High-Carbon DRI: the feeding material to improve performances and decrease CO2 emissions in both BF and EAF

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Is the innovative HYL Direct Reduction Technology developed jointly by Tenova and Danieli

The most competitive and environmentally clean solution for lowering the liquid steel production cost
FLEXIBILITY
> Same scheme for ANY energy source

ENVIRONMENTAL:
> lowest NOx emissions: 0.030 kg_{NOx} / t_{DRI}
> Selective removal of iron ore reduction’s by-products: H_2O & CO_2
ENERGIRON
PLANT EMISSIONS ARE IN ACCORDANCE WITH THE MOST STRINGENT ENVIRONMENTAL REGULATIONS WORLDWIDE

> No need to preheat the combustion air to high temperature, due to the high energy efficiency of the process itself results in eliminating high NOx generation;
> NOx emissions additionally reduced with ultra-low NOx burners and/or SCR;
> Low dust emission from heater thanks to low tail gas purged from reducing circuit to burners

<table>
<thead>
<tr>
<th>Emission Type</th>
<th>Concentration Range</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOx with Ultra Low NOx burners</td>
<td>30-80</td>
<td>mg/Nm³</td>
</tr>
<tr>
<td>NOx with Selective Catalytic Removal</td>
<td>10-50</td>
<td>mg/Nm³</td>
</tr>
<tr>
<td>SO₂ (w/o and with sulphur removal)</td>
<td>250-negligible</td>
<td>mg/Nm³</td>
</tr>
<tr>
<td>CO</td>
<td>20-100</td>
<td>mg/Nm³</td>
</tr>
<tr>
<td>Dust from heater stack</td>
<td>1-5</td>
<td>mg/Nm³</td>
</tr>
<tr>
<td>Dust from material handling dedusting</td>
<td>5-20</td>
<td>mg/Nm³</td>
</tr>
</tbody>
</table>
HIGH CARBON DRI: USE IN EAF

DRI IS USED IN EAFS TO COMPLETELY OR PARTIALLY REPLACE SCRAP:

1. Higher Volumetric Weight
2. Uniformity of Chemical Analysis
3. Freedom from Undesirable Elements
4. Continuous Charging
5. Less Flicker
6. Less noise level
7. Better Bath Steering
8. Lower Nitrogen Content
9. Foamy Slag Practice

DRI WITH HIGH CONTENT OF IRON CARBIDE PROVIDES FURTHER ADVANTAGES...
CARBON IN EAF IS REQUIRED TO REDUCE RESIDUAL FEO IN THE DRI

### TRADITIONAL DRI
- C ≈ 1.5 ± 2%
- 30%–40% C in GRAPHITE form

### LOW-C DRI
- GRAPHITE/COAL
- OXYGEN E.E.
- YIELD Injected carbon < < 100%
  > Particles blowoff
  > Ash/impurities

### ENERGIRON DRI
- C ≈ 1.5 ± 4.5%
- C mostly in CEMENTITE form

### HIGH-C DRI
- OXYGEN E.E.
- YIELD carbon bond to DRI ≈ 100%
  > ~ 33 kWh / tLS saved
  > ~ 10 Nm3 O2 / 1% C

CARBURIZATION IN ENERGIRON PROCESS

\[3Fe^0 + CH_4 \rightarrow Fe_3C + 2H_2\]

- T > 1050 °C
- P ≈ 6 ÷ 8 barg
- CH\(_4\) > 20%
- H\(_2\) / CO ≈ 5

CEMENTITE IS SOURCE OF ENERGY IN EAF

\[Fe_3C \rightarrow 3Fe + C + \text{Heat}\]

\[2C + O_2 \rightarrow CO + \text{Heat}\]

\[\sim 8 \text{ kWh} / t_{\text{LS}} \text{ saved depending on post-combustion factor}\]
OPTIMUM CARBON CONTENT IN DRI DEPENDS ON EACH SPECIFIC APPLICATION AND STEEL GRADE:

- ENERGIRON plants are not designed to produce DRI with a specific C content, it can be easily adjusted by setting few operating parameters
- Feeding DRI with correct C content allows to reduce the residual FeO without graphite injection into EAF, that has lower efficiency
- Feeding to EAF C in cementite form, provides thermal energy (from Fe₃C dissociation) to the EAF
- C in DRI reacts with O₂ injected into EAF, providing thermal energy, better stirring, foamy slag
- Higher C content in DRI provides longer electrode’s life
- Higher C content in DRI provides longer EAF refractory’s life
- Feeding DRI with correct C content allows to reduce the tap-to-tap time, anyhow excessive C content in DRI can cause longer tap-to-tap time (refining time to get rid of C)

+ 4.5% DRI used as P.I. Replacement

3.0 ÷ 4.5 % DRI used in combination with scrap

2.0 ÷ 3.0 % EAF fed by DRI only

- 2.0% Special applications
HIGH-C DRI CAN BE FED TO BF:

1. **TO KEEP SAME LIQUID STEEL PRODUCTION RATE.** In this case the main target is reduction of environmental impact due to a decrease of specific coal consumption and CO$_2$ emissions by lowering PCI consumption.

2. **TO INCREASE HM PRODUCTIVITY IN THE BF**, decreasing not only specific consumption figures and CO$_2$ emissions but also achieving savings in production costs.
EFFECT OF DRI IN THE BF BURDEN ON CARBON SAVINGS
Example: Standardized graph as per Flint operating factors
Based on Fe°/FeT ~ 32% metallized charge, the expected Carbon rate savings are expected to be 85 – 90 kg;

i.e. CARBON SAVINGS
~ 27-30 kg/10% Mtz
EFFECT OF DRI IN THE BF BURDEN ON PRODUCTIVITY

Hot Metal (HM) production increase; about 6-7% per each 10% of burden metallisation. Based on Fe° / FeT ~ 32% metallised charge, the expected Productivity increase is expected to be 19-23%.

However; the estimate of productivity increase depends on multiple factors; i.e.

- Size and quality of raw materials
- Operating practices
- Oxygen injection, PCI
- Permeability
- Charge distribution

<table>
<thead>
<tr>
<th>Reference</th>
<th>% Productivity increase 10% Mtz</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>IRSID</td>
<td>6,6</td>
<td>Theoretical calculation</td>
</tr>
<tr>
<td>STELCO</td>
<td>6,5</td>
<td>5,15% NG injection</td>
</tr>
<tr>
<td>AHMSA</td>
<td>7,9</td>
<td>BF operating at low productivity</td>
</tr>
<tr>
<td>USIMINAS</td>
<td>7,9</td>
<td>Tests up to 15% Mtz</td>
</tr>
</tbody>
</table>

AK Steel has achieved 19% increase for production ~5.500 ton/d with 181 kg HBI/t HM

Optimising operating practices related to oxygen, NG injection, etc

\[ y = 0.928x + 4846.6 \]
\[ r^2 = 0.617 \]

9/91 – 11/93

![Graph showing relationship between HBI (MT/day) and Production (MT/day)](attachment://graph.png)
Hot Metal (HM) production increase; about 7-8% per each 10% of burden metallisation.

Lower coke rate; about 7% per each 10% of burden metallisation.

\[
\begin{align*}
\text{US Bureau of mines} & \quad (1965) \\
\text{US Steel} & \quad (1966) \\
\text{Stelco} & \quad (1964) \\
\text{Yawata Steel} & \quad (1965) \\
\text{Kawasaki Steel} & \quad (1966) \\
\text{Ahmsa} & \quad (1978)
\end{align*}
\]
ENERGIRON DRP
INTEGRATED WITH BF
BASE CASE: TYPICAL INTEGRATED MILL BF-BOF

- **Coking Coal**: 455 kg/t<sub>LS</sub>
- **PCI**: 161 kg/t<sub>LS</sub>
- **Burden**: 1520 kg/t<sub>LS</sub>

**Main energy lines distribution**

- **0.94 t HM**
- **0.17 t scrap**
- **1.00 t LS**

**CO2 Emissions**
- 1.80 t/t<sub>LS</sub>

**Export Power**
- 324 kWh/t<sub>LS</sub>

**Note:** Power credit included in CO<sub>2</sub> Emissions

Ref: 0.5kg CO<sub>2</sub>/kWh

**Net CO2 Emissions**
- 1.60 t/t<sub>LS</sub>
CASE 1: REPLACEMENT OF BF-BOF by DRP-EAF (a) w/o & (b) w CO2 off-taking

- Natural Gas: 190 / 140 Nm³/t\textsubscript{LS}
- DR pellets: 930 / 690 kg/t\textsubscript{LS}
- Coking Coal: 190 / 260 kg/t\textsubscript{LS}
- PCI: 66 / 92 kg/t\textsubscript{LS}
- Burden: 620 / 870 kg/t\textsubscript{LS}

Main energy lines distribution:
- BFG
- COG

0.66 / 0.49 t DRI
0.59 / 0.43 t LS
0.39 / 0.54 t HM
0.07 / 0.10 t scrap
0.41 / 0.57 t LS

Non-selective CO\textsubscript{2} Emissions: 1.20 / 1.08 t/t\textsubscript{LS}
Selective CO\textsubscript{2} Emissions: 0 / 0.12 t/t\textsubscript{LS}
Import Power: 150 / 25 kWh/t\textsubscript{LS}

Note: Power Consumption included in CO\textsubscript{2} Emissions
Ref: 0.5kg CO\textsubscript{2}/kWh
CASE 2: INTEGRATION OF DRP-EAF IN BF-BOF with CO₂ off-taking

- **Coking Coal**: 455 kg/t<sub>LS</sub>
- **PCI**: 43 kg/t<sub>LS</sub>
- **Burden**: 1140 kg/t<sub>LS</sub>
- **DR IO Pellets**: 480 kg/t<sub>LS</sub>

**CO₂ Emissions**
- Non-selective: 1,36 t/t<sub>LS</sub>
- Selective: 0 / 0.5 t/t<sub>LS</sub>

**Import Power**: 155 kWh/t<sub>LS</sub>

**Limitations**:
- Total COG availability for DRP
- > max. % metallic burden (DRI) to BF

**Note**: Power credit included in CO₂ Emissions
Ref: 0.5kg CO₂/kWh
**CASE 3: EXTERNAL DRI TO BF**

(a) w / (b) w/o CO₂ off-taking

- **Natural Gas**
  104 Nm³/t<sub>LS</sub>

- **DR IO pellets**
  520 kg/t<sub>LS</sub>

- **Coking Coal**
  455 kg/t<sub>LS</sub>

- **PCI**
  43 kg/t<sub>LS</sub>

- **Burden**
  1140 kg/t<sub>LS</sub>

- **0.37 t DRI**

- **0.94 t HM**

- **0.17 t scrap**

- **1.00 t LS**

- **CO₂ Emissions**
  - Selective (+4%)
  - 0.06 t/t<sub>LS</sub>
  - Non-selective (+5%)
  - 0.09 t/t<sub>LS</sub>

Limitations:
- max. % metallic burden (DRI) to BF

**Main energy lines distribution**

- **CO₂ Emissions**
  - Non-selective (-19%)
  - 1.30 t/t<sub>LS</sub>

- **Exit Power**
  - 300 kWh/t<sub>LS</sub>

**Note:** Power credit included in CO₂ Emissions

Ref: 0.5kg CO₂/kWh
**CO₂ EMISSIONS – STEELMAKING ROUTES**

<table>
<thead>
<tr>
<th>Methodology</th>
<th>CO₂ Emissions (kg/Ton Liquid Steel)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BF-BOF</td>
<td>100%</td>
</tr>
<tr>
<td>DRP-EAF</td>
<td>50%</td>
</tr>
<tr>
<td>DRP-EAF + BF-BOF</td>
<td>75%</td>
</tr>
<tr>
<td>DRI (w/COG) to BF (*)</td>
<td>85%</td>
</tr>
<tr>
<td>DRI (w/COG) to BF (**)</td>
<td>88%</td>
</tr>
<tr>
<td>DRI (w/NG) to BF (*)</td>
<td>86%</td>
</tr>
<tr>
<td>DRI (w/NG) to BF (**)</td>
<td>90%</td>
</tr>
</tbody>
</table>

Notes:
(*) With CO₂ off-taking / commercialization
(**) Without CO₂ off-taking / commercialization
The ZR patented scheme for using COG has been tested under the following scenarios:

- Campaigns during 1997: With CO₂ absorption and oxygen injection (ZR)
- Laboratory tests at AHMSA to prove destruction of BTX with hot DRI; 1980’s
- 2008; Tests at Zdz, Poland in a joint effort between ArcelorMittal and Tenova HYL to confirm the above

**EFFICIENCY** - No need of external combustion chamber or additional reactor

Now in analysis with JSW to implement this scheme in the existing HYL plant in India
REFERENCES
<table>
<thead>
<tr>
<th>Company</th>
<th>Modules</th>
<th>Capacity</th>
<th>Carbon Range</th>
<th>Metal Range</th>
<th>Start-up Date</th>
<th>DRI Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMIRATES STEEL</td>
<td>Two modules</td>
<td>2.0 MTPY each</td>
<td>1.5% - 2.5%</td>
<td>94% - 96%</td>
<td>2009/2011</td>
<td>Hot DRI feed to EAF</td>
</tr>
<tr>
<td>SUEZ STEEL</td>
<td>One module</td>
<td>2.0 MTPY</td>
<td>3.0% - 4.0%</td>
<td>94% - 96%</td>
<td>2013</td>
<td>Hot DRI feed to EAF</td>
</tr>
<tr>
<td>NUCOR</td>
<td>One module</td>
<td>2.5 MTPY</td>
<td>3.0% - 4.5%</td>
<td>94% - 96.5%</td>
<td>2013</td>
<td>Cold DRI</td>
</tr>
<tr>
<td>EZZ STEEL</td>
<td>One module</td>
<td>1.95 MTPY</td>
<td>1.5% - 2.5%</td>
<td>94% - 96%</td>
<td>2015</td>
<td>Cold DRI</td>
</tr>
</tbody>
</table>

**UNMATCHED EXPERIENCE IN HIGH CAPACITY MODULES**
Energiron is the only proven Direct Reduction Technology available on the market with a productivity rate up to 2.5 Mtpy in a single module, able to compete with BF-BOF route.

> Controlled carbon content value in DRI affect positively EAF operation in terms of OPEX, and only Energiron can produce it.

> HyTemp system gives unmatched results in liquid steel productivity and efficiency.

> Energiron has designed and supplied facilities that are successfully operating under some of the strictest environmental standards in the world.