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A Pioneer Remembered

www.midrex.com
Recently it was announced that Metalloinvest had chosen MIDREX® Technology for Lebedinsky GOK’s (LGOK) third HBI plant. Metalloinvest officially contracted Siemens VAI and Midrex to build this new HBI plant on 31 August 2012 (see the news & views article on page 16 for more).

This is an achievement that we are very happy to talk about. LGOK is one of only two DRI and HBI producers that have built and operated both MIDREX® and HyL Plants and elected to build another plant. In both cases the Client, after owning both technologies, selected MIDREX for their new plants.

The other of course was Hadeed, who like LGOK, also contracted Siemens VAI and Midrex to build their fifth DRI plant. Previously Hadeed built three MIDREX Plants, tried an HyL plant for their fourth, but came back to MIDREX for their latest plant.

Why? The answer, in my opinion, simply put is quality and value. MIDREX Technology is known for its unparalleled productivity, product quality and performance. But the quality and value of MIDREX goes far beyond the construction of the actual plant. More than 30 years of actual production experience, data and innovation back up our technology.

Our Clients are licensed to own and operate the MIDREX Process and our success is dependent on their success. To this end we devote ourselves to continuous improvements for the MIDREX Plants built and in current operation. We communicate these improvements not only from Midrex Technologies, Inc. to our Clients, but also we encourage a free exchange of ideas between the plant owners and operators themselves. Everyone wins. It is all part of the quality and value that we bring to our clients.

One aspect to this effort is that Kobe Steel Ltd. (KSL), owner of the MIDREX® Process, along with Midrex sponsors an annual International Conference on MIDREX® Technology for qualified licensors of the MIDREX® Plants. This meeting allows Midrex to listen directly to any challenges the licensees may be facing. In the past this conference was known simply as the MIDREX Operations Seminar and was usually held at the home of Midrex in Charlotte, NC, USA. But beginning in 2008 we began reshaping the meeting to be a true professional international conference, holding the conference in cities around the world. In recent years the new International Conference on MIDREX® Technology has been held in St. Petersburg, Russia, Cairo, Egypt and London, England – home of Midrex UK Ltd. This year's event was held in September 2012 in beautiful Vienna, Austria. Midrex's long time Construction Licensee, Siemens VAI very graciously joined KSL in sponsoring this year's event, undoubtedly contributing to the quality of the Conference.
COMMENTARY

Continued from page 2

Now I have been in, out and around Midrex since 1979 and will state with certainty that this year’s Conference was the best ever. It may sound trite, but it is true. The attendance, venue, organization, meals, entertainment and most importantly, the quality and content of the papers and presentations was exceptional.

Representatives from twenty of the twenty eight licensees of the MIDREX Process attended the Conference with total attendance including Licensees, invited speakers and guests topping 140 people.

The venue for the event was the in the center of the city and within walking distance of the Kaertner Street, Vienna’s main run through the center of town allowing easy access to many different points of interest including St. Stephen’s Cathedral, The State Opera, the Concert Hall and of course, lots of shopping. Even with within these surroundings we were at capacity in the conference for the full week!

The program featured addresses by Jim McClaskey, President and CEO of Midrex and Werner Auer CEO of Siemens VAI, as well as top industry consultants including Gilles Calis of Steel Consult International, and Jim Lennon, Economic Consultant for Macquarie bank. The program also included presentations on by Midrex and Praxair on the Thermal Reactor System™ (TRS™) developed by our two companies designed to produce a high quality gas from coke oven off gas for use in the MIDREX and MXCOL® Processes (no doubt DFM will soon report further in detail on these developments).

Program topics as expect delved into process improvements and operation and maintenance techniques, but more so the expanded event also addressed other issues peripheral to MIDREX® operation, but beneficial to client operations. Of the items we can discuss here included discussion on the new SIMPAX System, COREX/MIDREX Plant technology and Siemens VAI’s new Circular Pelletizing technology. This revolutionary technology affords DRI plant owners the possibility of economically installing a pelletizing plant suitable for smaller scale production compared to other technologies in use and a very good match for individual application alongside a MIDREX or MXCOL® Plant.

The balance of the presentations were somewhat confidential to the MIDREX Family and cannot be discussed in this forum, but they were informative, useful, well prepared and even entertaining at times. And if you are like me, it is always good to have fun while learning something of value.

So what does make a repeat customer? I think the question may be best answered with another question: How can we provide the best quality and value to our clients? For Midrex, it is something that we always keep in mind as we continue to improve upon our core technology and services to our clients, as our repeat customers already know.
INTRODUCTION
From meager beginnings more than 40 years ago to 75 million tons being produced annually today, Direct Reduced Iron (DRI) has found its place in the global steelmaking industry. Since 1970, world DRI consumption has grown by almost 100 : 1, a remarkable record by a rapidly increasing industry. DRI’s product forms and industry role have steadily evolved. It is a staple of the EAF industry and has found usage in integrated mills as well. DRI may still be defined by the removal of oxygen from iron oxide without melting, but it is not the same product it once was. DRI has grown and evolved into something bigger and better.

The following article is a primer on DRI’s evolution, examining production growth, technology options, regions of production, and most importantly the evolution of product forms and usage.

WHAT IS DRI?
Direct reduced iron is iron that is made from ore by removing oxygen chemically bound to the iron, without melting. That is, if a pellet of iron ore is fed into a direct reduction furnace, that very same pellet will be discharged from the furnace but the iron which was bound to oxygen in the form of iron oxide (a type of rust) will be free of oxygen as the pellet is discharged. In short, the iron will be metallic.

THE PATH TO DIRECT REDUCTION: The growth and development of blast furnace ironmaking
Over centuries, ironmaking grew but was restrained by one major difficulty, sourcing the fuel. The standard fuel was charcoal made from wood. It had been made and used for millennia, but there just wasn’t enough of it. The charcoal requirement of a single small blast furnace making only one or two tons per day of iron could swiftly deforest everything within tens of miles of the furnace. By and large, this is how North Africa, most of Western Europe and Eastern North America were deforested. There is a popular image created by romantic novelists and by Hollywood of the farmers deforesting America. It is mostly untrue. By the time the farmers got there, the woods were already cut. All they had to do was remove the stumps. Alternatively, the farmers cut the trees and hauled them to the charcoal furnaces for sale.

APPLICATION OF COKE TO BLAST FURNACE IRONMAKING
In 1709, Alexander Darby made the great breakthrough that many use as the starting point of the industrial revolution. He broke ironmaking free from charcoal. Instead he made coke from coal. The coke was rich in carbon like the charcoal and it was partially desulfurized by the coking process which also drove off the volatiles. Despite his revolutionary breakthrough, the idea
did not ‘catch-on’ quickly. It was 70 years later before the famous "Iron Bridge" was constructed using iron cast at the foundry owned by Darby's grandson.

Estimates of world iron production in 1709 are about 135 thousand tons. It was 1820 before production rose to one million tons per year. Average growth rate was only about 1.8% per year. This is not the sort of growth one would expect following a revolution. It certainly compares poorly to the rapid growth of the past decade which occasionally exceeded 10% per year.

**IMPROVEMENTS**
The problem was that even though as iron became less and less expensive and more and more uses were being found for it, none of them used it on a really large scale. That was the case until the railroad industry came along. Railroads needed a lot of iron and the ironmaking boom took off. For the last eighty years of the 19th century world ironmaking grew at an average rate of about 4.8%, reaching 42 million tons per year by 1900. To accomplish this numerous improvements were necessary in the technology.

- **Discovery and selection of better ores.** Early furnaces were often charged with ores that today would be considered very low grade; for instance, ‘bog ores’ made by concentration (over millennia) of iron in the waste sediments at the bottom of shallow ponds. Finding and mining of better ores greatly improved productivity and fuel efficiency.

- **Discovery and use of better coals for coking.** Coals with fewer contaminants and coals that would produce stronger coke.

- **Sizing of the ores** (rather than feeding 'run of mine' ore to the blast furnace). By screening the ore, the permeability of the burden within the blast furnace was enhanced. Decreased fines meant that the burden was not ‘blinded’ to the flow of gases.

- **Increased blast volume to the furnace**

- **Increased blast pressure**

- **Increased height and diameter of the furnaces**

- **Use of hot blast (patented in 1828)**, helping to raise the temperature within the furnace

- The increasing pressures necessitated banding the furnace with steel. Prior to this a blast furnace structure had been merely a stack of stones to make the shape of the vessel. With the advent of higher pressures, both from the blast and from the solids burden of the larger and higher furnaces the stones would be pushed apart and the furnace would fall. So the furnaces became banded with steel. Over time, the bands were designed wider and wider so that they would be stronger and eventually they were designed as a single continuous steel vessel, not only providing strength but also providing a gas tight structure so that gas pressures could be raised higher still.

The preceeding list is just a very short sample of the many innovations that were brought to bear in ironmaking technology. Additional important improvements involved preparation of the ore with the intent of improving burden permeability and increasing productivity. These included use of sintered ores and of pellets. The implementation of pelletizing also brought along a major opportunity for beneficiating the ores. By the time pelletizing was being developed, many of the higher grade iron ore mines had been exhausted. Particularly in the United States, we were faced with the problem of entering into World War II using iron ores that were 30% Fe, and below. Beneficiation was becoming a necessity.
Overall, the productivity of a typical blast furnace had been brought up from less than one-half ton per day per cubic meter to well over two tons per day per cubic meter. Simultaneously, the working volume of blast furnaces increased by about 1000 : 1. But, the final really big step was yet to come. That was direct reduction.

Early Development of Direct Reduction and Why Direct Reduction Was Wanted

During the 1930's Direct Reduction was envisioned as a means of further beneficiating iron ore. Most of the work done by a blast furnace, (about six parts out of seven), is reducing the iron, which is removing the oxygen from the iron oxide. Only about one-seventh of the needed energy is for melting. If ore could be charged to a blast furnace partially reduced already, the productivity of the furnace should be greatly increased and at the same time the specific energy consumption should decline markedly. Development started rapidly. The predecessor companies of Midrex Technologies, Inc. were involved in one process development. But development had to be halted because of World War II.

After the war development resumed in earnest. The history reads like a list of the major steel companies of the world at that time. In North America and in Europe, Stelco, US Steel, Armco, National, Republic and Thyssen each undertook major efforts, each one investing as much as one billion dollars (in today's money) toward development of a Direct Reduction process. Other large companies also entered the race. Lurgi in Germany developed a process. Esso (predecessor of Exxon) developed one. By mid-1974, there were more than two hundred patents registered with the US Patent Office for direct reduction processes. Today, nearly all of these 200-plus patented processes have failed. The initial investments were lost. A few companies did, however, succeed and commercial DRI production emerged by the late 1950s.

One of these companies was the predecessor to what is now Midrex Technologies, Inc. In the mid-1960s, Don Beggs, the chief of Research and Development for the Midland-Ross Corporation in Toledo, Ohio realized that he could combine two of Midland-Ross's technologies to form a direct reduction technology. One was a shaft furnace used for induration of iron oxide pellets. The other was a gas generator that reformed methane together with carbon dioxide and water vapor into carbon monoxide and hydrogen. The resultant gas, being rich in carbon monoxide, was used for carburization (hardening) of metals. Beggs saw that if he could take the reformed gas and feed it into a shaft furnace filled with iron oxide pellets, the pellets would reduce and if he could recycle the off gas from the reduction furnace back to the reformer, then the process would be remarkably efficient.

The mass and energy balances for the process were calculated to determine if the concept would work. The data confirmed the feasibility and development of the equipment began, thus the MIDREX® Direct Reduction Process was born.

By 1965, R&D for direct reduction was underway in numerous labs and on a large scale. That year one-third of the papers accepted for publication in the Proceedings of the Ironmaking Conference of the American Institute Mining, Metallurgical and Petroleum Engineers were about direct reduction: either how to produce DRI or how to apply it to steelmaking. Multiple tests were conducted at steel works around the world testing the use of DRI in blast furnaces using commercial quantities of DRI for the tests. Nearly all of the discussion involved the usage of DRI in blast furnaces. Almost nothing was said about EAF's.

Reality was moving in a different direction. DR plants being built were directing their production to EAF steelmaking, not blast furnace oxygen furnace steelmaking. The steels being made in those EAF's were flat products and seamless tube steel products that require low levels of residual metals. Prior to the application of DRI it was extremely difficult to make these products in EAF's because of the very limited supply of low residual, high grade scrap steel that could be sourced to feed to the EAF's.

By the late 1960's another major development was made, continuous charging was devised; enabling the EAF's to accept as much as 100% DRI feed.

Now let's skip ahead to today.

First MIDREX® Plants built at Oregon Steel Mills in Portland, Oregon, USA, 1969.
There are three basic means of producing DRI which have been widely replicated worldwide on a commercial scale.

Shaft furnace. A burden of solids, (the iron ore), descends in counter-current to a wind of reducing gases, hydrogen and carbon monoxide, at elevated temperatures. The hydrogen and carbon monoxide reduce the iron so that the iron becomes metallic. Shaft furnaces today produce more than three-fourths of all DRI. MIDREX® Direct Reduction Furnaces make 80% of that. Most shaft furnaces are provided a reducing gas that is made by reforming of natural gas, (methane). Other methods are also in practice. One, a MIDREX® Plant in South Africa has been operating for more than a decade using a synthesis gas (syngas) made via gasification of coal. The gasifier at that site is a COREX® iron reduction reactor. A similar MIDREX Plant is under construction in India where COREX syngas is used to supply the MIDREX Plant. Also, in India, a MIDREX MXCOL® Plant is being built. In this process, the syngas is supplied by a standard coal gasifier.

Fluidized bed. Carefully sized iron ore fines are charged into a fluidized bed with a carrier gas consisting in large part of CO and H₂ at high temperature. The fines remain in the fluidized bed long enough to be reduced. Upon discharge, they are compressed into briquettes (HBI). It is necessary to carefully size the fines because fines that are too large will not reduce sufficiently plus they will “fall out” of the fluidized bed, and fines that are too small will be “blown out the top” of the fluidized bed before they can be reduced. This leads to a relatively low yield of iron ore to DRI. The major advantage of the process is that it can use fines without any need for agglomeration into pellets or sinter, but its disadvantage is that it uses a relatively large amount of ore to produce one ton of iron.

Currently there is only one fluidized bed direct reduction plant in operation, worldwide. It is in Venezuela and last year it produced only 0.7% of the world’s DRI.

Rotary Kiln. Last year, almost one-fourth of the world’s DRI was made in rotary kilns. These are long, on the order of 100 meters, cylindrical furnaces that are rolled over and over with a charge of iron ore and coal fed to the slightly more elevated end of the cylinder. As the cylinder rolls the material moves downhill to the other end and under heat from burners, the coal is activated and partially oxidized to form CO which reduces the iron.

The capital cost of these kilns is relatively low compared to other methods of reducing iron, but the drawbacks are that the iron product tends to become contaminated by impurities brought in within the coal and the process tends to be extremely polluting. The process is primarily utilized within India.

PRODUCT VARIATIONS – COLD DRI, HOT BRIQUETTED IRON AND HOT DRI

COLD DRI (CDRI)

Since the advent of modern, commercially produced DRI in 1957, CDRI has been the standard form. Of the 75 million tons per year of DRI currently being produced more than 60 million tons per year are made as CDRI. Before the start-up of the first HBI plant in 1974, all DRI was made as CDRI.

CDRI is made by cooling the iron immediately after it is reduced to the metallic form and before it is exposed to the atmosphere. The cooling is done by gases that are then cooled by water, then cleaned and compressed for recycling in order to cool additional DRI. Were the DRI not cooled, it would burn once it is in the air. Typically, it must be cooled to 60 °C, or below.

CDRI has been used for almost every form of steel that is produced. Even though its use is often associated with the production of high grade, low residual metal, low nitrogen products, most of it is actually applied to the making of the common grades of long products, reinforcing bar and light structural. Why? Because in many locations local demand for these light construction steels is sufficient to justify building of an EAF mini-mill, but there is not enough scrap steel available to supply the EAF. In such a location, a DRI plant is an excellent alternative to importing large quantities of scrap steel or to building a high cost blast furnace complex.

CDRI can be transported, but it must be handled with care. Specifically, care must be taken to absolutely insure that no DRI at too high a temperature is included in the batch being shipped and great care must be taken to be absolutely certain that none of the CDRI is wetted, either before loading for shipment or during shipment. Otherwise, there can be a significant risk of the CDRI self-heating, even to the point of ignition.
HOT BRIQUETTED IRON (HBI)
Difficulties encountered in handling and shipping of CDRI were the initiative that drove the development of Hot Briquetted Iron (HBI). Chemically the same as CDRI, HBI is compacted from the DRI just as it is discharged from the reduction furnace while it is still hot. For it to qualify as HBI within the guidelines of the International Maritime Organization, HBI must be compacted to at least 5.0 grams per cc and the operation must be done using DRI that is at least 650°C as it enters the briquetting dies.

HBI was first developed for a DR process in South America. Today, that plant is the only one of its kind operating, but the HBI technology has spread to other processes so that each year approximately eight million tons of HBI are made. The MIDREX® Plants making HBI ship their product to nations around the globe. Such widespread shipment would be daunting but for the easy handling and shipping characteristics endowed by hot briquetting. Beginning with the first MIDREX® Hot Briquetting plant started in Sabah, (Borneo), Malaysia in 1983, MIDREX® HBI now accounts for more than 90% of all HBI involved in transcontinental trade.

HOT DRI (HDRI)
The ability to transport DRI from the reduction furnace to the steel-making furnace while still hot was developed during the latter 1990’s. The reasoning for doing so is obvious. Sensible heat contained within the DRI after reduction represents a large share of the heat needed for melting. By conserving this heat, not only are there significant energy savings, but also time savings. A melting furnace has a finite amount of power that can be applied. Once the maximum power input rate is underway, there is no way to go any faster. By decreasing the required energy input for melting, by using hot charged DRI, tap-to-tap times can be lowered, thereby increasing the productivity of the melter. Typically, the melting furnace is the limiting feature of the overall steel works. Thus simply by using HDRI, the output of the entire steelworks is increased.

This increase is quite large. For instance, consider the case of a 100 ton per hour furnace using only CDRI as charge. Let’s assume this furnace has a power-on-time of 50 minutes and uses 10 minutes of time, on average, for power-off activities. So, it produces 100 tons every 60 minutes. Now, let’s replace the CDRI with HDRI, lowering the needed energy by about 20%. Thus the power-on-time is decreased to 40 minutes and the tap-to-tap is down to 50 minutes. Now, the furnace is making 100 tons every 50 minutes, so it is making 120 tons per hour; a 20% increase over its prior production rate. When one considers that a typical one million ton per hour mini-mill costs more than $500 million dollars to build, it becomes clear there are massive cost savings by using HDRI.

In order for successful usage of HDRI, the HDRI needs to be transported safely keeping as much sensible heat as possible. Midrex offers multiple methods for hot transport: HOTLINK® (gravity transport), Hot Transport Conveyors and Hot Transport Vessels that allow application for a wide variety of existing mills as well as new greenfield sites. Midrex pioneered the DRI furnace hot discharge feature that has been a part of all MIDREX HBI Plants since 1984.

For any of the hot transport options, the MIDREX® Plant is designed to produce CDRI or HBI as a secondary product stream when the meltshop cannot accept HDRI. CDRI is produced using a proven MIDREX® DRI cooler. For HBI, briquetting machines are located underneath the shaft furnace. Plants are designed to produce the two products simultaneously and to switch from one product to another quickly without disrupting product flow.

APPLICATION OF DRI PRODUCTS
Originally intended to be used by blast furnaces to improve their productivity and lower their fuel consumption, direct reduced iron, once commercially developed was immediately applied to electric furnace steelmaking instead and specifically to the manufacture of steel products that require low residual metals content and low nitrogen contents. However, in the 1970’s a number of plants were built not to make iron for low
residual steels, but simply because the availability of scrap steel at certain locations was not sufficient to supply an EAF. The cost of transporting scrap steel to the sites was prohibitive. For this reason, many DRI plants were built to make iron for the manufacture of small structural steel such as reinforcing bar and light angles. This application became so common that many people actually came to identify DRI with rebar mills.

But then with the advent of the thin slab caster (TSC) in the early 1990’s, a renewed recognition arose for the purity of DRI and its usefulness in making sheet steels. This caused DR plants to be built to supply iron for the EAF/TSC mills. Today, DRI is used for making almost every type of carbon steel. And, importantly, DRI's purity allows electric arc furnaces to produce steels that were historically considered to be solely within the domain of oxygen furnace steelmaking. Just a short list of the types of steel to which very large tonnages of DRI are applied would include all types of sheets up to and including exposed auto body steels, extra deep drawing quality, wire and fine wire products, special bar quality, forging bar quality and seamless tube products.

The advent of hot briquetting has allowed DRI/HBI to be used by steel mills where it would not be reasonable to build a direct reduction plant; mills whose demand is insufficient to consume the entire output of a DR plant. The advent of HDRI has much improved the economics of DRI further expanding the realm of its use.

And, of course there are applications for DRI outside the EAF steelmaking industry. Today, more than ten percent of the HBI that is involved in intercontinental shipment is bound for use in blast furnaces; the original purpose for developing direct reduction. Practiced mostly in North America and in Western Europe, it is used for two main reasons. One is to routinely increase the production from a specific blast furnace, to either increase the steel output from a works or to allow for the closure of a smaller, older, less efficient blast furnace. The other is to raise the output of a blast furnace while one of its sister blast furnaces is taken down for maintenance.

Also, HBI is used in oxygen furnaces to augment the supply of low residual metallics. This practice is most common in the Far East where supplies of prime grades of scrap steel, relative to demand, are much less than in Western nations.

NEW TRENDS & DEVELOPMENTS
The DRI industry has not yet stopped evolving. If anything the development of new technologies for manufacture and use of direct reduced iron is accelerating.

Use of lower grades of iron ore
One development that is being forced upon the ironmaking industry by simple Malthusian force is the use of lower grades of iron ore for making steel. To date, mankind has made approximately 35 billion tons of iron, using well over 50 billion tons of ore in the process. The rate of ironmaking has been rapidly growing. Over half of the 35 billion tons were made within the last 30 years. The other ‘less than half’ was made in the preceding three thousand years.

As one might expect miners are always trying to take the least costly, highest quality ores. After taking 50+ billion tons to-date, much of the truly high quality ore has already been used. As so, necessity demands that we adjust to using lower grades. The MIDREX® Process can easily reduce lower grade ores, but the issue is that costs increase in steelmaking by using these ores. Midrex Technologies, Inc. is actively working with partners to develop new melting practices, techniques and equipment to accommodate the lesser grade ores of the future. In fact,
lower quality ores are often used in MIDREX® Plants depending on the cost of the raw materials and the impact of downstream steelmaking operations. The Midrex Materials Testing Lab can evaluate these ores on a case by case basis to determine practicality of use.

**Alternate fuels and reductants for DRI production**

Another major set of developments is in the field of fuels and reductants. Historically, Midrex and the direct reduction industry have heavily concentrated on use of natural gas. But, in the late-1990’s Midrex started operation of one plant in South Africa that is fueled by gas made from coal. The gas is the offgas of a COREX® Hot Metal plant. Having proven this concept, Midrex has developed alternate methods and can accept syngas from any of a wide variety of coal gasification processes.

MXCOL® (pronounced “M-X-coal”) is the name and trademark for the commercially proven MIDREX® Shaft Furnace technology that uses syngas derived from coal. MXCOL® can receive syngas from many sources including commercial gasifiers (using high or low quality coals or other alternative fuels) and the new Thermal Reactor System™ from Midrex Technologies, Inc. and Praxair, Inc. (technology using an innovative partial oxidation system).

Currently both a COREX®/MIDREX® Plant and an MXCOL® Plant (using coal gasification) are being built in India for two separate clients.

**COG SOLUTION**

Coke ovens produce coke for use in blast furnaces and generate an offgas containing CO and H₂. This gas is used typically for feedstock to chemical plants, heating applications and production of electricity, but chemically can have more economic value to the steelmaker to create additional iron units.

The MXCOL® option for using coke oven gas (COG) incorporates the new Thermal Reactor System™ that can condition this COG allowing the production of DRI in a MIDREX® Furnace. This technology better uses offgases from the coke-making operation to make DRI, and can increase the productivity of blast furnaces by providing additional HBI feed.

**CONCLUSION**

DRI has grown and evolved into something bigger and better from its simple origins. DRI can legitimately be defined, and more importantly utilized in 3 specific product forms. The technology for producing these product forms has steadily improved and made leaps to break outside the preconceived notions of how the product can be defined and how it can be used. All of these advancements are being developed so that steelmakers can be more efficient and thus most profitable. From new and broader sources of iron ore to new to broader sources of reductants and fuels, Midrex Technologies Inc. is helping to pave the way.
LOOKING AT DRI FOR EAF USAGE:

The correct carbon content?

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Editor’s Note:
Carbon in Direct Reduced Iron (DRI) has substantial influence on the production of liquid steel using the Direct Reduction Plant and EAF route. The percentage of preferred carbon in DRI is a source of discussion as some DRI technology providers insist that higher levels of carbon are needed in every case, which is simply untrue. The proper level is best to be determined by steelmakers and Electric Arc Furnace (EAF) technology providers. The following article examines SIEMENS VAI’s (SVAI) experience with DRI carbon content of 2.0-2.6% as a current benchmark for low-cost and high productive steelmaking. The paper details SVAI’s ULTIMATE EAF Technology used with MIDREX® Technology.

INTRODUCTION: DRI OPTIONS TO THE EAF
With approximately 80% of the total world natural gas-based DRI output, the MIDREX® Process is the leading DRI production process in the world. The solid product of the MIDREX® Direct Reduction Process, DRI also sometimes referred to as sponge iron, typically has a total iron content in the range of 90–94% Fe. After the DRI is discharged from the MIDREX® Process’s shaft furnace, it can be compressed hot into Hot Briquetted Iron (HBI) for safe storage and transportation or directly hot charged into the electric arc furnace in form of hot DRI (HDRI).

The hot-transport system used is a pan-type conveyor with special designed metallic deep drawn pans from Aumund Fördertechnik. The system is fully covered to minimize the temperature losses feeding the hot DRI directly into the EAF. In addition, containers may also be used to transport the DRI greater distances.

The DRI can be cooled and transferred as cold DRI (CDRI) and stored in bins before being charged into the EAF.

The combination of developed technologies (MIDREX Plant and SIMETAL® ULTIMATE EAF steelmaking) enables steelmakers to establish the shortest route from iron ore to liquid steel.

SVAI’S “ULTIMATE” EAF TECHNOLOGY
The ULTIMATE EAF combines modern technologies including ultra high power input (up to 1,500 kVA/t) and the latest oxygen and carbon RCB injection technology. It also has design features such as ultra high shell design, heavy mill type components, strong, simple and reliable – existing in the product range of SVAI. This combination leads to an Electric Arc Furnace where the cycle times can be extremely short and the corresponding productivity reaches the level of larger furnace sizes or converter plants. A comparison of an 180t Standard EAF and an ULTIMATE 120t EAF has demonstrated the same production of liquid steel,
or in other words production capacity increases up to 50% comparing EAFs with the same tap weight.

**THE TWO MAIN REASONS FOR THIS ARE:**

- The possibility of a higher electrical power input
- A far higher efficiency of chemical energy, decarburization and scrap preheating compared to the same size (tap weight) standard furnace.

Because of this, the ULTIMATE EAF is a solution for increasing productivity with a given heat size in existing steel plants or to reach extensive productivity levels requested by new steel plant projects.

**EAF PRODUCTIVITY: MELTING OF DRI**

The productivity of the EAF depends on the TTT (tap to tap time) consisting of the power off time (delays, turn around time) and power on time.

One aspect to reduce TTT is first to decrease the power off time. The EAF charging mix impacts the loading time of the EAF. A conventional furnace using 100% scrap generally needs a two baskets loading that represent a power off time of about 4 minutes. High DRI input will reduce the scrap amount, loading time and therefore the power off time. In case of 100% continuous feeding of DRI no additional time and energy will be lost for opening the roof and loading scrap. Besides, a good management of the oxygen and carbon via the RCB injection technology enables perfect foaming slag control and high electrical power input, yielding a shorter power on time.
Regarding power on time the following DRI characteristics have substantial influence:

- Total Fe in the DRI
- Degree of metallization of the DRI
- Charging temperature
- Carbon content

**IMPACT OF CHARGING TEMPERATURE ON EAF**

By feeding HDRI between 500°C and 600°C into the EAF, the energy consumption and thus the power on time is drastically reduced compared to CDRI input, due to the utilization of the sensible heat of the HDRI. Substantial energy savings and productivity increase can be achieved with continuous feeding of HDRI. The higher the temperature of HDRI, the lower the energy consumption in the EAF (Figure 4).

Increasing the carbon content for HDRI will result in a lower Direct Reduction (DR) plant productivity, due to the time necessary to form higher carbon content. The productivity of the DR-plant for CDRI is less carbon-content-dependent, because carbon formation can take place during the cooling process of the DRI in the shaft furnace as long as a carburizing source is available abundantly.

DRI quality is characterized by the iron content / metallization rate. High carbon content and the consequently low metallization rate means basically less Fe.

**DRI CARBON - INFLUENCE ON PRODUCTIVITY AND ENERGY CONSUMPTION OF THE EAF**

In scrap-based EAF process, carbon is very important to boost the electrical power input with additional chemical energy and enable foaming slag. In DRI melting, carbon is basically important to reduce the remaining iron oxides contained in the sponge iron. It helps to start and control the foaming slag process that is most important during the long flat bath operation. The more DRI continuously fed the longer the flat bath process. The remaining excess carbon also serves as energy source with significant effect on the energy balance of the EAF. To utilize the chemical heat of the excess carbon contained in DRI it is necessary to supply sufficient oxygen to the steel bath area.

As the DRI is continuously fed according the power input into the furnace (kg/MW/min), the feeding rate is well known. Knowing also the DRI analysis, carbon and iron oxides rates are then defined, so that the injection of oxygen and carbon can be balanced.

If the oxygen supply is too low, the process is slowed down by the deterioration of the foaming slag quality and extra delays will take place for decarburization with power off before tapping.

On the other hand the oxygen flow is limited by the amount of CO generated into the furnace, the boiling reactions and the capacity of the off-gas system. The limiting factor for the oxygen
supply is the steel bath area and as consequence the overall furnace geometry (furnace diameter / steel levels / volume ratio).

For safe EAF operation there is a limit for the decarburization rate because of dangerous boiling reactions. The decarburization of steel creates CO bubbles that have to travel through the liquid steel bath to the bath surface and through the slag. Reaching lower carbon contents, the oxygen injected will oxidize more iron that is afterwards reduced in the slag by carbon injection, generating CO and foaming slag. Decarburization rate is measured as CO generation in steel bath.

When mastering the foaming slag, which can easily fill the whole furnace, the process is very smooth and power fluctuations are reduced. Thus the use of high power and high current enable the right thermal equilibrium that allows high feeding rates of sponge iron. However, as soon as the carbon/oxygen equilibrium is disturbed a “plasma ball” can be generated, leading to electrode lifting and possible arcing towards the water-cooled panels.

Thanks to the SVAI Refining Combined Burner (RCB) injection technology – the multi-points supersonic oxygen streams are injected through the side-wall panels enabling a closed door operation. In several installations worldwide, using either hot DRI or hot metal, it was proven that a decarburization rate up to 12 Nm³/min/m² bath of CO can be safely handled, avoiding dangerous boiling reactions. This results in a carbon reduction capacity of max. 390 kg/h/m². In example, more than 24,000 Nm³/h can be blown in a 300t EAF.

Another important feature of the RCB technology is the availability to start blowing oxygen at the very beginning of the process when feeding 100% DRI. The long supersonic stream reaches the liquid heel level without splashing or damaging the refractory.

The optimum DRI carbon content in SVAI high performance EAFs for maximizing productivity, minimizing electric energy consumption and safe operation was found to be between 2.0 and 2.6% (Figure 6).

The sponge iron continuous feeding rate is dependant upon the thermal equilibrium of the steel bath, which must be kept throughout the process at a temperature range of 1570-1590°C.

With limited electrical power (100 MW) and oxygen injection (24 Nm³/t), 40-42 kg/min/MW could be reached with cold DRI and up to 60 kg/min/MW with hot DRI at a temperature of < 600°C. Even though this last rate could be boosted by more power input and/or intense oxygen injection the main limitation will remain the hot DRI availability.

Finally, in Hadeed, breaking world records were achieved with the combined process route – MIDREX DR Plant / SIMETAL ULTIMATE EAF – during the 48 hours performance tests using 100% of hot DRI:

- 60 heats produced
- Average electrical consumption of 385 kWh/t liquid steel
- Electrodes consumption < 0.7 kg/t
- Power On Time: average 39.6 minutes
- Tap To Tap time: average 48.1 minutes

![Figure 6: SIMETAL ULTIMATE EAF productivity and electric energy consumption versus carbon content](image-url)
These results demonstrate the efficiency and reliability of MIDREX and SVAI Technology for the production and use of hot DRI.

**HIGH CARBON DRI – IS IT A BENEFIT?**

The main economic factors for the production of liquid steel in the EAF are:

- productivity
- feed material cost (e.g. DRI from MIDREX DR Plant, purchased HBI/scrap)
- energy consumption (electric energy, oxygen)
- consumables (e.g. electrodes)

The use of DRI enables the steelmaker to achieve highest productivity and lowest consumption figures for highest steel quality requirements. SVAI’s EAF experience is that a DRI carbon content of 2.0-2.6%, when using 100% DRI, is an up to date benchmark for economical and environmental steel making (Figure 7). MIDREX Plants produce DRI at that carbon content which is an ideal feedstock for EAF steel production using 100% DRI.

Using DRI with carbon content above 2.6% does not make sense, because high carbon content and consequently low metallization rate means basically less Fe and eventually more DRI tonnage for the same Fe yield. This excess carbon has also to be removed in the EAF and therefore lead to longer blowing time and to longer power on time. DRI with ultra high carbon content (e.g. 3% - 5%) is higher in production cost and lower in productivity compared to “optimal” DRI (2.0% - 2.6%) when used for 100% in the EAF:

- A mix of ultra-high Carbon HDRI with scrap optimizes the performance and the productivity of the EAF operation; however it will not achieve the same productivity and steel quality compared to 100% MIDREX HDRI.
- A mix of ultra-high Carbon CDRI with scrap achieves similar performances and productivity of the EAF operation, compared to 100% MIDREX CDRI; however the same steel quality can not achieved.

Adding more than 50% DRI to the classical scrap input of the EAF, the following can be summarized:

- The very first priority for a smooth EAF operation is a constant DRI quality and feed rate - it has high impact on the economical aspect.
- HDRI provides additional sensible heat, reducing energy consumption and Power On Time, consequently enhancing productivity.
- Short TTT time will enhance the savings, which means that excessive decarburization down times of high DRI carbon content have to be avoided for an efficient and feasible steel mill operation.

With the use of HDRI at a carbon content of 2.0-2.6%, SVAI has proven that the “HDRI Melting Process” is the forward-looking solution which enables the steelmaker to achieve low cost steel production for highest steel quality requirements.

Relatively small carbon content (< 2.6%) and sensible heat of the DRI (hot DRI) means beside economic aspects also environmental advantages. The use of hot DRI at lower carbon contents leads to small CO₂ emissions and to environmental friendlier steel production.
Metalloinvest chooses Siemens and MIDREX® Technology for its new HBI Plants

Siemens Metals Technologies and consortium partner Midrex Technologies, Inc. signed a contract with the Russian Metalloinvest Company to expand the hot briquetted iron (HBI) production at Lebedinsky Mining and Processing Integrated Works (Lebedinsky GOK) in Gubkin (Belgorod Region, Russia). The new plant with a rated capacity of 1.8 million metric tons of hot briquetted iron per year will be the largest single HBI module in the world.

The consortium with Siemens and Midrex is responsible for the process turn-key including engineering, manufacturing and supply of mechanical and electrical equipment and level 1 and level 2 automation. The MIDREX® Direct Reduction Process was chosen for the LGOK’s second module in 2005 and now Metalloinvest has decided that its third HBI facility will also use proven MIDREX® Technology to produce high quality HBI. The existing MIDREX® HBI plant, delivered by the consortium of Siemens and Midrex, began operation in 2007 and is currently the world’s largest briquetting module producing 1.4 Mtpy.

With the expansion Metalloinvest - the largest iron ore producer in Russia - meets the growing demand for hot briquetted iron in Russia, Europe, Asia and Middle East. Eduard Potapov, Chief Executive Officer of Metalloinvest, commented: “HBI production growth is one of the top priorities of Metalloinvest’s development strategy. Construction of the new plant will allow it to strengthen the Company’s positions on the global HBI market and significantly increase production volume of high value-added iron ore products.”

Iron ores, comprised mostly of magnetite, are first concentrated and processed to DR-grade pellets. These pellets are then fed into a MIDREX® Furnace where they are reduced to metallic iron followed by discharging into hot-briquetting machines, producing HBI with a metallization degree exceeding 93 percent. The briquettes have an apparent density exceeding 5.0 g/cm³ and are well suited for transport due to the low quantity of fines generated during handling.

Metalloinvest is a leading global iron ore and HBI producer and supplier and one of the regional steel producers. Metalloinvest was the leading producer of merchant HBI globally with approximately 36% global market share in 2011 and is the largest HBI/DRI producer in the CIS, according to CRU. Currently, LGOK operates two HBI plants producing 2.4 Mtpy in total. The feed for the new HBI plant consist of 100% pellets produced from Lebedinsky GOK iron ore.

Metalloinvest also owns Oskol Electrometallurgical Works (OEMK), a mini-mill in the same region operating four MIDREX® Plants that produce DRI for onsite EAF’s. Metalloinvest is a global player in the production of beneficiated iron ore products, processing the majority of its primary iron ore concentrate production into value-added products, such as high-grade iron ore concentrate, iron ore pellets, HBI/DRI, and finished steel products.
MIDREX News & Views

Midrex Announces Todd Ames as New General Manager-Plant Sales MENA region

Over the past few years, Midrex’s sales team has become more regionally focused so that the company can get closer to its customers and strengthen relationships with them. Midrex has accomplished this by specifying key individuals to interface with clients in particular geographical regions. Sales efforts in the CIS are under Ken Joyner’s direction. In China, Jeff McEneny leads Midrex Shanghai, and Midrex India is managed by KC Woody. Now, the Middle East/North Africa (MENA) region will be led by Todd Ames who will manage MIDREX® shaft furnace sales.

MENA continues to be a hot bed of opportunity for new direct reduction projects. Annual production in this region accounted for nearly 35% of the world’s DRI in 2011 and significant growth is expected. The annual production growth in the MENA region since 2009 is unmatched by any other area showing a remarkable jump from 2009 to 2011 of nearly 30%.

Ames has worked in Midrex Shaft Furnace sales since 2006 and his technical background and experience provide a solid foundation for developing projects in the MENA region. With his new promotion, Ames will continue to have a leading role within the Midrex sales department to manage the development HDRI, HBI and CDRI Plant projects.

A Pioneer Remembered

Marvin E. Tester, one of the pioneers of the MIDREX® Process, died October 8. He was involved in the early development of the MIDREX Process at Surface Combustion, a division of Midland Ross Corporation located in Toledo, OH. In addition, Tester played a key role in the start-ups of the Portland, Georgetown and Sidbec MIDREX® Plants, which in turn, paved the way for the success of the MIDREX Process.

“Marv was a true engineer and innovator,” said James D. McClaskey, President & CEO of Midrex Technologies, Inc. “His legacy lives on in the Direct Reduction industry as the engineers who have since followed him continue to refine and improve upon the innovative process that he helped to develop. He was a great individual and team player and he will be missed.”

Mr. Tester moved to Charlotte in 1974 when Midrex was purchased by the Korf Group and worked at Midrex’s Research and Technical Center where he was frequently involved in plant testing. He retired from Midrex in 1986 and moved to Elk Park, NC.