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We care about your Business

The outstanding achievements obtained during the past few months confirm Energiron as the state-of-the-art technology for DRI production. The Energiron technology is the only one that has proven the capability to produce more than 300 t/h at 96% metallization and up to 4% C. This performance is the result of the continuous innovation we deliver to our clients, allowing them to obtain increased value in their production. Greater value through innovation has been realized in Energiron process plants at Emirates Steel, Suez Steel and Nucor, the unparalleled results from which, as described in this issue, are changing the face of the DR market. And whenever we have faced challenges during this process innovation, we have teamed up with our customers and found the right solutions to reach production excellence. In these times where steelmaking production is facing known challenges, the value brought by the DRI produced only with Energiron is the key to gain the needed competitive advantage.

Stefano Maggiolino
President & CEO
Tenova HYL
VIEWPOINT

Our last issue of HYL NEWS dealt in detail with the Carbon Question. This topic has been cause for debate and discussion, although more commercially motivated than technically warranted. Nevertheless, since only the ENERGIRON DR process can, to date, produce truly high carbon DRI (above 3% C), we feel it necessary to continue to provide clarification on this topic.

From the steelmaker’s point of view, we discussed the value of combined carbon in DRI in terms of producing steel more efficiently, at lower cost and of higher quality. The generation of chemical energy in the EAF provides significant advantages for modern steel producers and is universally recognized as a best practice.

An additional and very significant advantage of High Carbon DRI is the fact that it is more stable and less reactive than what we refer to as “conventional DRI”. In this issue, we present detailed results of testing conducted using DRI with a high content of carbon in the form of iron carbide, and show conclusively that this type of product is less reactive than conventional DRI. The impact of this is important for DRI producers who need to store or ship the product, and also for shippers, brokers and product handlers in the business of commercializing DRI and HBI.

We hope you find the articles in this issue to be informative and we welcome your comments and observations. You can always find additional information through our websites at www.tenova.com and www.energiron.com.

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Technically, direct reduced iron (DRI) can be defined as iron ore or ferrous oxide which has been reduced to metal without melting it. Using either gaseous or solid reductants, iron ore is subjected to a process to eliminate or reduce the oxygen content and obtain a solid, porous and metallized product.

The porosity is due to the removal of the oxygen that was contained in the iron ore pellet or lump, leaving a significantly greater surface area available for the iron to recombine with free oxygen in order to return to its natural oxidized state. DRI was once more commonly called “sponge iron” for this reason, and in some regions such as India and Pakistan, the term is still very commonly used.

This porosity means that DRI, under certain conditions of temperature and moisture, can react rapidly with oxygen. Rapid reoxidation became a cause for concern as manufacturers – and later shippers and traders – were faced with the potential for fires and explosions if proper handling procedures were not followed.

The early history of DRI production involved onsite production and use of the product almost exclusively. However, as time passed and companies began transporting the product to steel mills over distances that often involved maritime shipping, incidents began to occur involving spontaneous combustion of DRI in cargo holds of ships, on docks in rainy weather while awaiting loading procedures, or in outdoor patios where rain could soak DRI piles and eventually generate hot spots.

It should be pointed out that the vast majority of incidents relating to DRI reactivity during shipping could be traced to either improper preparation of the ship’s hold prior to loading the material, or to the use of un-seaworthy vessels, or both.

HBI was later developed as a solution to the maritime shipping problem. Since HBI has a much lower surface area than DRI, it is less likely to reoxidize in a manner hazardous to shipping. The International Maritime Organization (IMO) developed a set of rules governing the maritime shipping of DRI and also HBI, the compacted form of the same product.
Although HBI is a product designed for overseas shipping, more conventional DRI is shipped every year all over the world than HBI. This is primarily because DRI is generally shipped “inter-company” – from a company’s DRI production facility in one country or region, to a steel mill owned by that same company in a different country or region. It can be argued that more judicious care is taken with the product since it is under the control of the owner company, but in any case the point is clear: when proper procedures are followed, DRI can safely and readily be shipped overseas with little product degradation and no hazardous effects.

Differentiating conventional DRI from High Carbon DRI
To date, all data regarding the transportation and safety of shipping DRI has been based on what we are calling “conventional DRI”. That is, DRI produced by any of several DR processes using a natural gas reformer and producing a DRI product with a carbon level typically from 0.8 to 2.5% carbon.

This is the first step in avoiding an “apples-to-oranges” comparison that is quite commonly used. The simple fact is that any tests or calculations that have been presented regarding the reactivity and/or safety of high carbon DRI are invalid for the simple reason that to date, only ENERGIRON ZR plants can produce High Carbon DRI.

In order for a conventional DR plant to produce carbon above 2.5%, the residence time must be increased as a flow of natural gas is circulated in the reactor cooling zone. This increase in carbon is essentially deposition of carbon (soot) on the surface of the DRI pellets. It is generally not uniform and is not in combined form with the iron content of the pellet since it does not occur chemically.

Because an ENERGIRON ZR plant carries out the natural gas reforming within the reduction reactor, the DRI acts as a catalyst to the reaction, thus chemically “contaminating” the DRI with carbon in the form of Fe₃C or iron carbide. The carbon content in such plants is not only controllable, but generally the same across the reactor burden, and can be selected from 3 to 5%, with 3.5-4% being typical.

For this simple reason, any claims made that so-called “high carbon DRI” has been tested and shown to be equally as reactive as conventional DRI are simply not comparing similar products. Simulating “high carbon” by injecting natural gas to the cooling zone is not the same as producing High Carbon DRI via the reformerless ENERGIRON ZR process.
To properly document the behavior of our High Carbon DRI, studies were conducted over the past several years. In-house studies, of course, were the first step. Actual plant conditions and product behavior was observed and documented, and laboratory tests were conducted that validated the initial observations that High Carbon DRI appeared to be less reactive than conventional DRI produced in the same plant installation.

Additional tests were conducted with the help of local universities, and commercial laboratories were used to produce more extensive testing and validation. To determine a basis of safety and hazard assessment involving High Carbon DRI, an extensive series of tests were carried out by Chilworth Technology Ltd, U.K.

Testing purpose and procedures
Every process or solids handling operation requires a defined Basis of Safety appropriate to its hazard potential. The objective of any hazard assessment is to provide an acceptable level of safety consistent with the manufacturing, engineering and economic requirements of the process as well as satisfying all applicable regulations. While numerous tests were conducted, for the purposes of this report in line with stability for handling and shipping of DRI, we will concentrate on defining the propensity for the sample to self-heat and also to potentially generate flammable gases when brought into contact with air, distilled water or sea water.

The tests are in accordance with the United Nations Recommendations on the Transportation of Dangerous Goods, Manual of Tests and Criteria for substances of Class 4, Division 4.2.

For the self-heating tests, cubic sample containers of 25 mm and 100 mm side lengths were used. The open top cubes are manufactured from stainless steel net, with a mesh opening of 0.053 mm. Each container is housed in a cubic container cover, manufactured from stainless steel net with a mesh opening of 0.595 mm and slightly larger than the sample container, so that the container fits in this cover. In order to minimize the effects of air circulation, another stainless steel cage, manufactured from a net with a mesh opening of 0.595 and 150 x 150 x 250 mm in size, should be further installed to house the cover.

The sample container is filled to the brim with the DRI sample and the container tapped several times. If the sample is seen to settle then more material is added and it should be leveled to the brim. The container is housed in the cover and hung in the center of the oven.

### High Carbon DRI Test Sample

<table>
<thead>
<tr>
<th>Chemical composition</th>
<th>% (wt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total iron</td>
<td>88.85%</td>
</tr>
<tr>
<td>Gangue SiO2+Al2O3+CaO+MgO+Mn+S+P Ti, V, Cu, Na, K</td>
<td>5.9% Traces</td>
</tr>
<tr>
<td>Carbon</td>
<td>3.66%</td>
</tr>
</tbody>
</table>

### Physical characteristics

<table>
<thead>
<tr>
<th>Physical state</th>
<th>Solid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appearance</td>
<td>Light grey</td>
</tr>
<tr>
<td>Odor</td>
<td>None</td>
</tr>
<tr>
<td>Bulk density</td>
<td>1.6-1.7 kg/dm³</td>
</tr>
<tr>
<td>Porosity</td>
<td>About 50%</td>
</tr>
<tr>
<td>Water pick-up</td>
<td>About 12%</td>
</tr>
<tr>
<td>Size distribution</td>
<td>6-20 mm  &lt;6 &gt;20</td>
</tr>
<tr>
<td></td>
<td>90-95%   &lt;5% &lt;5%</td>
</tr>
</tbody>
</table>
A hot air circulating-type oven with a capacity of more than 9 liters and able to control the internal temperature at 140 ± 2°C is used. In the initial test (with a 100 mm cube), the oven temperature is raised to 140°C and held isothermally for 24 hours. The temperature of the sample and oven are continually monitored/recorded. Inconel sheathed thermocouples are used for accurate temperature measurement. One thermocouple is placed in the center of the sample and the other between the sample container and the oven wall.

**Interpretation of Results**
As seen in the chart below, the high carbon DRI sample temperature was raised to 140°C, temperature of the oven, and held stable over time. No self-heating was observed by the sample throughout the entire test periods. It was determined that this type of DRI should be classified as ‘Not a self-heating substance of Class 4, Division 4.2’.

**Air and water reactivity tests**
The air reactivity test is conducted in accordance with the United Nations Recommendations on the Transportation of Dangerous Goods, Manual of Tests and Criteria for substances of Class 4, Division 4.2. For contact with water, the tests are in accordance with UN Transport of Dangerous Goods Recommendations Test N.5.

No gas was generated in any of the tests conducted, during either the initial or final phases of testing procedure. The sample is therefore exempt from classification as a Division 4.3 substance.

For comparative purposes, the charts on the next page show the results of High Carbon DRI versus our own standard HYL DRI to show the effect of combined carbon versus conventional carbon in DRI.

**The effect of carbide in DRI**
As mentioned earlier, it is not possible to compare all DRI products since – regarding carbon composition – the differences are significant. In addition to the certified laboratory testing that was carried out on our high carbon DRI product, we were able to validate the results further at the Ternium Monterrey DR facilities.
DRI was obtained from the 3M plant, previously a conventional (reformer-based) plant, and the 4M plant using the reformerless ZR process configuration. It was therefore possible to run controlled tests using samples from both plants at the same metallization levels, but with carbon content at 2% for the conventional process and 4% for the ZR process plant.

The charts show the reactivity of the DRI samples from both types of carbon-bearing DRI when subjected to the same reactivity tests for air, air and water and salt water exposure. It is abundantly clear that the difference in results is due to the combined carbon content of the ENERGIRON ZR process DRI. The carbon resulting from deposition via process gas is not the same as combined carbon produced in an integrated reforming/reducing shaft furnace.

**Importance for shipping and handling**

More DRI is shipped worldwide every year than HBI. So why bother determining the added safety of high carbon DRI, if conventional DRI is so routinely transported?

The first reason is safety. Even following standard shipping and handling procedures for DRI, accidents can happen. Having a product that exceeds the safety requirements for its category can help assure shipments are conducted in the utmost safety.

Insurance for such shipments based on that possibility is an added cost that affects the delivered price of the DRI to the end user. The additional cost of producing HBI should also be considered based on the expected routine use and handling of the product. Domestic producers shipping to domestic consumers, for example, can avoid added costs by producing and shipping high carbon DRI.

When you read that carbon makes no difference, consider the source.
Nucor Steel Louisiana, USA. – June 2015: After the combined team effort that has led to the restart of the 2.5 mtpy ENERGIRON DRI plant in Convent, LA, Tenova HYL announces the successful repair of the process gas heater with the recommencement of production at Nucor Steel Louisiana, and the client’s final acceptance of this state-of-the-art ENERGIRON plant.

This DRI plant has demonstrated its ability to routinely produce premium quality DRI with metallization of 96%, carbon ranging from 3.6 to 4.0% and at a productivity above 300 tph. The plant operation is smooth and stable.

No other DRI plant has ever shown the capacity to produce direct reduced iron at such levels of quality and at the highest production level in the world.

Considering the DRI quality obtained and selective CO₂ removal, the plant achieves one of the most efficient NG consumption rates worldwide; just ~2.4 Gcal/t of product.
The Suez Steel Energiron ZR Direct Reduction Plant is the world’s largest module producing hot DRI. This plant is based on the innovative Energiron Zero Reformer technology, jointly developed by Tenova and Danieli, and is equipped with a dual reactor designed to discharge either hot or cold high carbon DRI. The plant futures a pneumatic transport system integrated with an EAF which allows the Hot DRI to be conveyed directly from the reactor discharge to the EAF charging system.

The module’s high process flexibility permits scheduling production according to the particular requirements of any actual or final user. The Energiron DRP converts iron ore into metallic iron by means of hot (>1080°C) reducing gases that flow in the direction opposite to the solid material inside the moving bed shaft furnace (reactor), operated at a pressure of approximately 6 barg on the top. In the Zero Reformer configuration, the natural gas, used as a reducing agent makeup, is fed directly into the reactor where it is converted into reformed gas by exploiting the catalytic power of the DRI.

Since the reducing gases are generated in the reduction section, the overall energy efficiency of the direct reduction is optimized and most of the energy supplied to the process is taken by the product with minimal energy losses to the environment.

This arrangement results in very low natural gas consumption, even lower than 2.35 Gcal/t.

On last November 2014, it was announced that the Suez Steel Company (SSC) Energiron Direct Reduction Plant (1.95 Mtpy capacity) and the corresponding integrated meltshop (1.28 Mtpy of liquid steel capacity) successfully passed the Performance Tests. The table below shows the results achieved during the performance test of the DRP.

<table>
<thead>
<tr>
<th>DRP ENERGIRON ZR PARAMETER</th>
<th>UNIT</th>
<th>ACHIEVED RESULT</th>
<th>TARGET</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production</td>
<td>tonne</td>
<td>29,262</td>
<td>29,250</td>
</tr>
<tr>
<td>Metallisation (avg)</td>
<td>%</td>
<td>94.28</td>
<td>94</td>
</tr>
<tr>
<td>Carbon content (avg)</td>
<td>%</td>
<td>3.52</td>
<td>3.5</td>
</tr>
<tr>
<td>Natural gas consumption (avg)</td>
<td>Net Gcal/tDRI</td>
<td>2.40</td>
<td>2.42</td>
</tr>
<tr>
<td>Electricity consumption (incl: DRP Core + MH + Aux systems+ CAP)</td>
<td>kWh/tDRI</td>
<td>93.17</td>
<td>95</td>
</tr>
<tr>
<td>Hot DRI Temperature</td>
<td>°C</td>
<td>600</td>
<td>600</td>
</tr>
<tr>
<td>Iron oxide Consumption (dry, screened)</td>
<td>tIO / tDRI</td>
<td>1.38</td>
<td>1.40</td>
</tr>
</tbody>
</table>
**EMIRATES STEEL: EXPANDED DRI CAPACITY FOR STEEL GROWTH**

Emirates Steel sets new productivity target
The steel production target at Emirates Steel was to increase the hourly nominal productivity from 196 tls/h to 236.8 tls/h, commencing with Plant 2. The key factors for this capacity enhancement are the reduction of EAF power off time and electrical energy consumption.

The two integrated plants (Plant 1 and Plant 2) are each based on a direct reduction plant (ENERGIRON® technology) that directly feeds the steel meltshop by means of a HYTEMP® Pneumatic Transport System. The EAF at Plant 2, originally designed to work for an hourly productivity of 196 tls/h, has the same design as the EAF of Plant 1. The nominal charging practice is 10% cold DRI and 90% Hot DRI, continuously fed from the fifth hole and coming from the DRI plant through the HYTEMP tower.

Part of this project included the revamping of the ENERGIRON Direct Reduction Plant at the Emirates Steel Phase II integrated facility. After carrying out a series of tasks in the core area equipment, the plant was put back in service and the performance was as expected. The following results were achieved during the tests.

**Test results after revamp of ESI II from 1.6 Mtpy to 2.0 Mtpy :**

<table>
<thead>
<tr>
<th>DRP ENERGIRON PARAMETER</th>
<th>UNIT</th>
<th>ACHIEVED RESULT</th>
<th>TARGET</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production</td>
<td>tonne</td>
<td>78579</td>
<td>75000</td>
</tr>
<tr>
<td>Metallization (avg)</td>
<td>%</td>
<td>95.28</td>
<td>94</td>
</tr>
<tr>
<td>Carbon Content (avg)</td>
<td>%</td>
<td>2.56</td>
<td>2.5</td>
</tr>
<tr>
<td>Natural Gas Consumption (avg)</td>
<td>Net Gcal/tDRI</td>
<td>2.52</td>
<td>2.65</td>
</tr>
<tr>
<td>Electricity consumption (only DRP Core)</td>
<td>kWh/tDRI</td>
<td>24.14</td>
<td>35</td>
</tr>
<tr>
<td>Cold DRI Temperature (avg)</td>
<td>°C</td>
<td>41</td>
<td>60</td>
</tr>
<tr>
<td>Iron Oxide consumption</td>
<td>t IOP/t of DRI</td>
<td>1.41</td>
<td>1.44</td>
</tr>
</tbody>
</table>

With the increased capacity of the DRP, the the targets for the increased EAF productivity were successfully achieved and the results were the following:

<table>
<thead>
<tr>
<th>EAF Performance</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric consumption</td>
<td>380 kWh/tLs</td>
</tr>
<tr>
<td>Tap - Tap Time</td>
<td>38 min</td>
</tr>
<tr>
<td>Condition 1</td>
<td>90% Hot DRI</td>
</tr>
<tr>
<td>Condition 2</td>
<td>10% Cold DRI</td>
</tr>
<tr>
<td>Mtz. 95.7%</td>
<td>Mtz. 96%</td>
</tr>
<tr>
<td>C 2%</td>
<td>C 2%</td>
</tr>
</tbody>
</table>
Look for Tenova HYL at the following events:

**August 13 -14**
Indian Iron Ore and Pellets Summit  
Hyatt Regency  
Kolkata, INDIA

**August 17 -20**
ABM Week - 45th Ironmaking & Mineral Technology Seminar  
Riocentro  
Rio de Janeiro, Brazil

**September 14 - 16**
Iranian Iron and Steel Conference  
Kish International Convention Center  
Kish Island, Iran

**September 30 – October 2**
IIMA Fall Meeting  
Intercontinental Hotel  
Vienna, Austria

**November 9 - 11**
Latin American Steel Congress & Expo Alacero-56  
Hilton Hotel, Puerto Madero  
Buenos Aires, Argentina

**November 11 - 12**
AMM 3rd DRI & Mini-mills Conference  
Hyatt Rosemont Hotel  
Chicago, USA

**December 14 - 16**
Metal Bulletin - 19th Middle East Iron & Steel Conference  
Atlantis, The Palm  
Dubai, UAE