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- Lebedinsky GOK – A legend in the production of HBI
- High Carbon Briquettes (HCB) – The future of Briquetted DRI
- 2016 ENERGIRON Licensees Conference
This year is about to come to an end and it is time to draw conclusions and make new plans.

The ironmaking and steelmaking industry has gone through tough times, but our technology licensees have had many things to celebrate, as we did in our ENERGIRON Licensees Conference in October.

Among other achievements, the local conditions in Egypt have allowed Suez Steel to maintain constant production in the last months; Ezz Steel, after its record start up, has been producing with the agility that a challenging market requires. Nucor has been steadily producing its premium quality high carbon DRI in line with the request of its meltshops. Emirates Steel with its visionary project of Enhanced Oil Recovery has become the greenest ironmaker worldwide. In other words, facts confirm that ENERGIRON is the benchmark technology in DRI production, also thanks to the sharing of experiences and best practices among the users.

These are clear examples of how maintaining a technological advantage helps companies stay at competitive levels, despite the cyclical nature of the iron and steel industry. With added advantages, such as the ENERGIRON High Carbon Briquetting technology, ironmaking will continue to advance as the industry enters a new upswing.

A new year is coming and it is time to offer good wishes to all our readers, sure that the technological innovation and plant reliability that are core results of our plants will help the ENERGIRON users team overcome the challenges of the moment.

Stefano Maggiolino
President & CEO
TENOVA HYL
In this issue we will talk about HBI (Hot Briquetted Iron), highlighting the performance and the characteristics of one of the most prominent HBI producers in the world: Metalloinvest’s – Lebedinsky GOK. They operate a Direct Reduction plant capable of producing 0.9 MTPY of HBI and it has been in operation since 2001. LGOK has been surpassing design capacity over the past years, maintaining an outstanding record in terms of quality and availability.

Looking to the future, the ENERGIRON technology also allows the production of High Carbon Briquetted DRI. High Carbon Briquettes (HCB), which can be produced thanks to the Zero Reformer scheme, offer a premium product that will allow optimization of the EAF performance using a premium High-C metallic charge with the handling and transport benefits of briquettes. This presents not only advantages for steelmakers but also the lowest capital and operating costs in briquette production. We will present results related to the mechanical strength of this type of briquettes and to the already well known stability and ease of transportation of the high carbon DRI produced only with the ENERGIRON Technology.

To conclude this issue of HYL NEWS we offer a chronicle of the ENERGIRON Licensees Conference that took place in the month of October in Tenova’s headquarters in Italy.

We hope you will find the articles in this issue to be informative and we will welcome your comments and observations. You can always find additional information through our websites at www.tenova.com and www.energiron.com.
LEBEDINSKY GOK: A LONGSTANDING TRADITION IN HBI PRODUCTION

Metalloinvest’s Lebedinsky GOK is the largest plant for the mining and beneficiation of iron ore in Russia and the CIS, producing high-quality iron ore and raw materials. They are the only HBI producer in Russia and the CIS. Through open-pit mining, the plant develops an iron ore deposit with proven reserves of 3.9 billion tons.

The main Lebedinsky GOK products are:
- Iron ore concentrate
- Non-fluxed pellets
- Fluxed pellets
- HBI

It is the last of the above listed products that we will focus on in this issue of the HYL NEWS. As a proud technology supplier for Lebedinsky GOK we will highlight the characteristics, product quality and the excellent performance of the DRP owned and operated by LebGOK.

Lebedinsky GOK was the pioneer in CIS region to acquire the technology required for the production of HBI and they are currently operating two DRP capable of producing HBI. The first of these facilities was licensed by Tenova HYL and it utilizes the former HYL-III process scheme. This plant started up back in 2001 and ever since it has proven to be an outstanding testament of reliability and of steady quality on their products.

The plant has a design capacity of 900,000 tons of HBI per year and, as it was already mentioned, it uses the classic process scheme that utilizes a steam-methane reformer for the production of reducing gases. The basic process scheme is shown in the figure below.
Hot briquetted iron is produced from iron ore pellets that are introduced in a reactor continuously discharging DRI pellets at a controlled rate (for LebGOK this is in average at 127 tons of DRI per hour). Inside the reactor, the conditions of temperature (~930°C) and pressure allow for the oxygen within the iron ore pellets to be removed by the reducing gases that are flowing in countercurrent.

The reduction agent used is natural gas that has been converted to mostly Hydrogen and Carbon Monoxide in a reformer unit.

After this reduction process, the highly metallized material is then discharged from the shaft at high temperature and then it enters the briquetting process where it is formed into briquettes with a length of 100-120mm, a width of 45-55mm, a depth of 30-40mm, and a weigh of 0.5-0.7kg.

This product contains virgin units of metallic iron that are highly valuable for the steelmaking process. HBI is primarily used in the production of a wide range of quality steels for the machinery-building, mill-building, oil and gas, auto industry, rail, bearing and hardware industries.

LebGOK is the only Russian producer of this high value-added HBI, a direct complement for ferrous scrap materials. This product is made available to the market, so the plant availability is really important.

The chart below shows the plant availability in the past 10 years, which has been steady above 98% and has made LebGOK one of the most reliable sources of Metallics in the CIS region.
PRODUCT QUALITY

With such steady production it is also important to highlight that the product quality of this DRP is quite high and constant as well.

LebGOK reports an average product quality of:

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe Total</td>
<td>90.69%</td>
</tr>
<tr>
<td>Fe Metallic</td>
<td>85.3%</td>
</tr>
<tr>
<td>Metallization</td>
<td>94.06%</td>
</tr>
<tr>
<td>Carbon Content</td>
<td>1.1%</td>
</tr>
<tr>
<td>Density</td>
<td>5.0 kg/dm$^3$</td>
</tr>
<tr>
<td>Tumbler index</td>
<td>72.5% (size grade +25mm)</td>
</tr>
</tbody>
</table>

PLANT PRODUCTIVITY

The plant design capacity is 900,000 tons of HBI per year, however LebGOK has already exceeded the 1 Million tons per year mark for several years.

The chart below shows the yearly production records for the last 10 years.

These results confirm that for HBI production, ENERGIRON is the right choice in terms of quality, productivity and reliability.
HIGH CARBON BRIQUETTES (HCB) – THE FUTURE OF BRIQUETTED DRI

Background
DRI has traditionally been used in integrated mini-mills, where installations are prepared for DRI storage and charging. DRI can be charged in any existing EAF by batch charging or continuous feeding. It has been used as merchant product by steelmakers using it as captive metallic charge for their own meltpshops, not located nearby the DRI facility. In fact, DRI has been routinely and extensively transported overseas by ship, inland by trucks and railroad and through rivers by barges.

On the other hand, HBI is the more traditional merchant product, mainly for overseas transport. It can be used in any mill without special adaptations of existing installations related to handling, storage and transport, in a similar way as scrap, specifically for those EAF-based installations not using high percentages of DRI/HBI as metallic feed.

The significant benefits of High-C DRI in terms of higher productivity, lower power consumption and in reducing the overall Opex has also been well documented and extensively proven in actual EAF operations. This is mainly due to the high iron carbide (Fe3C) content of this premium DRI product. High-C DRI is nowadays being produced and consumed by a number of steelmakers using the ENERGIRON ZR (Zero Reformer) technology, including Ternium, Nucor Steel, Emirates Steel and Suez Steel among others.

To combine the best benefits from both High-C DRI and HBI, Tenova HYL has been committed to R&D programs for developing a unique and novel product: High-C DRI molded as HBI, to produce the unique High-C Briquette (HCB), with a carbon content above 3.0%, which can be produced through the state-of-the-art ZR process configuration.

For many years, Tenova HYL has researched the main factors affecting the production of good quality Hot Briquetted Iron (HBI) as part of its continuous R&D activities. Tenova HYL has conducted several HBI test programs going back to the late 80’s -before the first HYL HBI Plant was built- continuing into recent years. Some of these tests have been carried out with the support of Köppern GmbH & Co. KG in its facilities at Hattingen, Germany. In this article, the most recent testing is described: High-C DRI molded into High-C Briquettes.

Briquetting Tests Description and Test Material
The most recent test work consisted in testing High-C DRI produced in the Emirates Steel-3 HYL-ZR Micro-Module DR Plant located in Abu Dhabi, UAE. The objectives of test work were: i) to define the required parameters for hot briquetting of the High-C DRI in the Köppern roller press machine, which produces actual size briquettes and ii) to characterize the mechanical / physical properties of the High-C Briquettes.

The following corresponds to Tenova HYL analysis of the results from the tests.

To differentiate the effect of DRI size, two sets of tests were performed: using a) Entire Pellets (T.01 & T.02) and b) with Crushed Pellets (T.03 & T.04). The High-C DRI chemical composition and properties are shown below in Table 1 and Table 2, respectively.

The main variables considered for the tests were i) DRI particle size, ii) briquetting temperature and iii) HBI cooling method. Sample coding was then classified as shown in Table 3.
### Table 1. High-C DRI Physical Properties

<table>
<thead>
<tr>
<th>ITEM</th>
<th>ENTIRE PELLET</th>
<th>CRUSHED PELLET</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>T.01</td>
<td>T.02</td>
</tr>
<tr>
<td>Bulk Density</td>
<td>1.595</td>
<td>&gt;9,000</td>
</tr>
<tr>
<td>Vibration Density</td>
<td>1.905</td>
<td>&gt;9,000</td>
</tr>
<tr>
<td>Angle of Slip (steel)</td>
<td>13°/31°</td>
<td>&gt;9,000</td>
</tr>
<tr>
<td>Angle of Slip (HDPE)</td>
<td>*</td>
<td>13°/29°</td>
</tr>
<tr>
<td>Angle of Repose</td>
<td>*</td>
<td>34°</td>
</tr>
<tr>
<td>Particle Distribution</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20-10 mm</td>
<td>-</td>
<td>64.04</td>
</tr>
<tr>
<td>20 - 10 mm</td>
<td>%</td>
<td>17.07</td>
</tr>
<tr>
<td>10 - 8 mm</td>
<td>%</td>
<td>11.09</td>
</tr>
<tr>
<td>8 - 6.3 mm</td>
<td>%</td>
<td>5.65</td>
</tr>
<tr>
<td>6.3 - 5 mm</td>
<td>%</td>
<td>1.38</td>
</tr>
<tr>
<td>5 - 4 mm</td>
<td>%</td>
<td>0.58</td>
</tr>
<tr>
<td>4 - 3.15 mm</td>
<td>%</td>
<td>0.08</td>
</tr>
<tr>
<td>3.15 - 2 mm</td>
<td>%</td>
<td>0.08</td>
</tr>
<tr>
<td>&lt;2 mm</td>
<td>%</td>
<td>0.11</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 2. High-C DRI Physical Properties

<table>
<thead>
<tr>
<th>TEST</th>
<th>DRI PARTICLE SIZE</th>
<th>TEMPERATURE (*)</th>
<th>COOLING METHOD</th>
</tr>
</thead>
<tbody>
<tr>
<td>T.01</td>
<td>Entire</td>
<td>640°C</td>
<td>Type a = ambient air</td>
</tr>
<tr>
<td>T.02</td>
<td>Entire</td>
<td>538°C</td>
<td>Type b = water spraying</td>
</tr>
<tr>
<td>T.03</td>
<td>Crushed</td>
<td>628°C</td>
<td>Type c = water quenching</td>
</tr>
<tr>
<td>T.04</td>
<td>Crushed</td>
<td>678°C</td>
<td>(*) Note: Temp on briquette after pressing</td>
</tr>
</tbody>
</table>
TEST DESCRIPTION

For hot briquetting of the test material an industrial scale roller press made by Köppern was used. The roller press is equipped with a screw feeder, segments with 138 cm³ briquette pockets and a metal belt conveyor.

Prior to briquetting, the test material was heated up in an electrical furnace with nitrogen blanketing up to the desired testing temperature. It was put in a hopper and then discharged to the screw feeder, which conveys the material to the roller press. Köppern equipment for the roller tests are shown in Pictures 1a, 1b and 1c below.

The tests default settings were:

- The furnace temperatures were set to ≥ 750 °C in the core
- The target temperature of the feed was in the range of 700 °C for both materials: entire and broken pellets
- The pressing force target was 150 kN/cm
- Nitrogen bubble pressure 120 bar
- Preset pressure 250 bar
- The peripheral speed of the rollers was set to 0.31 m/s (6 rpm)
- The screw revolution was set to 120 rpm
After briquettes were produced, they were separated to be cooled in three different ways as indicated in Table 3.

After cooling down by water, the briquettes were dried at 105°C. In order to determine the briquette quality, a shatter, compression strength and tumbling test was conducted for every produced sample and every cooling type. The briquette density was also obtained.

The density of the briquettes was determined by using liquid displacement.

For the shatter test, six briquettes of all cooling types of the four tests were dropped twice from a height of 5 m. Afterwards the sample was screened to the different size ranges: > 40 mm, 40 – 25 mm, 25 – 20 mm, 20 – 6.3 mm, 6.3 – 0.5 mm and < 0.5 mm. The percentage > 20 mm after the four drops is an indication of briquette strength.

The compression test indicates the force required to crush the briquettes. The compression strength value is also an indication of the briquette strength and it can be used to estimate the maximum storage height in bins or piles. As it can be seen in the result table, all values were higher than 9,000 N (which is the limit of the testing machine!) and none of the briquettes was broken at that value.

The tumbler test was performed in a drum rotating at a controlled speed (rpm) and up to 200 rotations. The particle size distribution was obtained after tumbling and is an indication of briquette quality in view to handling during transportation of the same. The samples were screened to the size ranges > 40 mm, 40 – 25 mm, 25 – 20 mm, 20 – 6.3 mm, 6.3 – 0.5 mm and < 0.5 mm. The percentage > 20 mm is an indication of briquette strength.

The following table summarizes the test results by each tested sample.

<table>
<thead>
<tr>
<th>TEST</th>
<th>DENSITY (g/cm³)</th>
<th>SHATTER STRENGTH (%)</th>
<th>COMPRESSION STRENGTH (N)</th>
<th>TUMBLING STRENGTH (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T.01</td>
<td>5.05</td>
<td>91-95</td>
<td>&gt;9,000</td>
<td>84-85</td>
</tr>
<tr>
<td>T.02</td>
<td>4.96</td>
<td>81-88</td>
<td>&gt;9,000</td>
<td>65-76</td>
</tr>
<tr>
<td>T.03</td>
<td>4.93</td>
<td>98</td>
<td>&gt;9,000</td>
<td>91</td>
</tr>
<tr>
<td>T.04</td>
<td>5.08</td>
<td>97-98</td>
<td>&gt;9,000</td>
<td>90-94</td>
</tr>
</tbody>
</table>

As it can be observed from the above table, the density in all samples is about 5.0 g/cm³ which is the requirement in accordance with current International Maritime Regulations for HBI transporting.

The shatter test for grain sizes > 20mm shows values more than 90% while the tumbling tests shows values >85%.

The most impressive result was the compression strength which in all cases was >9,000 N (machine limit) and there were no broken briquettes. The test T.02 showed lower values since material temperature was lower as it can be noted in table 3.
In general, all strength-related testing results have demonstrated that the High-C Briquettes produced easily have acceptable strength and density values which are totally comparable to the traditional HBI product currently in the market. The significant difference, however, is that the High-C Briquettes will provide additional chemical energy when being melted in the EAF. Please refer to figures below for High-C Briquettes pictures.

As per tests results:

- The High-C DRI can be hot briquetted with roller press to create briquettes of nominal volume 138 cm³.
- With the test parameters in terms of temperature, specific pressing force (approx. 150-155 kN/cm), briquettes with good physical strength can be produced.
- The whole briquetting parameters were useful for hot briquetting the High-C DRI.
- Soft crushing the pellets seems to be useful for reaching higher briquettes qualities compared to original pellets.
- The air cooling and the spray cooling method show all the results in the highest values for briquetting strength.

By replacing some units of Fe by C in the DRI, density of the produced briquette is expected to be lower, simply because of Fe and C densities' difference. What is impressive is the mechanical strength of the High-C Briquette, which is what really matters in terms of exposed area and safety. In any case, based on the test results, it can be observed that High-C Briquettes can be produced with similar mechanical properties as compared to the standard HBI product. Density figures are in the range of 5.0 g/cm³, satisfying IMO regulations for overseas transport.

The unique High-C Briquettes will provide the final user with invaluable benefits of both High-C DRI and HBI, together in a single product which can be only produced with the ENERGIRON DR Technology.
Organized by Tenova HYL and Danieli, the conference had the aim of gathering together the ENERGIRON Licensees from all over the world and sharing their views, expectations and experiences.

Through the Conference, the ENERGIRON team’s intent was to support every Licensee Company in maximizing the potential of its ENERGIRON plant.

The target of working together and sharing experiences was successfully achieved by all of the participants, who could exchange ideas and bring directly their personal experience from the plants.

Thanks to the large variety of ENERGIRON plant configurations, all of the Licensees contributed on some specific topic, actively participating in the discussions.

Many technical aspects of the proprietary equipment were reviewed according to the Lessons Learned principles with the focus of continuously improving the reliability and the performance of the plants.

To keep an eye on the future of Ironmaking, new Research & Development projects were presented to draw the attention of the Licensees to topics that Tenova HYL is following. These include safety, environment (with emphasis on the value that CO2 may have as a by-product), digitalization, fine recovery and other innovative issues.

The first day was characterized by presenting the present and future of the ENERGIRON technology and of the main conceptual common features and differences between the ENERGIRON Plants owned and operated by the Licensees. Moreover, each one of the Licensees had the opportunity to present his own plant and share with the other Licensees and the ENERGIRON team their results, practices and views.

The second day, the ENERGIRON team dealt with plant making and project execution and covered ENERGIRON service and spare parts. In the afternoon, an open discussion gave the Licensees the opportunity to raise topics, share doubts and make proposals.

By contributing their direct experiences, the Licensees let the ENERGIRON team and the other Licensees grow together.
The conference was successful and was attended by many Licensees from all over the world.

The most important companies with their executives, together with some special guests attended the event, enjoying the Campus and some local attractions.

Among them Arcelor Mittal (Mexico), Emirates Steel (UAE), Ezz Steel (Egypt), Suez Steel (Egypt), Sabic Hadeed (Saudi Arabia), Lebedinsky (Russia), Nucor (USA) and Ternium (Mexico).

“This event achieved its targeted goal to create a synergic and constructive effort to improve all our plants, by sharing the best operation and maintenance practices of the Licensees that meet excellent results in terms of performance and reliability” stated Stefano Maggiolino, Tenova HYL CEO. “The Licensees are aware and proud of the premium quality product that can be produced with our technology, with clear benefits in their steel production”, he added.

“Excellent organization, personal attention, great participation and openness by Tenova to take into account all contributions, has been the most relevant aspect of the event”, confirmed Mario Llamas, Quality Manager from Ternium.
CALENDAR OF EVENTS

December 2016 – March 2017

Look for Tenova HYL at the following events:

- December 12 - 14
  Metal Bulletin 18th Middle East Iron & Steel Conference
  Atlantis, The Palm
  Dubai, UAE

- February 19 - 21
  AIST - Scrap Supplements & Alternative Ironmaking
  Wyndham Lake Buena Vista
  Orlando, Florida - USA

- March 2017
  CONAC 2017
  Monterrey
  México