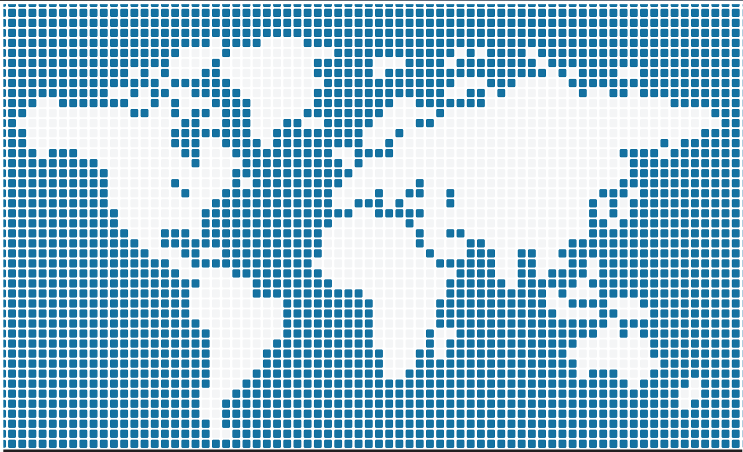

3RD/4TH QUARTER 2011

DIRECT FROM MIDREX

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COMMENTARY

Plant performance and innovation

By Antony Elliot
Manager of Technical Services

The world of direct reduction has grown substantially over the past 40 years in large part due to the productivity of MIDREX® Plants and the outstanding efforts of MIDREX Plant operators. This is no chance happening. Becoming the world technology leader in direct reduction has taken great effort, time and continuous improvement.

By January 1st of 2011 there were 61 MIDREX® Modules in operation, which produced over 42 million tons of DRI in 2010. In terms of shaft furnace production, MIDREX Plants represented more than 80 percent of the world production last year. MIDREX® Technology drives some of the world's newest and most productive DR plants as well as providing the foundation for the industry's oldest operating modules that in many cases still out perform competing plants half their age.

In October 2011, Midrex hosted its annual operator's seminar in London, England, drawing together a very diverse audience of executives and operators from around the world. Over the week long program, MIDREX Licensees and the Midrex Technical Services group discussed operating results and the latest innovations. We also recognized the exceptional production milestones that has made Midrex a true leader and innovator in the DR industry.

Innovation takes many forms, but true innovation leads to remarkable results. This year we recognized four modules that have reached 20 million tons of production (see featured article on page 7). Although many of our innovations have become commonplace within MIDREX® Plants, we have also introduced some newer technology packages and options including MXCOL®, designed to meet real world applications and scenarios.

Also in this issue we examine the amount of iron ore required to make one ton of DRI in the article: "How much iron is needed to make one ton of DRI?" Various figures are presented for other technologies, but this article examines the entire picture from ore up to steelmaking based on chemistry and operational experience.

Ultimately our innovations are designed to provide progressive solutions to meet the need for consistent product quality and plant availability. MIDREX Technology provides our clients with the best option for high quality products and outstanding profitability. Performance is achieved through innovation, in our case the cumulative efforts of many people since we began four decades ago.

"Innovation takes many forms, but true innovation leads to remarkable results... Ultimately our innovations are designed to provide progressive solutions to meet the need for consistent product quality and plant availability."

DIRECT REDUCTION: TECHNOLOGY ISSUES PART 1:
How much iron ore is needed to make one ton of DRI?

Editor's Note: This is the first in a series of articles addressing key issues regarding direct reduction technology.

INTRODUCTION

An appreciable degree of confusion has arisen concerning the efficiency of direct reduction plants in converting iron ore (in the form of pellets or lump ore) to iron, specifically, regarding the quantity of ore required to produce one ton of DRI; the oxide to product ratio. This point is particularly important in light of today's remarkably high iron ore costs.

Mostly the confusion derives from plant suppliers stating the efficiency of their plants while using differing 'end points' within the ore/product handling stream. Various options for boundary limits are shown in *Figure 1*. For instance, if one were to describe the system as beginning upstream of an oxide screen and another were to begin their system downstream of the oxide screen, the latter might appear to have better efficiency when stating the ore-to-product yield, as the number would be smaller. Unless the boundaries of the systems were clearly stated, and understood, the latter could boast of having superior technology even if that is not the case.

There are three boundary limits of interest when analyzing iron oxide requirements in DR processes: across the DR furnace only, from upstream of the iron oxide screen through the product screen, and from upstream of the iron oxide screen through feeding of DRI to the EAF. These three cases are shown in *Figure 1* and *Table I* describes the significant sources of yield loss through the EAF.

BOUNDARY LIMITS 1: ACROSS THE SHAFT FURNACE ONLY

The factors that determine the amount of oxide required to produce one ton of DRI include the loss of oxygen, addition of carbon, oxide fines losses from screening, processing in the reduction furnace, and screening of DRI product. What is the theoretical value for direct reduction measured across the shaft furnace? This is represented by the smallest (red dashed) box

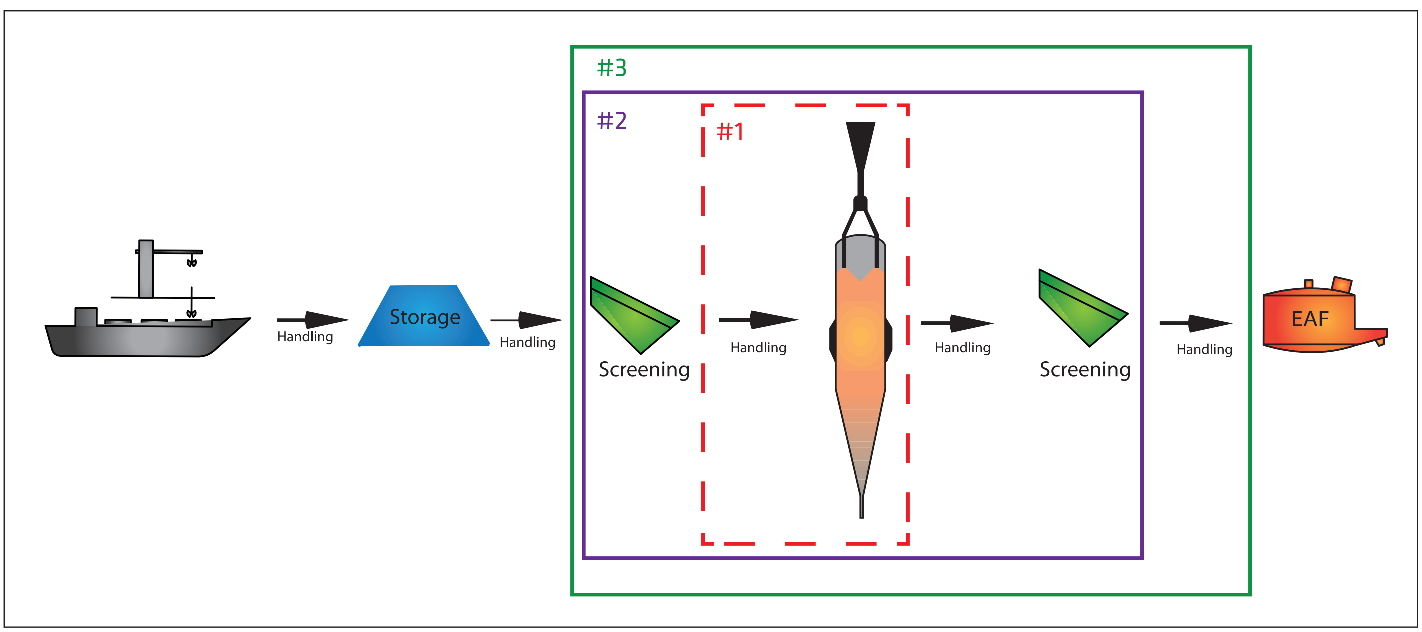

FIGURE 1. *Boundary Limits for Calculating Oxide/DRI Yield*

in *Figure 1* were there no fines or dust losses. *Figure 2* shows how the oxide/DRI ratio varies with DRI metallization and carbon content for a good quality DR pellet. Assuming 94 percent metallization and 2.5 percent carbon, the theoretical oxide/DRI ratio (or yield) is 1.35. The theoretical yield is the same for any type of shaft furnace DR process because it is only dependent on the chemistry of the iron oxide and the DRI.

The theoretical yield is unrealistic in practice because it does not take into account fines losses. A full scale, month long, commercial test was conducted some years back in order to demonstrate the MIDREX® Technology to a customer. This test showed that the MIDREX® Direct Reduction Furnace operating day after day with good quality pellets had fines losses of only 1.3 percent above the theoretical yield. Theoretical yield being the point at which only the mass changes caused by chemistry (reduction, carbonization and variances in gangue/total iron) are calculated with no adjustment for fines or dust losses, whatsoever.

Some claim that oxide consumption can be decreased by 2 percent to 4 percent by operating at higher gas pressure within the reduction furnace. Obviously, it is physically impossible to decrease the oxide consumption by this amount because it would be below the theoretical value.

Typical fines losses from the reduction furnace to the offgases in either the Midrex or a competitor's process are one percent to one-and-a-half percent.

BOUNDARY LIMITS 2: UPSTREAM OF THE IRON OXIDE SCREEN THROUGH THE PRODUCT SCREEN

These limits are indicated by the purple box in *Figure 1*. In most cases when discussing the oxide/DRI ratio, these boundary limits are the ones of interest, with the figure generally ranging from 1.42-1.50. Most DR plants screen the iron oxide feed to reduce losses to the offgas and minimize flow problems in the shaft furnace. MIDREX Plants generally screen the oxide at 6 mm and 3 mm and feed the minus 6 mm/plus 3 mm material to the furnace at a controlled rate. This facilitates better material flow through the shaft furnace. Other plants often screen at 3 mm, resulting in the same net fines losses of two to four percent, but the lack of controlled feeding of the minus 6 mm/plus 3 mm fraction can result in more erratic furnace flow and lower process efficiency.

Many plants making cold DRI (CDRI) do not screen the DRI product for feeding to the EAF and screening is not necessary for plants making hot DRI. For the CDRI plants that do screen product, fines losses are typically two to four percent.

Summarizing the losses from oxide screening (2 to 4 percent), to the shaft furnace offgas (1 to 1-1/2 percent), and in product screening (2 to 4 percent), the typical value for either a MIDREX or

TABLE I *POTENTIAL DR PLANT YIELD LOSSES*

Oxide receiving through DR Plant
To ground *(only for new plants with unprepared oxide storage yards)*
Oxide screen
Oxide dust collection
Top gas scrubber
Cooling gas scrubber
Product dust collection
Briquette cooling *(if included)*
Product screen
DRI Transport through EAF
Hot transport dust collection *(Midrex) or Degassing of pneumatic stream (others)*
EAF slag
EAF flue gas system and Bag house

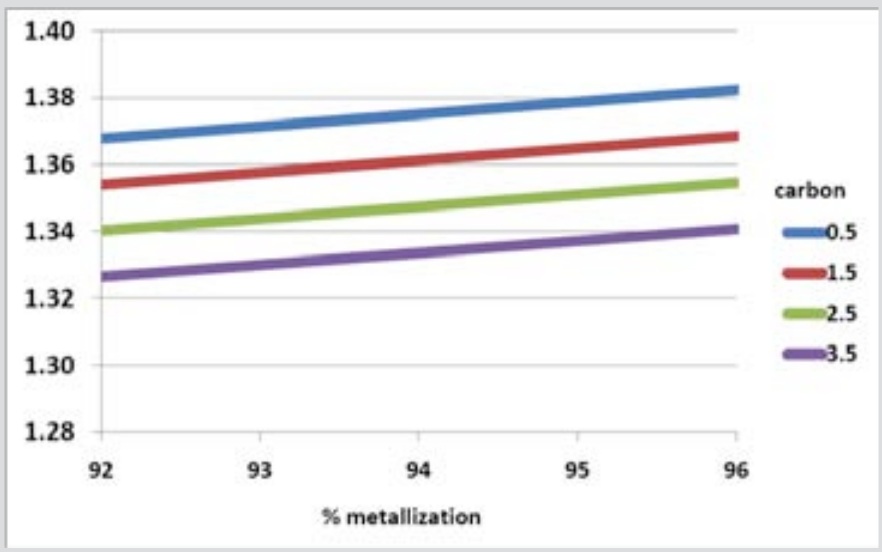

FIGURE 2 *Theoretical Oxide/DRI Ratio Versus Metallization and Carbon Content*

other technology plant is 1.45 t of oxide per ton of DRI with 94% metallization and 2.5% carbon.

The best way to compare the actual oxide-to-product efficiency of various designs of direct reduction technologies is to evaluate the experiences of companies that operate plants from multiple suppliers. There are four companies that own both a MIDREX® Direct Reduction Plant and a plant of a competing technology. (These processes represent over 98 percent of all currently operating DR capacity that is fueled by natural gas.) Responses from Midrex questionnaires regarding comparison of MIDREX Plant's oxide-to-product ratio to that of competitor plants show that the Midrex plant is better than the competitor, with an advantage of as much as 2.8 percent when the comparison includes DRI product handling through the product screen.

At today's iron ore prices, this amounts to more than $10 million for each one million tons of DRI produced.

BOUNDARY LIMITS 3: UPSTREAM OF THE IRON OXIDE SCREEN TO EAF FEED POINT

This is the relevant system for a DR plant discharging hot DRI (HDRI) and transporting it to the EAF in either a continuous or batch transport system and is shown as the green box in *Figure 1*. Therefore Midrex's techniques for conveying DRI to the EAF were designed to be gentle in order to create as few fines as possible. There are three types of hot DRI (HDRI) handling designed by Midrex, according to the distance from the reduction furnace to the steelmaking furnace. If the reduction furnace can be placed immediately alongside the steel shop, Midrex can design the reduction furnace to direct feed the shop using a predominately gravity system. This is known as HOTLINK®. If the reduction furnace is within 200 meters of the steel shop, the MIDREX® Hot Transport Conveyor system is recommended. For longer distances, up to 40 km, MIDREX® Hot Transport Containers, analogous to the torpedo cars that are used for hot metal from blast furnaces, may be used.

A "real world" comparison can be made between two alternative continuous systems, the MIDREX® Hot Transport Conveyor and a pneumatic technology from a competitor, since both are in operation. Since the MIDREX Hot Transport Conveyor uses buckets to carry the HDRI, fines generation is minimal. In contrast, pneumatic systems use gas to blow DRI at high velocity through pipes to carry it to the EAF or to a product cooler. This method results in significant fines generation, as much as 8-10 percent. These fines may never make it into the steelmaking bath; instead they may be trapped in the slag layer or simply carried out in the EAF exhaust system.

TABLE II *TYPICAL OXIDE HANDLING SYSTEM*

Ship loading
Vessel unloading
Conveyors and transfers to storage
Reclaim
Conveyors and transfers to screening
Oxide screening
Conveyors and transfers to day storage
Feeding day storage
Movement through day storage
Discharge from day storage
Conveyors and transfers to reduction furnace

MINIMIZING OXIDE HANDLING LOSSES

To minimize loses, it is important to provide gentle handling for both oxide and DRI product at all steps throughout the materials handling system. An approximation of a typical oxide handling procedure is shown in *Table II*. (This is not to be construed as a best practices concept, but merely as a typical example.)

A primary guideline for any handling system is that drop distances are always to be kept to a minimum. If this is not possible, cushioning of the drop location should be provided by a system that is easily reparable. (The continuous stream of falling material will be damaging to almost any cushioning material, thus thought should be put into how to quickly and inexpensively repair the cushion.)

Normally the greatest drop and thus the most damaging step that oxide experiences is the loading of the ship as ore is dispatched from the mining company. For this reason, some buyers require sampling and surveying of cargoes at vessel discharge. The next most damaging step is usually the unloading of the vessel, and third is likely to be stacking of ore for storage after unloading. In each of these steps the rule to minimize the drop should be obeyed as much as practical. For unloading, which is almost always performed with a clamshell bucket, one helpful technique is to employ a "soft unloading" whereby the bucket carrying ore from the ship is lowered onto the surface of the receiving pile of ore (whether in a hopper or alongside on the quay) before opening the bucket rather than allowing the bucket to open and drop the ore onto the pile. Similarly, a guideline for stacking is to keep the stream spilling onto the storage stack as short as possible. One technique is to always maintain the stacker close to the top of an existing pile, frequently moving the stacker along as it fills the space below itself, and with each movement of the stacker, only moving along a short distance of a meter, or so, always staying close to the peak of the storage pile.

For design of conveyor and transfer systems, again, drops must always be kept to a reasonably practical minimum.

MINIMIZING DRI HANDLING LOSSES

Table III shows the components of a typical DRI handling system.

Great care must be taken with DRI since its strength (crush strength) is less than half that of oxide. The superiority of Midrex's handling systems is especially evident in the handling of hot DRI.

TABLE III *Typical DRI Handling System*

Reduction furnace
Discharge from reduction furnace
A variety of handling systems
FOR COLD DRI
Conveyors and transfers to silos
Through the silos
Discharge from silos
Conveyors and transfers to short term storage in the melt shop
Discharge from the storage bin
Conveyors and transfers to the steelmaking furnace
Charging to the steelmaking furnace
FOR HOT DRI
Charging from reduction furnace to transfer containers
Discharge from containers/charging to steelmaking furnace
Direct gravity feed from reduction furnace to short term storage for steelmaking
Discharge from short term storage/charging to steelmaking furnace
Charging to pneumatic feed system
Entrainment in pneumatic stream and high velocity transport to melt shop
(Note the high velocity and resultant turbulence causes much breakage and
erosion of fragile DRI, especially at bends in the pneumatic line)
Charging to short term storage
Discharge from storage bin/charging to steelmaking furnace

SUMMARY

To summarize, confusion has been introduced into the marketplace for DR plants concerning the oxide/product efficiency (yield) of competing DR technologies. When doing this analysis, it is essential to carefully define the boundary limits of the system and it is recommended the customer for a new plant carefully educate himself regarding this subject. A typical theoretical minimum oxide/DRI ratio across the DR furnace is 1.35 at 94% metallization and 2.5% carbon assuming use of good quality DR pellets. More commonly, the oxide/DRI ratio is specified from the inlet of the iron oxide screen through the discharge of the product screen and on this basis the actual yield for a MIDREX Plant is typically 1.45 including fines losses. The best way to compare the performance of a MIDREX Plant with the competition is to discuss the subject with companies who own each of the competing technologies. These comparisons indicate that the MIDREX oxide consumption is equivalent to or lower than the competition. ■

MIDREX News & Views

Four MIDREX® Modules surpass the 20 million ton production mark

At the recent MIDREX®2011 Licensee conference held in London this past October, four separate modules were recognized for reaching the prestigious 20 MTPY milestone in DRI production. In 2011, single MIDREX® Modules at EZDK 1 and Qatar Steel 1, each exceed the milestone of having produced more than 20 million tons of DRI. In addition, another two MIDREX Modules, at ArcelorMittal Lázaro Cárdenas and Acindar were also each recognized for surpassing the 20 million ton production mark. ArcelorMittal Lázaro Cárdenas exceeded this record in the second half of 2010 while Acindar reached this record in the second half of 2006.

EZDK 1

EZDK 1 achieved this milestone in the beginning of March and achieved this total production since its startup in Nov 1986, over a period of just over 24 years. At the original rated capacity for EZDK 1 of 716,000 tons per year it should have taken this module almost 28 years to reach the 20 million ton production mark. The only significant modification to this module has been the addition of oxygen injection systems, in 2001.

EZDK

QATAR STEEL 1

Qatar Steel 1 began operations in August 1978 and produced more than 20 million tons of DRI by May of 2011. The original rated capacity for Qatar Steel 1 was 400,000 tons per year and would have required 50 years for Qatar Steel to achieve this milestone, yet the DR plant surpassed the milestone in less than 33 years.

QATAR STEEL 1

During the period 2001-2007 Qatar Steel 1 has achieved more than 8000 hours of operation every year and averaged more than 8300 hours of operation for this period. After reduced production levels in 2008 and 2009 due to the financial crisis, Qatar Steel 1 has again achieved 8200 hours of operation in 2010 in what we expect will be the start of another long period of high plant availability. After the introduction of oxygen injection in 2003 Qatar Steel 1 has been achieving production levels exceeding 800,000 tons of DRI per year and natural gas consumptions in the range of 2.3-2.4 netGcal/t of DRI.

ARCELORMITTAL LÁZARO CÁRDENAS

The MIDREX Module at ArcelorMittal Lázaro Cárdenas had already produced more than 20 MTPY by the second half of 2010 since its startup in August 1997. During this time AM Lázaro Cárdenas module has not received any significant modification and has averaged more than 1.5 million tons per year compared to its rated capacity of 1.2 million tons per year. AM Lázaro Cárdenas is currently the annual production record-holder for a single DR module, having produced 1,758,000 tons of DRI with 8267 hours of operation in 2004 with their 6.65 m diameter shaft furnace. They have also reported a natural gas consumption of 2.30 + 0.10 netGcal/t for 11 of the 14 years that the module has been in operation.

ARCELORMITTAL LÁZARO CÁRDENAS

ACINDAR

Acindar in the second half of 2006 surpassed the 20 million ton production mark. Acindar has seen some significant modifications since its startup in August 1978 (mainly the expansion of its reformer from 220 tubes to 240 tubes in 1983, oxygen injection addition in 1994, and a further expansion to 320 tubes in 1997). In its 28 years of operation until 2006, Acindar averaged more than 700,000 tons per year compared to its initial rated capacity of 420,000 tons per year. Note that both EZDK 1 and Acindar, with 5.5 m and 5.6 m diameter shaft furnaces have reached productions of 1.0 million tons per year with operating hours exceeding 8000 hours per year. Currently Acindar is expected to reach its 25 million ton production milestone sometime in 2012.

The above numbers are a testimony not only of the productivity, energy efficiency, and reliability of the MIDREX Modules but also of the skill and dedication of the personnel who operate and maintain these Modules. We congratulate each plant and look forward to new records being set.

ACINDAR

Christopher M. Ravenscroft: Editor

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CONTACTING MIDREX

General E-mail:
info@midrex.com

Phone: (704) 373-1600
2725 Water Ridge Parkway
Charlotte, NC 28217 USA

General Press/Media Inquiries
Christopher M. Ravenscroft
cravenscroft@midrex.com
Phone: (704) 378-3380