Shenwu Lab
Industrialization – PT. TITAN Project
Job Site of RHF in Progress in Indonesia
Shenwu’s New Regenerative Rotary Hearth Furnace Direct Reduction Iron-making Process

1. Raw material treatment
   - Low sulphur and low ash carbonaceous substance (coal, biomass, scrap rubber, plastic etc)

2. Metallized pellet
   - Metallized pellet
   - Crushing and ball milling
   - Magnetic separation
   - Iron powder
   - Briquette
   - Iron briquette

3. Shenwu regenerative RHF direct reduction process
   - Metallized pellet
   - Hot-charging into electric furnace, iron and slag separating
   - Molten iron

Additive

Iron ore
(Low grade iron ore, refractory iron ore, composite associated iron ore, iron-bearing solid waste slag)
<table>
<thead>
<tr>
<th>SN</th>
<th>Project Name</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Longmang Group 70,000 TPY of V-Ti Magnetite DR Project, China</td>
<td>Complete</td>
</tr>
<tr>
<td>2</td>
<td>Pan-Steel 100,000 TPY of V-Ti Magnetite DR Project, China</td>
<td>Complete</td>
</tr>
<tr>
<td>3</td>
<td>Rockcheck Steel 800,000 TPY DRI Project, China</td>
<td>Complete</td>
</tr>
<tr>
<td>4</td>
<td>Sha-Steel 300,000 TPY of Metallurgical Dust DR Project, China</td>
<td>Complete</td>
</tr>
<tr>
<td>5</td>
<td>PT. TITAN 2,400,000 (80*3) TPY laterite -Nickel ore Project, Indonesia</td>
<td>Under Construction</td>
</tr>
<tr>
<td>6</td>
<td>PT. BALINTON 2,400,000 (80*3) TPY laterite -Nickel ore Project, Indonesia</td>
<td>Under Construction</td>
</tr>
</tbody>
</table>
Advantages of HSF

1. Low CO$_2$ Emission

   The CO$_2$ Emission of HSF is 20% lower than blast furnace.

2. Low Air Pollution Emission

   The emission of air pollution of SO$_x$, NO$_x$ and PM2.5 of HSF is 90% lower than blast furnace.

3. Wide adaptibility

   Processing of low grade iron ores containing TFe between 45-55% also for other mineral resources like V-Ti Magnetite, High Poolitic.
4. Low Energy Consumption

The reaction temperature for blast furnace is around $1500 \, ^\circ C$, while it’s only around $900 \, ^\circ C$ for HSF, where the energy consumption is reduced by 30% compared with blast furnace.

5. High Product Quality

The product DRI or HBI is best raw material for pure steel and high grade steel making.

<table>
<thead>
<tr>
<th>Hazardous Element</th>
<th>DRI</th>
<th>Scrap Steel</th>
<th>Molten Iron</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>$\leq 0.03%$</td>
<td>$\leq 0.05%$</td>
<td>$\leq 0.20%$</td>
</tr>
<tr>
<td>S</td>
<td>$\leq 0.01%$</td>
<td>$\leq 0.05%$</td>
<td>$\leq 0.05%$</td>
</tr>
</tbody>
</table>

6. High Capacity

The yield of single unit can be up to $1.8\text{Mtpa}$.
HSF for Pilot Test
Gasifier for Pilot Test
Electrical Smelter for Pilot Test
Gas Smelter for Pilot Test
### HSF Pilot Test Result

#### V-Ti sea sand ore

<table>
<thead>
<tr>
<th>Element</th>
<th>$TFe$</th>
<th>$TiO_2$</th>
<th>$V_2O_5$</th>
<th>$CaO$</th>
<th>$MgO$</th>
<th>$Al_2O_3$</th>
<th>$SiO_2$</th>
<th>$S$</th>
<th>$P$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schreyerite Sea Sand</td>
<td>54.49</td>
<td>13.00</td>
<td>0.84</td>
<td>0.33</td>
<td>3.10</td>
<td>3.66</td>
<td>2.58</td>
<td>0.02</td>
<td>0.03</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Element</th>
<th>$TiO_2$</th>
<th>$V_2O_5$</th>
<th>$FeO$</th>
<th>$SiO_2$</th>
<th>$CaO$</th>
<th>$MgO$</th>
<th>$Al_2O_3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ti Slag</td>
<td>55.04</td>
<td>0.36</td>
<td>4.58</td>
<td>7.39</td>
<td>1.48</td>
<td>14.56</td>
<td>15.95</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Element</th>
<th>$V_2O_5$</th>
<th>$FeO$</th>
<th>$SiO_2$</th>
<th>$CaO$</th>
<th>$MgO$</th>
</tr>
</thead>
<tbody>
<tr>
<td>V Slag</td>
<td>16.71</td>
<td>28.58</td>
<td>25.72</td>
<td>17.36</td>
<td>6.86</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Element</th>
<th>$Fe$</th>
<th>$Ti$</th>
<th>$V$</th>
<th>$C$</th>
<th>$Si$</th>
<th>$S$</th>
<th>$P$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Molten Iron</td>
<td>98.02</td>
<td>0.14</td>
<td>0.08</td>
<td>1.71</td>
<td>0.05</td>
<td>0.01</td>
<td>0.02</td>
</tr>
</tbody>
</table>

**Conclusion:** the recovery rates of Ti, V, Fe are 98%, 75%, 95%.
Shenwu has built the **internationally first** COG – HSF DRI production line

- **EPC of 0.3Mtpa DRI project of Shanxi Taihang Mining Co., Ltd, with COG- HSF process, under construction.**

- **First successful candidate in the bid of 1Mtpa DRI project of Inner Mongolia Dazhong Mining Co., with NG – HSF process.**

- **Framework Agreement with Qingdao Steel for 4Mtpa Schreysterite Comprehensive Utilization Project, via Coal Gasification – HSF process.**
Industrialization
<table>
<thead>
<tr>
<th>Comparison</th>
<th>Luigi</th>
<th>Ende</th>
<th>ICC</th>
<th>Shenwu</th>
<th>Texaco</th>
<th>Shell</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gasification technological process</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Requirement of coal</td>
<td>Limited</td>
<td>Low grade coal</td>
<td>No limit</td>
<td>No limit</td>
<td>Limited</td>
<td>Limited</td>
</tr>
<tr>
<td>size</td>
<td>6-50mm</td>
<td>0-10mm</td>
<td>0-6mm</td>
<td>0-6mm</td>
<td>&lt;0.1mm</td>
<td>&lt;0.1mm</td>
</tr>
<tr>
<td>Method of coal sending</td>
<td>Lump coal</td>
<td>Pulverized coal</td>
<td>Pulverized coal</td>
<td>Pulverized coal</td>
<td>CWS</td>
<td>Dry pulverized coal</td>
</tr>
<tr>
<td>Method of slagging</td>
<td>Solid</td>
<td>Solid</td>
<td>Ash agglomeration</td>
<td>Solid</td>
<td>Liquid</td>
<td>Liquid</td>
</tr>
<tr>
<td>Gasification temp (℃)</td>
<td>500-1200</td>
<td>950-1000</td>
<td>950</td>
<td>900-1000</td>
<td>1260-1500</td>
<td>1260-1500</td>
</tr>
<tr>
<td>Gasification pressure (MPa)</td>
<td>2.5-4.0</td>
<td>0.02</td>
<td>0.6</td>
<td>&lt;1.0</td>
<td>4.0-6.5</td>
<td>2.0-4.0</td>
</tr>
<tr>
<td>Cold gas efficiency (%)</td>
<td>85</td>
<td>78</td>
<td>72.7</td>
<td>80</td>
<td>76</td>
<td>80-83</td>
</tr>
<tr>
<td>Carbon conversion efficiency (%)</td>
<td>95</td>
<td>91-96</td>
<td>90</td>
<td>&gt;90</td>
<td>&gt;95</td>
<td>99</td>
</tr>
<tr>
<td>Heat efficiency (%)</td>
<td>90</td>
<td>84</td>
<td>78</td>
<td>&gt;90</td>
<td>87</td>
<td>94-99</td>
</tr>
<tr>
<td>Treatment capacity (t/d)</td>
<td>500</td>
<td>500</td>
<td>300</td>
<td>&gt;500</td>
<td>2000</td>
<td>2000</td>
</tr>
<tr>
<td>Environmental protection limits</td>
<td>High content of phenol</td>
<td>Little content of phenol</td>
<td>Little content of phenol</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
</tbody>
</table>
Process of Coal-making Gas

- Coal bunker
- Raw coal
- Breaking and separation
- Conveying and feeding
- Gas holder
- Purification
- Gasification system
Gasification Systematic Process

- **Coal**
- **Oxygen**
- **Cyclone separator**
- **Waste heat recoverer**
- **Deslagging hopper**
- **Fluidizing transporter**
- **Material reverting valve**
- **Gasifier**
- **Steam**
- **Soft water**
- **Recycling water**
- **Crude coal gas**
- **Ash bin**
- **Screw feeder**
- **Raw coal hopper**
- **Screw feeder**
<table>
<thead>
<tr>
<th>No.</th>
<th>Project</th>
<th>Technical index</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Applicable coal type and granule</td>
<td>Granule long flame coal, lignite, non-caking bitumite (such as above 6mm pulverized coal should below 3%)</td>
</tr>
<tr>
<td>2</td>
<td>Applicable moisture</td>
<td>5-35 wt.%</td>
</tr>
<tr>
<td>3</td>
<td>Usage amount of water steam</td>
<td>0-300 kg/t coal</td>
</tr>
<tr>
<td>4</td>
<td>Carbon conversion rate, %</td>
<td>&gt;90</td>
</tr>
<tr>
<td>5</td>
<td>Gasification system heat efficiency</td>
<td>&gt;90 %</td>
</tr>
<tr>
<td>6</td>
<td>Carbon-bearing amount of ash slag, %</td>
<td>3-8%</td>
</tr>
<tr>
<td>7</td>
<td>Operation load</td>
<td>50%-110%</td>
</tr>
<tr>
<td>8</td>
<td>Yearly operation time</td>
<td>&gt;7200 h</td>
</tr>
</tbody>
</table>
Thank you!

Beijing Shenwu Environment & Energy Technology Corp.
Tel: 010-60751999
Fax: 010-60759696