The FLEXIBLE DR Technology

Andres Villa
TENOVA HYL
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Commercially, since 2006 Tenova HYL has joined with Danieli to form the ENERGIRON alliance

- Energiron is the Innovative HYL Direct Reduction Technology jointly developed by Tenova and Danieli.
- Our combined resources are supplying the world’s most advanced DR plants to steelmakers worldwide.
Technology & Market Conditions

- In the world of Direct Reduction, it has often been true that technologies existed before proper market conditions came about.

- The ENERGIRON ZR (reformerless) process, perhaps the biggest breakthrough in the DR industry to date, was developed by HYL in the 1990’s, but was slow in taking off due to market conditions.

- Tenova HYL successfully implemented the HYTEMP System and High-Carbon DRI production in 1998, yet years passed before additional units were put into use, due to downturns in the industry.

- Developed DR modules from 200 kt/y to provide metallics to small mills to 2,500 kt/y to enter into the size range of integrated steel mills.

4M-Monterrey1998

ESI-UAE 2006
Introduction

- ENERGIRON DR technology is the state-of-the-art in direct reduction. It uses a simple plant configuration, has flexibility for using different sources of reducing gases and has the most efficient and flexible use of iron ores.

- Not only can natural gas be used, but also Coke Oven Gas and Syngas, in the same reliable and simple configuration.

- The process uniquely has the ability to produce High Carbon DRI, with important benefits in terms of higher stability, steel production costs and productivity.

- A key factor in many of the process advantages is directly related to the pressurized operation.
PROCESS SCHEME
The basic process configuration is **unchanged** for any energy source application and is characterized by its flexibility to process different gas analysis.

- The “make up” gas can be of any mixture of H₂, CO, CO₂ and hydrocarbons in any proportion.
- The selective removal of H₂O and CO₂ optimizes make-up requirements.
- The use of O₂ depends on hydrocarbons content.
- DRI Metallization and Carbon are controlled independently.
## ENERGIRON – Typical Consumptions by Gas Type

<table>
<thead>
<tr>
<th>Scheme</th>
<th>Natural gas</th>
<th>COG</th>
<th>Syngas</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Product</strong></td>
<td></td>
<td>Cold and/or hot DRI</td>
<td>Cold DRI</td>
</tr>
<tr>
<td>Plant capacity</td>
<td>t/a</td>
<td>200,000 – 2,500,000</td>
<td>200,000 – 2,500,000</td>
</tr>
<tr>
<td>Metallization</td>
<td>≥ 93%</td>
<td>≥ 93%</td>
<td>≥ 93%</td>
</tr>
<tr>
<td>Carbon</td>
<td>2 – 5%</td>
<td>2 – 4%</td>
<td>0.5 – 2%</td>
</tr>
</tbody>
</table>

### Main inputs

<table>
<thead>
<tr>
<th>Main inputs</th>
<th>Unit</th>
<th>Specific consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron ore</td>
<td>t/t</td>
<td>1.35 – 1.40</td>
</tr>
<tr>
<td>Natural gas, COG, syngas</td>
<td>Gcal/t</td>
<td>2.35</td>
</tr>
<tr>
<td>Electricity (core equipment)</td>
<td>kWh/t</td>
<td>65</td>
</tr>
<tr>
<td>Oxygen</td>
<td>Nm³/t</td>
<td>35 – 50</td>
</tr>
<tr>
<td>Water</td>
<td>m³/t</td>
<td>1.2</td>
</tr>
<tr>
<td>Labor</td>
<td>m-h/t</td>
<td>0.11 – 0.17</td>
</tr>
<tr>
<td>Maintenance</td>
<td>$US</td>
<td>3.0 – 3.3</td>
</tr>
</tbody>
</table>
Selective elimination of both by-products generated from the reduction process;

- water (H₂O) and
- carbon dioxide (CO₂),

which are eliminated through top gas scrubbing and CO₂ removal systems, respectively.

ENERGIRON provides selective CO₂ removal, which can be used for various applications (food industry, fertilizers, etc.) or sequestrated, with the potential decrease of GHG emissions.

Sulfur from iron ore and reducing gas make-up (natural gas, COG, etc.) is removed along with the CO₂ in the removal system.
When a DR plant is located inside an integrated Steel plant, the ideal condition is not to cool down the DRI but feed it Hot to the EAF.

The HYTEMP system takes full advantage of the continuous feeding of Hot DRI to an EAF maximizing the EAF productivity and minimizing the power and electrodes consumption.

Typical annual production ratio hot DRI/cold DRI: 90-95%/10-5% (as per experience from ESI & Ternium)
ENERGIRON DR Technology
Scheme with HYTEMP® System for Hot DRI transport

- Pneumatic transport; totally enclosed
- Flexible for feeding >1 EAF; no layout restrictions
- No effect on DRI quality; carrier inert gas
- Distance up to 400-500m

- Fully automated and integrated system
- No wearing parts and almost maintenance-free
- Minimum heat losses (~80°C)
- \( \text{N}_2 \) make-up: 5-8 \( \text{Nm}^3/\text{t} \)
- Power consumption: 3-6 kWh/t
- Compliance with all safety regulations
HIGH CARBON DRI
Due to prevailing conditions of:
- Temperature
- Gas composition

the ENERGIRON-ZR Process favors the diffusion of Carbon in the Iron matrix and the precipitation of Iron Carbide (Fe₃C).

The DRI with a high content of Fe₃C exhibits a much lower reactivity (no gas generated in any test conducted) than the standard DRI.

Additional energy required to produce 3.5-4% Carbon is marginal;
- In any case, by reducing Carbon in DRI, more CO₂ will be taken out through flue gases/CO₂ removal system
- Better option is to produce high-Carbon DRI and providing additional chemical energy to EAF
The DRI with a high content of Iron Carbide exhibits a much lower reactivity (no gas generated in any test conducted) than the standard DRI, as proven by tests from:

- HYL lab tests in 1998
- University of NL in 1998
- Chilworth Technology Ltd, UK in 2008
- Korea Institute of Fire Industry & Technology in 2012

<table>
<thead>
<tr>
<th>DRI Analysis – Nucor DR Plant</th>
<th>DRI Analysis – 4M ternium Plant</th>
<th>Conventional DRI analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metallization</td>
<td>Metallization</td>
<td>Metallization</td>
</tr>
<tr>
<td>Carbon</td>
<td>Carbon</td>
<td>Carbon</td>
</tr>
<tr>
<td>Fe°</td>
<td>Fe°</td>
<td>Fe°</td>
</tr>
<tr>
<td>Fe Total</td>
<td>Fe Total</td>
<td>Fe Total</td>
</tr>
<tr>
<td>Fe₃C</td>
<td>Fe₃C</td>
<td>Fe₃C</td>
</tr>
<tr>
<td>Gangue</td>
<td>Gangue</td>
<td>Gangue</td>
</tr>
<tr>
<td>%</td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>96%</td>
<td>94%</td>
<td>94%</td>
</tr>
<tr>
<td>4.3%</td>
<td>4%</td>
<td>2.2%</td>
</tr>
<tr>
<td>87.3%</td>
<td>83.0%</td>
<td>89.2%</td>
</tr>
<tr>
<td>90.9%</td>
<td>88.3%</td>
<td>92.9%</td>
</tr>
<tr>
<td>58.5%</td>
<td>55.1%</td>
<td>29.6%</td>
</tr>
<tr>
<td>3.8%</td>
<td>6.2%</td>
<td>3.9%</td>
</tr>
</tbody>
</table>

% Combined Carbon (cementite or iron carbide - Fe₃C) in DRI from ENERGIRON ZR Process

% Total Carbon in DRI
Stability of High Carbon DRI

• The High-C DRI from ENERGIRON ZR scheme, exhibits a significantly lower reactivity than the standard DRI.

• The onset temperature for the High Carbon DRI is higher (>206°C) than for standard DRI (140°C).

• The tendency to re-oxidize is lower for the High Carbon DRI (ODR ~ negligible) than that for a Standard DRI (ODR ~ 200 liters/ton/day).
High Carbon - hot DRI to EAF

- In general, as compared to scrap, melting DRI in EAF demands more power because of the DRI gangue content. However, the difference in power consumption almost become null when comparing melting 100% scrap vs 100% high-Carbon, Hot DRI in the EAF.
  - For both cases, the power consumption ranges from 360 - 400 kWh/tls.

- The combination of high-Carbon and high temperature in DRI yields power decrease of >160 kWh/tls and productivity increase of up to 22% for a practice of 90% hot-10% cold DRI (as compared to cold, low-C DRI).

Power Savings

EAF #2 at Ternium Monterrey steelmaking facility; 100% hot high-Carbon DRI with 94% Mtz & 3.7% Carbon
ENERGIRON
REFERENCES
Location: Mussafah Industrial Area Abu Dhabi (UAE)

Integrated Steel Complex for production of 1,400,000 tpy of Billets, Bars and Wire Rods:

- 1.60 MTPY ENERGIRON® DRP with REFORMER
- HyTemp® System for Meltshop feeding
- 1.45 MTPY Meltshop (1 EAF and 1 LF)
- 1.40 MTPY 6 Strands Continuous Casting Machine
- 1.10 MTPY Bar and Wire rod mills

• Start-up: 2009
EMIRATES STEEL – Phase 2

Location: Mussafah Industrial Area Abu Dhabi (UAE)
Integrated Steel Complex for production of 1,400,000 tpy of Billets, Blooms, Beam Blanks and medium/heavy sections:

- 1.60 MTPY ENERGIRON DRP with REFORMER
- HyTemp ® System for Meltshop feeding
- 1.45 MTPY Meltshop (1 EAF and 1 LF)
- 1.40 MTPY 5 Strands Continuous Casting Machine for Blooms Beam Blanks
- 1.40 MTPY Rolling Mill for medium – heavy sections up to 1.100 mm width

Start-up: 2011
PRODUCTION DATA - ES Phase 2
09.2012 - 08.2013

NOMINAL CAPACITY EXCEEDED AFTER 1 YEAR OF OPERATION!
EMIRATES STEEL - Capacity enhancement

Capacity enhancement of the Integrated Steel Complex, both Plant #1 and Plant #2, up to 2.000.000 Mtpy, by first half 2014.

NEW EQUIPMENT / MODIFICATIONS FOR ENHANCEMENT

- Additional Oxygen Lances
- Higher capacity Cooling Gas Compressor
- Higher capacity Pneumatic Transport Compressor
- Minor mechanical and electrical modifications

Flexibility to increase production rate with few modifications and limited plant shutdown
## EMIRATES STEEL Plant#2 - Capacity enhancement

Achieved results in Performance Tests, **February 2014**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Achieved Results</th>
<th>Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production</td>
<td>ton/h</td>
<td>261,93</td>
<td>250</td>
</tr>
<tr>
<td>Average Metallization</td>
<td>%</td>
<td>95.28</td>
<td>94</td>
</tr>
<tr>
<td>Average Carbon Content (with oxygen injection)</td>
<td>%</td>
<td>2.56</td>
<td>2.5</td>
</tr>
<tr>
<td>Average Natural Gas Consumption</td>
<td>Net Gcal/t of DRI</td>
<td>2.52</td>
<td>2.65</td>
</tr>
<tr>
<td>Average Electricity Consumption</td>
<td>kWh/t of DRI</td>
<td>24.14</td>
<td>35</td>
</tr>
<tr>
<td>Average Cold DRI temperature</td>
<td>°C</td>
<td>41</td>
<td>60</td>
</tr>
</tbody>
</table>

EMIRATES STEEL Plant#1 Capacity enhancement currently in progress
NUCOR STEEL
NUCOR STEEL
2,500,000 t/y - NUCOR St. James Parish, Louisiana (ENERGIRON)

- World’s largest single DR module of 2.5 MTPY for Cold DRI Production
- The only US plant in operation
- Started up 24\textsuperscript{th} Dec 2013
- Reached 95% metallization and ≥4% carbon in the first 24 hours of operation
- Production rate as expected since day #1
- Zero Reformer technology
• Located in St. James Parish, Louisiana (USA) by the Mississippi river

• Iron ore pellets are received via ocean going vessel in a port on the Mississippi River

• DRI is shipped to various Nucor plants via river barge

REFERENCES: NUCOR STEEL DRP

First vessel of Samarco iron ore delivery
History of **41** Complete Direct Reduction Plant out of which:

- **First Gas based HYL-I** DRI plant in 1957
- **First DRP** with zero-reformer technology Hylsa 4M Plant in 1998
- **World largest D.R. module** with 2,5 Mtpy at NUCOR USA in 2011
JSPL DR PROJECT ANGUL-2
Jindal Steel & Power, India

- World’s largest single DR module with COG/Syngas (BOFG as fuel) under Engineering
  - 2.5 million tpy capacity
  - **ENERGIRON ZR** scheme
  - 94% metallization
  - ≥2.5% carbon
- DRP can also operate with 100% NG if convenient
Tenova HYL together with Danieli & C. signed a contract for the first of four ENERGIRON DR plants for Jindal Steel & Power of India. Main characteristics:

- DRI Metallization of 94% and carbon of 2-2.5%
- Use of BOF gas as fuel for the process gas heater and other users.
- DRP capacity: 2.5 million tpa of cold and hot DRI in any combination.
- Use of syngas from coal gasification and COG as source of reducing gases in any proportion, with energy consumption in the range of 2.2 Gcal/t DRI.
COG and syngas, can be used from 0-100% in any proportion.

Under typical operation, the DRP will use syngas from 0.6 – 1.2 Gcal/t DRI and COG from 1.0 – 1.5 Gcal/t DRI in various operating modes and combinations.

Tail (purge) gas and BOF gas will be used as fuel in the Heater.

Total Process gas is ONLY 1.9 Gcal/t DRI as Syngas or COG
FINAL REMARKS

Shale gas has changed the world energy scenario, specifically for USA.

Coal gasification and use of COG presents a unique opportunity for high-volume gas-based DRI production.

**ENERGIRON ZR** plant sizes (2.5 Mmtpy) can compete with BF for ironmaking capacities.

**ENERGIRON ZR** Technology offers the most flexible, efficient and environmentally friendly option for metallics production.
Thank you