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www.midrex.com
COMMENTARY

MILESTONE AND MEMORIES:

In October 2007, Lebedinskiy GOK (LGOK) in Gubkin, Russia, lit the burners on what was at that time was the world’s largest hot briquetted iron (HBI) plant, LGOK II. In December 2007, less than two months after start-up, the 1.4 million tons per year (tpy) plant completed hot commissioning and passed the Plant Performance Test, beginning continuous commercial operation.

For the first two years of operation, the plant produced approximately 90 percent of its design capacity. Since then, for the past 5-plus years, the plant has operated over its 1.4 million tpy design capacity, and on April 26, 2015, the plant produced its ten millionth ton of HBI – quite a success story for LGOK.

So what made the project successful?

First, it was the commitment of LGOK and its parent company, Metalloinvest, to establish an operating program to keep the plant on line and operational. This commitment included extensive training of plant personnel and constant monitoring of plant operations to see how operations could be improved.

Second, it was the dedication of the plant management and the maintenance and operating personnel to make sure the plant stayed in operation.

Did things happen that needed to be repaired or changed? Of course, they did. LGOK II was a new plant and included some new equipment designs so some modifications had to be made. These issues and changes were never “show stoppers” and plant personnel handled them quickly and effectively. This was the first experience with an HBI plant for most of the operators and maintenance personnel, which makes their accomplishments even more outstanding. As their learning curve improved so did routine maintenance and operating practices, and operations became more smooth and steady.

Third, it was the close cooperation between LGOK, Midrex and Siemens VAI, (now Primetals), which formed a team that stood together to get things resolved. The three parties did not act within a client/supplier-type relationship but as partners all with the same objective. Midrex and Primetals had people on the site almost continuously for the first year of operation. The partnership between the companies and spirit of teamwork remain evident today. LGOK knows that assistance from Midrex and Primetals is only a phone call or email away. In fact, Midrex has maintained a representative office at the site continuously since construction started on...
LGOK II, thus providing LGOK personnel someone to talk with immediately who can contact the appropriate engineers or operators to assist in resolving any issues.

With the success of LGOK II, Metalloinvest soon made the decision to build an additional MIDREX® HBI Plant - LGOK III. The scope of this new plant is even bigger with a design capacity of 1.8 million tpy. The plant is well under construction and the planned start-up is for late 2016.

Prior to construction of its first MIDREX® HBI Plant, LGOK already was producing 1 million tpy of HBI. When LGOK III begins operations, their annual production will be 4.2 million tpy, making LGOK the world leader in the production of HBI.

Given the success of LGOK II and decision by Metalloinvest to build LGOK III, Midrex looks forward to working with them on additional projects in the future. We congratulate the plant operators and maintenance professionals that have achieved the milestone of producing 10 million tons of HBI. We also salute Metalloinvest in their quest to become the ore-based metallic iron leader. With an expected total production of 3.2 million tpy from the two MIDREX® Plants, LGOK has the 20 million tons mark in sight and a heartbeat away.

Midrex is proud to be partners with LGOK and Metalloinvest as partners and looks forward to a long and mutually rewarding relationship. Congratulations to all at LGOK and Metalloinvest, and as the saying goes, many happy returns!
Kobe Steel Ltd. (KSL) is one of Japan’s leading steelmakers and is comprised of numerous consolidated and equity-valued companies in Japan, Asia, Europe, and the Americas.

Since its founding in 1905, Kobe Steel, Ltd. (KSL) has pursued “monozukuri” — a Japanese approach to quality manufacturing — across a broad range of fields, supplying outstanding products and technologies that contribute to the advancement of industry and the promotion of a prosperous society. KSL is engaged in extremely diverse corporate activities including iron and steel, welding, aluminum and copper products, machinery, engineering, construction machinery, cranes and etc.

When Midrex was purchased on August 25, 1983, it became the first outright acquisition of a foreign company by KSL and positioned KSL as the world leader and innovator in direct reduction ironmaking technology.

Today, the Iron Unit Division, belonging to KSL’s Engineering Business Unit, administers the Midrex corporate relationship and participates as a MIDREX® Construction Licensee. The Iron Unit Division was established to implement EPC (engineering, procurement, and construction) projects such as steel making plants, industrial plants and chemical plants throughout the world. As a result, the Iron Unit Division is able to form strong project task forces staffed by highly experienced personnel to execute a variety of EPC projects.

Throughout the succeeding years, Midrex and KSL have cooperated closely in all aspects of the business to expand the technological boundaries of ironmaking and set the quality and performance standards of the direct reduction industry.

A KNACK FOR FIRST-OF-A-KIND PROJECTS
KSL has supplied 14 MIDREX NG™ (natural gas-based) Plants in 10 projects located throughout the world. Some of KSL’s major projects are shown in TABLE I.

EDITOR’S NOTE:
Kobe Steel, Ltd. (KSL) is the owner of Midrex Technologies, Inc., and the Licensor of MIDREX® Direct Reduction Technology. In the past 40 years, it has supplied 14 MIDREX NG™ (natural gas-based) Plants in 10 projects located throughout the world. These plants, all of which were completed and put into production on time, represent KSL’s skill, expertise and commitment to the direct reduction ironmaking industry. This article looks at KSL’s earliest involvement in the direct reduction industry and how it has distinguished itself as an innovator and a driving force in the supply of MIDREX® Direct Reduction Plants for the past 40 years.

By Hiroshi Tamazawa, Deputy General Manager, Iron Unit Division - Kobe Steel, Ltd., and Akihiro Sawada, Executive Vice President - Midrex Technologies, Inc.
In most of these projects, KSL’s role was much more than plant builder. KSL took on the responsibilities of operating the production facilities and managing the business operations of the QATAR STEEL I, Ferrominera Orinoco (FMO) and Complejo Siderúrgico de Guayana (COMSIGUA) projects. In the case of QATAR STEEL I, the know-how necessary for successful plant operation and effective corporate management was imparted to the client during the term of the operations & management services contract. Today QATAR STEEL is wholly owned, operated and managed by Industries Qatar, a national company.

The FMO project was supplied by KSL as build, operate and transfer (BOT). This concept took full advantage of almost 20 years of building and operating MIDREX® Plants, which facilitated securing project financing. COMSIGUA was the first award by limited recourse project financing in Venezuela.

KSL has been the MIDREX® Construction Licensee for a number of first-of-a-kind MIDREX NG™ Plants including the only one to make use of a steam reformer to supply a portion of the fuel and reducing gas (OPCO), the first commercial application of the MIDREX HOTLINK® plant design (Jindal Shadeed) and plants capable of simultaneous hot and cold discharge of DRI products (QATAR STEEL II and SULB). Each of these projects was executed on time despite significant challenges along the way.

### TABLE 1 Major MIDREX NG™ Plants Supplied by KSL as MIDREX® Construction Licensee

<table>
<thead>
<tr>
<th>Plant</th>
<th>Location</th>
<th>Design Capacity (Mt/y)</th>
<th>Product</th>
<th>Start-up</th>
<th>Project Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>QATAR STEEL I</td>
<td>Mesaieed, Qatar</td>
<td>0.40</td>
<td>CDRI</td>
<td>1978</td>
<td>First MIDREX® Plant Constructed by KSL Plant Operations/Management Services by KSL (Under Contract)</td>
</tr>
<tr>
<td>ANSDK I</td>
<td>El Dikheila, Egypt</td>
<td>0.72</td>
<td>CDRI</td>
<td>1986</td>
<td>First MIDREX® Module to Average &gt; 100 Tons/Hour on Annual Basis</td>
</tr>
<tr>
<td>OPCO</td>
<td>Puerto Ordaz, Venezuela</td>
<td>1.00</td>
<td>HBI</td>
<td>1990</td>
<td>Only MIDREX NG™ Plant to Use Steam Reformer Plant Operations/Management Services by KSL (Under BOT Lease Agreement) HBI Product Marketing by KSL (Midrex Support)</td>
</tr>
<tr>
<td>ANSDK II</td>
<td>El Dikheila, Egypt</td>
<td>0.80</td>
<td>CDRI</td>
<td>1997</td>
<td>Allowed for Expansion of Bar &amp; Wire Rod Production</td>
</tr>
<tr>
<td>COMSIGUA</td>
<td>Matanzas, Venezuela</td>
<td>1.00</td>
<td>HBI</td>
<td>1998</td>
<td>First Limited Recourse Project Financing by International Finance Corporation Plant Operations/Management Services by KSL, and HBI Product Marketing by KSL &amp; Partners (Midrex Support)</td>
</tr>
<tr>
<td>ANSDK III</td>
<td>El Dikheila, Egypt</td>
<td>0.80</td>
<td>CDRI</td>
<td>2000</td>
<td>Full Production Within 5 Months of Start-up Allowed for Expansion into Flat Products</td>
</tr>
<tr>
<td>QATAR STEEL II</td>
<td>Mesaieed, Qatar</td>
<td>1.50</td>
<td>CDRI/HBI</td>
<td>2007</td>
<td>3D Model Design, Global Engineering First CDRI/HBI MIDREX® Combination Plant</td>
</tr>
<tr>
<td>Jindal Shadeed</td>
<td>Sohar, Oman</td>
<td>1.50</td>
<td>HDRI/HBI</td>
<td>2011</td>
<td>First MIDREX® Plant Designed with HOTLINK® HDRI/HBI Combination Plant First Product Four Months Ahead of Schedule</td>
</tr>
<tr>
<td>SULB</td>
<td>Hidd, Bahrain</td>
<td>1.50</td>
<td>HDRI/CDRI</td>
<td>2013</td>
<td>HDRI/CDRI Combination Plant MIDREX® Reformer Sized for High Nitrogen &amp; CO₂ Content in Natural Gas</td>
</tr>
</tbody>
</table>

In most of these projects, KSL’s role was much more than plant builder. KSL took on the responsibilities of operating the production facilities and managing the business operations of the QATAR STEEL I, Ferrominera Orinoco (FMO) and Complejo Siderúrgico de Guayana (COMSIGUA) projects. In the case of QATAR STEEL I, the know-how necessary for successful plant operation and effective corporate management was imparted to the client during the term of the operations & management services contract. Today QATAR STEEL is wholly owned, operated and managed by Industries Qatar, a national company.

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KOBE STEEL LTD.,
AS MIDREX® CONSTRUCTION LICENSEE

Qatar Steel Company (Module I)

KSL’s relationship with Midrex began almost 10 years prior to KSL becoming the owner of the MIDREX® Direct Reduction Process and Midrex Corporation, as the company was then known. In 1974, Kobe Steel Ltd. (KSL) and a Japanese trading house entered into a joint venture with the Government of the State of Qatar to create Qatar Steel Company (QATAR STEEL) as the centerpiece of a national steel industry. A feasibility study found that the direct reduction/electric arc furnace (DR/EAF) process route was best suited for QATAR STEEL’s requirements. A subsequent study recommended the MIDREX® Direct Reduction Process because it was natural gas-based, adaptable to extreme the extreme climatic conditions in Qatar and had an excellent performance record. QATAR STEEL would become the first integrated steelmaking facility to be built in the GCC (Gulf Cooperation Council) region.

In 1975, a three-party agreement was signed by Midrex Corporation, Mitsui and Company Ltd. and Kobe Steel Ltd., which established KSL as a technical partner in the MIDREX® Construction License of Mitsui for the QATAR STEEL project.

The MIDREX® Direct Reduction Plant started operations in August 1978, less than 17 months after the start of construction. The plant reached its rated hourly production within the first 24 hours of start-up. Average metallization during the performance guarantee test was 94 percent, plant availability was 98 percent and gas consumption was 20 percent better than the guarantee.

In addition to the contracts for turnkey supply of the MIDREX® Plant, EAF melt shop, continuous caster and rolling mill, KSL was awarded an eight-year plant operations & management services contract, which commenced at the commissioning and start-up of the production units. The management services contract later was extend for an additional three years.

Included in the plant operations & management services contract were:

- Supervision of plant commissioning
- Organizational planning and recruiting
- Administration of marketing, purchasing, accounting and daily business operations
- Plant operations (entire works)
- Annual budgeting

Qatar Steel I Project Challenges

Local conditions in Qatar presented a number of challenges to which KSL responded with the following solutions:

- Equipment had to be capable of withstanding extremely high temperatures, seasonal high humidity, sandstorms and salt pollution
- A closed circuit cooling system using a heat exchanger system instead of a cooling tower system was chosen to minimize the consumption of industrial water. There can be considerable loss of water in a cooling tower system from evaporation and by splashing.
- A desulfurization system was installed to treat the high amount (2,000 ppm) of hydrogen sulfide (H₂S) in the crude natural gas supplied to the MIDREX® Plant.
- Flicker compensating equipment was installed for operation of the EAF melt shop. The large amount of electricity consumed by the EAF melt shop could cause a major disruption of the electric power supply network in Qatar.
- A centralized maintenance system was established for repairing and maintaining installed systems and equipment, as there were few sub-contractors available for such work in Qatar.
- Production equipment was designed to interface easily with automated operation and control systems in order to simplify plant procedures for newly trained operating personnel.
In second quarter of 1984, KSL signed an equipment and services supply contract with ANSDK for a 716,000 tons/year MIDREX® Plant, the first of three to be supplied by KSL in El Dikheila, Egypt. Today the plants are owned by Ezz Steel and known as EZDK I, II and III.

ANSDK I was supplied by KSL in cooperation with Lurgi GmbH, also a MIDREX® Construction Licensee at the time. The two subsequent plants were supplied by KSL in cooperation with Midrex, and each is rated at 800,000 tons/year.

When ANSDK I began production in 1986, it was the largest single module CDRI plant in the world. Going into its performance guarantee test, ANSDK I was operating at 90 tons/hour, well in excess of its rated hourly capacity.

Within the first week of operation in November 1996, ANSDK II was operating above its rated daily capacity, and the plant was operating 12 percent above rated monthly capacity in less than a year after start-up.

ANSDK III reached full production after its first five months of operation. During this period, the plant consistently produced DRI with metallization in excess of 94 percent. KSL was awarded a separate contract in 1998 to expand the mineral jetty to facilitate materials handling from the iron ore yard at the jetty to ANSDK III.

A KSL-led consortium signed an agreement with CVG in June 1996 to supply the largest dedicated merchant HBI plant (1 million tons/year). COMSIGUA was the first use of limited recourse project financing in Venezuela.

Groundbreaking occurred in November 1996, and the first HBI was produced in August 1998. The COMSIGUA plant passed its performance guarantee test in October 1998, operating at 112 percent of hourly production rate during the test period, and the first HBI shipment took place the same month.

In February 2005, QATAR STEEL contracted KSL to supply a 1.5 million tons/year MIDREX® Combination Plant, the world’s first DR facility designed and constructed to simultaneously produce multiple DRI products. QATAR STEEL II is capable of producing CDRI for use in the new QATAR STEEL EAF melt.
shop or HBI for merchant sale or storage for future local use.

QATAR STEEL II was started up producing CDRI in July 2007 and added HBI in September 2007. Almost the entire production from QATAR STEEL II in 2014 was CDRI, with metallization averaging 94.6 percent for the year. In its seventh full year of operation, QATAR STEEL II set a new annual production record for the fourth consecutive year. It was operated 19 percent over rated annual capacity and set a new monthly production record of 230 t/h.

Jindal Shadeed Iron & Steel LLC (Jindal Shaded)

The first MIDREX Plant designed for HOTLINK', direct gravity feed of HDRI to a close-coupled EAF melt shop, was constructed by KSL in Sohar, Oman. Jindal Steel and Power Ltd. (JSPL) acquired the project from Shadeed Iron and Steel Company LLC during construction and renamed it Jindal Shadeed Iron and Steel LLC (Jindal Steel).

By having the 1.5 million tons/year MIDREX Plant equipped to produce HBI as well as HDRI for direct feeding via HOTLINK', JSPL was able to make good use of the facility while the EAF melt shop was still under construction. Jindal Shaded first produced HBI in December 2010, less than four months after its acquisition and four months ahead of schedule. In 2014, the plant transferred HDRI to a nearby steel melt shop in insulated hot transport vessels, as well as operating its HOTLINK' system to directly feed the adjacent Jindal Shadeed melt shop.

Bahrain United Steel Company (SULB)

KSL signed a contract in March 2010 for turnkey supply of a 1.5 million tons/year MIDREX Combination Plant as part of SULB’s integrated steelworks to be located adjacent to a six million tons/year iron ore pelletizing plant also constructed by KSL for Gulf Industrial Investment Co. (E.C.).

Commissioning of the MIDREX Plant was performed with no significant start-up issues, and the performance guarantee test was passed on the first attempt in only three days. SULB began commercial operation in February 2013, producing only CDRI while awaiting completion and commissioning of the melt shop and rolling mill. HDRI production began in August 2013. CDRI and HDRI metallization and carbon have exceeded the guaranteed values during actual simultaneous operation.

KEYS TO KSL PROJECT EXECUTION SUCCESS

The total cycle time of building a MIDREX NG™ or MXCOL' Direct Reduction Plant from excavation to production is a major consideration in the financial sustainability of the project. KSL has developed and closely follows a set of guidelines for executing the engineering, erection, commissioning and start-up of these MIDREX Plants that has produced a perfect on schedule record.
1. Understanding the technology reduces unknowns and “what ifs”
KSL maintains close communication with Midrex in all phases of the technology, from R&D to project execution. KSL project task force team members have a thorough understanding of the principles of the MIDREX® Process. Iron Unit Division managers and specialists participate in a broad range of categories, such as engineering, procurement, construction, operation, maintenance, QA/QC and logistics. A Risk Management Meeting is conducted during the planning phase of a project in order to minimize the chance of unknown risks. Follow up meetings are held periodically, as well as Monthly Progress Review Meetings.

2. Careful and accurate project planning prior to execution
Over the 40 years KSL has been involved with MIDREX® Direct Reduction Technology, an extensive database of “lessons learned” from previous projects has been assembled and serves as a powerful tool for accurate project planning. Typically, a “lessons learned” meeting is conducted as one of the wrap up activities of a project in order to strengthen the database. Feedback from clients, engineering subcontractors, project contractors and vendors, as well as from Midrex and KSL is essential for continuous improvement of project performance.

3. On-site execution and review during each project phase
Plant capacities have increased significantly in the almost 40 years between QATAR STEEL I and II and dual product combination plants have been introduced, as shown in TABLE I. These advances in direct reduction technology have resulted in significant increases in critical path activities including design engineering, civil works and equipment procurement.

To minimize the risk of critical path delays, KSL works closely with Midrex in all phases of a project. This allows for construction time schedules to be planned and site work to be initiated without waiting for 100 percent completion of design engineering. The ability for Midrex to issue partial drawings based on the KSL site activities schedule is instrumental in meeting the overall project completion date.

Likewise, bulk material procurement such as piping, fittings and valves needs the step-wise preparation of a bill of quantities by Midrex. Preparations to start fabrication and construction work should be done in exact timing with issuance of Midrex documents and drawings.

4. Continual effort to improve project execution
KSL and Midrex are committed to continuous improvement of their project execution capabilities (see Figure 1). As the figure illustrates, each factor depends on and contributes to the success of the process in a closed loop cycle. Well-informed project personnel produce more accurate plans and project schedules and a better overall project experience, which increases the “lessons learned”, which are applied to good engineering practice to improve the capabilities of the project team.

5. Stressing teamwork among ourselves and with our clients
Rallying all who have a stake in the success of a project including suppliers, contractors to perform “as a team on the same boat” is a KSL goal on every MIDREX® Plant project. When the project team has a strong, mutual willingness, the plant will be completed on-schedule, production will be brought on-line quicker and profitability is achieved much faster.

FIGURE 1 Continuous Improvement Cycle of Project Execution Capability
CONCLUSION
KSL & MIDREX – PARTNERS FOR PROGRESS
More than 40 years ago Kobe Steel identified the importance of direct reduction technology to the future of ironmaking and recognized the potential of MIDREX® Direct Reduction Technology. KSL was already one of Japan’s most highly diversified companies when it acquired the assets of Midrex Corporation in 1983. It was KSL’s first experience owning a foreign company and how it chose to manage its acquisition has proven to be truly visionary.

Together, KSL and Midrex technical and commercial personnel have established MIDREX® Technology as the direct reduction industry standard for quality and performance. The steadfast support of KSL has enabled Midrex to weather steel industry downturns and to emerge with the strength to capitalize on the opportunities that have come with the recoveries.

The mutual commitment of KSL and Midrex to assuring that the products are available to meet the requirements of the global steel industry is evident in the close cooperation with operators of MIDREX® Plants, collaboration with proprietary vendors and related technology suppliers and the ongoing expansion of R&D capabilities – people and facilities.

BEYOND THE MIDREX® PROCESS
In the 1960s, Surface Combustion, the forerunner of Midrex, developed the Heat Fast Process for reducing iron ore using coal in a rotary hearth furnace (RHF). Much pilot plant and demonstration work was done, but it was halted so the company could concentrate on what become the natural gas-based MIDREX® Process. In 1989, KSL and Midrex revisited the Heat Fast work and resumed research. The resulting process was named FASTMET® and a 150 kilogram/hour pilot plant was built at the Midrex Research & Development Technology Center. Based on successful test campaigns conducted from 1992-94, KSL constructed a demonstration plant at its Kakogawa Works in Japan.

The demonstration plant was started up in 1995 and was eventually converted into a small commercial plant.

Today FASTMET® technology is used to reclaim useful iron units from iron-bearing dust generated by iron and steel production furnaces. KSL has built six FASTMET® Plants for recycling steel mill wastes, having a total feed capacity of approximately one million tons/year. These plants are successfully reducing the environmental impact of steel mills in Japan.

RHF-based projects in which KSL has been involved.

<table>
<thead>
<tr>
<th>Project</th>
<th>Process</th>
<th>Design Capacity (Mt/y)</th>
<th>Location</th>
<th>Start-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nippon Steel &amp; Sumitomo Metal</td>
<td>FASTMET</td>
<td>190,000*</td>
<td>Japan</td>
<td>April, 2000</td>
</tr>
<tr>
<td>(Hirohata Works)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kobe Steel, Ltd. (Kakogawa Works)</td>
<td>FASTMET</td>
<td>16,000*</td>
<td>Japan</td>
<td>April, 2001</td>
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<tr>
<td>Nippon Steel &amp; Sumitomo Metal</td>
<td>FASTMET</td>
<td>190,000*</td>
<td>Japan</td>
<td>February 2005</td>
</tr>
<tr>
<td>(Hirohata Works No.2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nippon Steel &amp; Sumitomo Metal</td>
<td>FASTMET</td>
<td>190,000*</td>
<td>Japan</td>
<td>December 2008</td>
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<tr>
<td>(Hirohata Works No.3)</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>JFE (Fukuyama Works)</td>
<td>FASTMET</td>
<td>190,000*</td>
<td>Japan</td>
<td>April, 2009</td>
</tr>
<tr>
<td>Nittetsu Shinko Metal Refine</td>
<td>FASTMET</td>
<td>190,000*</td>
<td>Japan</td>
<td>October 2011</td>
</tr>
</tbody>
</table>

* Feed material capacity
**BACKGROUND**

In 2009, there was a lack of medium and heavy section steelmaking capacity in the area to support the significant growth that the Gulf Coast Region of MENA was experiencing. The Regional Industrial Investment Vehicle, Foulath, was interested in finding a partner with whom to develop such a business to fill this role. Yamato Kogyo, Ltd. of Japan, which has medium and heavy section experience and know-how, was interested in investing in the MENA region. As a result, the two parties formed a partnership, SULB, to develop a project to build the desired steelmaking facility.

Foulath already had interest in an iron oxide pelletizing plant at Hidd, Bahrain. The site had adequate adjacent land on which to build the proposed steel plant. The Hidd site has excellent access to both land and oceangoing transportation to the entire emerging GCC (Gulf Cooperation Council) market and when coupled with the pelletizing capacity immediately next door, proved to be an excellent location. After careful study of the market demand and other available steel capacity in the area, the decision was made to build an electric arc furnace (EAF)-based steel works capable of 900,000 tons per year of liquid steel and a heavy sections rolling mill with an annual capacity of 700,000 tons. SULB selected SMS Concast AG of Switzerland, SMS Meer GmbH of Germany, and Samsung Engineering Co., Ltd. of South Korea to provide the EAF melt shop and heavy sections rolling mill.

As is the case with most integrated steel mills in MENA, SULB chose to include a direct reduction plant as the primary source of iron units for the EAF melt shop. A tender for the DRI plant was issued in January 2008, and based on the operational success of other MIDREX® Direct Reduction Plants in the MENA region, contracts were awarded in 2010 to Kobe Steel Ltd. and Midrex Technologies, Inc. for a 1.5 million tons per year DRI plant. The plant would be designed as a MIDREX® Combination Plant capable of simultaneous production of hot and cold DRI
FIGURE 1 SULB’s location in Hidd, Bahrain

(HDRI and CDRI, respectively). During the design phase of the project, SULB elected to include an HDRI transport conveyor. Paramount to this decision was the successful operation and performance of the HDRI transport and handling system at Hadeed (Module E) installed in 2007 by Aumund Fördertechnik GmbH, in cooperation with Midrex and Primetals (formerly Siemens VAI).

The DRI plant follows the MIDREX NG™ flowsheet, which utilizes natural gas to create reducing gas for making DRI in the MIDREX® Shaft Furnace. The design basis summary of the plant is shown in Figure 2.

CHALLENGES AND START-UP

The SULB reformer was designed to be larger than MIDREX® Reformers at other comparably sized plants in order to better handle the unusually high nitrogen and carbon dioxide content of the incoming natural gas (>11 percent and >6 percent, respectively). Also, the natural gas source in Bahrain contains an average of 600 ppm sulfur, so a separate natural gas treatment process was required. A Merichem LO-CAT® processing unit was selected and included as part of the project scope.

In the MIDREX® Reformer, natural gas is heated and catalytically reformed along with recycled CO₂ and H₂O from the reduction process to generate a rich reducing gas. As part of the

<table>
<thead>
<tr>
<th>ITEM DESCRIPTION</th>
<th>DESIGN DATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hourly Production Capacity (Tons/Hour)</td>
<td>187.5</td>
</tr>
<tr>
<td>Rated Annual Capacity (Tons/Year)</td>
<td>1,500,000</td>
</tr>
<tr>
<td>Net annual Operating Time (Hrs)</td>
<td>8000</td>
</tr>
<tr>
<td>Product Metallization (%)</td>
<td>93</td>
</tr>
<tr>
<td>Product Carbon (%)</td>
<td>2.0</td>
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<tr>
<td>Furnace Diameter (m)</td>
<td>7.15</td>
</tr>
<tr>
<td>Hot DRI Transport</td>
<td>Hot DRI Conveyor</td>
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<tr>
<td>Process Gas Compressor</td>
<td>Centrifugal</td>
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<tr>
<td>Cold DRI Production</td>
<td>External Cooler</td>
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<tr>
<td>Oxygen Injection System</td>
<td>Included</td>
</tr>
<tr>
<td>Reformed Gas Cooler</td>
<td>Included</td>
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</table>

FIGURE 2 Design Basis Summary of SULB MIDREX NG™ Plant

MIDREX NG™ plant design, the reduction byproducts, CO₂ and H₂O, along with unreacted H₂ and CO are recycled to minimize energy consumption and to produce additional reducing gas. In addition to providing reducing gas, the MIDREX® Reformer also supplies the energy needed for the reduction reactions within the MIDREX® Shaft Furnace.

By design, the MIDREX® Reformer is able to manage CO₂ in the recycle gas in order to capitalize on the heating value of the
Recycle gas and generate more reducing gas. This means less natural gas is needed to produce the desired amount of reducing gas.

The recycle of byproduct CO₂ from the reduction furnace creates an additional reforming reaction of CH₄ + CO₂ to produce 2H₂ and 2CO, generating extra reducing gas for making DRI. The MIDREX® Reformer enables recycled gas and hot reformed gas to be fed to the shaft furnace without quenching and reheating, thus resulting in a very efficient process. This single component eliminates the need for a separate CO₂ removal system and a process gas re-heater, as well as the cost to build and operate these units.

Commissioning of the MIDREX® Plant was performed with no significant start-up issues. The performance guarantee test (PGT) was conducted only 30 days after provisional acceptance. The PGT, which was passed on the first attempt in only three days, proved that the DRI plant was ready for production. The PGT results are shown in Figure 3.

The DRI plant began commercial operation on 3 February 2013, producing only CDRI. As there was an immediate regional market for the CDRI, the plant was able to produce product and generate revenue while awaiting completion and commissioning of the melt shop and rolling mill.

HDRI production began in August 2013, following commissioning and completion of the PGT. Once stable operation was achieved, the actual simultaneous production of both CDRI and HDRI closely matched or exceeded both the guarantee values and the actual PGT values, as shown in Figure 4.

Consumption values had been a concern throughout the process evaluation and design phases of the project; therefore, SULB was very pleased that the actual values when operating were remarkably close to those expected for each constituent. Of particular interest was the improvement in iron oxide and water consumption, as shown in Figure 5.

The SULB DRI plant eclipsed design values within its first full year of normal operations. These improvements over design values have significant cost and environmental advantages especially considering the expected life of the MIDREX® Plant based on others in operation.

In addition to meeting and exceeding production milestones, the ability of the MIDREX® Plant to reliably and simultaneously produce HDRI and CDRI has been an important factor for SULB. This has allowed SULB to supply HDRI required by the melt shop while producing CDRI for both internal use and export. SULB has the option to vary production when and if necessary in response to market or melt shop conditions.

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1. Production rate
2. Product metallization
3. Product carbon
4. Product temperature

---

**FIGURE 3** Performance Guarantee Test Results

<table>
<thead>
<tr>
<th>ITEM DESCRIPTION</th>
<th>COLD DRI PGT 28-31 MAR 2013</th>
<th>HOT DRI PGT 23-26 OCT 2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production rate</td>
<td>187.5 tons/hr</td>
<td>187.5 tons/hr</td>
</tr>
<tr>
<td>Product metallization</td>
<td>94.36 %</td>
<td>94.9 %</td>
</tr>
<tr>
<td>Product carbon</td>
<td>2.19 %</td>
<td>2.28 %</td>
</tr>
<tr>
<td>Product temperature</td>
<td>49° C</td>
<td>652° C*</td>
</tr>
</tbody>
</table>

* at product discharge chamber (PDC)

**FIGURE 4** DRI Product Quality While Simultaneously Producing CDRI and HDRI at Design Capacity (187.5tph)

<table>
<thead>
<tr>
<th>Specification</th>
<th>Guaranteed</th>
<th>Actual (CDRI)</th>
<th>Actual (HDRI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metallization</td>
<td>93.0 %</td>
<td>94.0</td>
<td>94.5 %</td>
</tr>
<tr>
<td>Carbon</td>
<td>2.0 %</td>
<td>2.2 %</td>
<td>2.4 %</td>
</tr>
<tr>
<td>DRI discharge temp.</td>
<td>50/600°C</td>
<td>49 °C</td>
<td>600 °C</td>
</tr>
</tbody>
</table>

**FIGURE 5** Consumption Figures During Actual Operation

<table>
<thead>
<tr>
<th>Description</th>
<th>Unit</th>
<th>Expected</th>
<th>Actual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxide</td>
<td>Ton/Ton</td>
<td>1.44</td>
<td>1.42</td>
</tr>
<tr>
<td>Natural gas</td>
<td>Gcal/Ton</td>
<td>2.55</td>
<td>2.55</td>
</tr>
<tr>
<td>Power (Core)</td>
<td>KWH/Ton</td>
<td>130</td>
<td>125</td>
</tr>
<tr>
<td>Oxygen</td>
<td>Nm3/Ton</td>
<td>15</td>
<td>18.5</td>
</tr>
<tr>
<td>Lime</td>
<td>Kg/Ton of oxide</td>
<td>2.50</td>
<td>2.12</td>
</tr>
<tr>
<td>Water</td>
<td>m³/Ton</td>
<td>0.30</td>
<td>0.23</td>
</tr>
</tbody>
</table>
The splits for both production and use are shown in Figure 6.

**Production Statistics since Feb 2013 - Aug 2014**

<table>
<thead>
<tr>
<th>Production Type</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cold DRI Produced</td>
<td>36%</td>
</tr>
<tr>
<td>Hot DRI Produced</td>
<td>64%</td>
</tr>
<tr>
<td>CDRI Utilized in the Meltshop</td>
<td>30%</td>
</tr>
<tr>
<td>HDRI Utilized in the Meltshop</td>
<td>34%</td>
</tr>
<tr>
<td>CDRI Exported</td>
<td>36%</td>
</tr>
</tbody>
</table>

**FIGURE 6 HDRI & CDRI Production and Use**

**CONCLUSION**

SULB’s MIDREX® Direct Reduction Plant was commissioned in 2013, adding Bahrain to the growing list of DRI producing countries in the MENA region. The Kobe Steel/Midrex project team and the client addressed unique challenges including varying natural gas specifications beyond the original project scope to add HDRI transport. Despite the challenges, SULB’s MIDREX® Plant began commercial operation on time and on schedule with no major start-up issues. The new DRI plant, with an annual capacity of 1.5 million metric tons, can produce hot DRI (HDRI) and cold DRI (CDRI) simultaneously. It is a key strategic factor in SULB’s efforts to fill the void of medium and heavy sections steelmaking capacity in the MENA region.
Technology should be...

• designed to fit your needs
• designed to work reliably
• designed to make life easier

DRI Technology is designed by Midrex to work for you.

Christopher M. Ravenscroft: Editor

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