ADVANCING DRI PRODUCT FLEXIBILITY: NEW TECHNOLOGIES AND APPLICATIONS FOR STEELMAKERS BY MAXIMIZING OPERATIONAL FLEXIBILITY OF MIDREX® DRI PLANTS

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SYNOPSIS

Worldwide, there are approximately 70 MIDREX® Plants producing Direct Reduced Iron (DRI) products such cold direct reduced iron (CDRI), hot direct reduced iron (HDRI) and hot briquetted iron (HBI), or a combination of these forms of DRI (figure 1). Over nearly five decades the MIDREX® Process has been in use, product carbon levels have varied based on location and use, and in 2015 MIDREX Plants produced MIDREX® DRI Products with carbon levels of approximately 0.5% to 3%.

Indeed, the MIDREX® Process has the flexibility to produce DRI with controllable and varying amounts of carbon as desired by the plant operator.

Recently, Midrex Technologies, Inc. has created a new flexible technology that can increase the carbon content of DRI produced in a MIDREX® Plant up to 4.5% carbon. The name of this patent pending innovative technology is ACT™, which stands Adjustable Carbon Technology. ACT™ provides for the MIDREX® DRI Plants to produce the widest range of carbon in DRI Products and can be easily adjusted during operation. The technology can easily be retrofitted to existing plants and is ready for deployment to MIDREX® customers that desire the flexibility to produce a higher carbon DRI/HBI.

Keywords: Ironmaking, ACT™, Adjustable Carbon Technology, Innovation, MIDREX® Direct Reduction Process, Direct reduced iron, DRI, HDRI, HBI, product quality

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Midrex’s ACT™ Features:
This technology with the following key features:

- Can be used in every type of MIDREX® Plant; CDRI, HDRI, HBI or a combo plant
- Allows amount of carbon in DRI to be adjusted up or down.
- Added carbon comes without cooling off the DRI.
- Approximately 90-92% of the carbon in MIDREX DRI Products will be in the form of iron carbide, Fe₃C.
- This technology is a “bolt on” type design.
- ACT™ can be integrated into existing MIDREX® Plants and used for new MIDREX® Plants.
- The technology can be turned on and off to suit the desired carbon level; the MIDREX® Process can operate without it.

The purpose of this paper is to familiarize you with this recent technology development.

Background

DRI is a premium ore-based metallic (OBM) raw material made by removing chemically-bound oxygen from iron oxide pellets and lump ores without melting. DRI is high in iron content and low in copper and other undesirable metals, tramp elements, and nitrogen content. It is used to make a broad range of steel products, including: all types of sheets up to and including exposed auto body, extra deep drawing quality, fine wire, special bar quality, forging bar quality, plate and seamless tubes (figure 2). Its physical and chemical characteristics make it desirable for use in the electric arc furnace (EAF), blast furnace (BF), and basic oxygen furnace (BOF).

EAF steelmaking and DRI have been closely associated for half a century. Traditionally, DRI products have been used in Electric Arc Furnaces as a supplementary iron unit in order to produce various steel products Depending on the available metallic charge.
(scrap, hot metal etc.) and the steel product manufactured (long, flat etc.), carbon in the DRI products can have a beneficial effect to EAF operation. The optimum for each melt-shop can vary drastically.

Figure 2 – Flow of DRI Products in Steelmaking

In the MIDREX® Shaft Furnace, carbon is added to DRI in three places:

- The reduction zone. In the MIDREX® Process, the main purpose of the reduction zone is to metallize the iron to the desired product metallization using reductants CO and H₂ produced by the MIDREX® Reformer. However, some carbon is added in the reduction zone by the nature of the reactions occurring in the reduction zone.

- The transition zone. A controlled flow of transition zone natural gas is added, and this is the main means of adding and controlling the amount of carbon in
MIDREX DRI Products. The natural gas feedstock to MIDREX Plants contains hydrocarbons, mostly methane, and using methane as an example, the carbon comes by:

- CH₄ → C + 2H₂ (endothermic)  
  (I)

- 3Fe + CH₄ → Fe₃C + 2H₂ (endothermic)  
  (II)

- The cooling zone. MIDREX® Plants that have a cold discharge furnace use cooling gas to cool the DRI; the cooling gas contains hydrocarbons, and carbon is added in a similar manner as in the transition zone.

The carbon-forming reactions are endothermic (a reaction that absorbs energy) and cools the DRI; for plants producing CDRI, this is desired. For plants producing HDRI or HBI, this cooling is not usually desired.
Midrex Research and Development

To meet the market demands of a more flexible product, the Midrex Research and Technology Development group was challenged to develop a new technology to add carbon without cooling the DRI. The technology had to be flexible (meaning carbon can be adjusted easily during plant operation) and “bolted on” the existing MIDREX® process to permit retrofit of existing plants and be offered as an option on new plants. Midrex personnel came up with the conceptual idea, theoretical calculations and computer modeling (thermodynamic and kinetic); laboratory testing was performed to prove the concept.

The principle of the ACT™ innovative consists of:

- Carbon monoxide (CO), made in the MIDREX® Reformer, is added to the transition zone in the form of a CO-rich gas stream. The CO contacts the DRI
bed, and the resulting exothermic reactions (reactions that release energy) provide extra energy:

- \( 3\text{Fe} + \text{CO} + \text{H}_2 \rightarrow \text{Fe}_3\text{C} + \text{H}_2\text{O} \) (exothermic)  
  (III)

- \( 3\text{Fe} + 2\text{CO} \rightarrow \text{Fe}_3\text{C} + \text{CO}_2 \) (exothermic)  
  (IV)

- \( \text{CO} + \text{H}_2 \rightarrow \text{C} + \text{H}_2\text{O} \) (exothermic)  
  (V)

- \( 2\text{CO} \rightarrow \text{C} + \text{CO}_2 \) (exothermic)  
  (VI)

- Transition zone natural gas is added along with the CO rich stream, using the CO-generated energy to provide the energy to produce additional carbon without sacrificing temperature.

- \( 3\text{Fe} + \text{CH}_4 \rightarrow \text{Fe}_3\text{C} + 2\text{H}_2 \) (endothermic)  
  (VII)

- \( \text{CH}_4 \rightarrow \text{C} + 2\text{H}_2 \) (endothermic)  
  (VIII)

By adjusting the amount of CO in the transition zone, the MIDREX® DRI plant operator can adjust the amount of energy added to the bed. Adjusting the natural gas addition will control the carbon content of the DRI. Using these simple principles, this technology allows for independent control of the temperature increase and amount of carbon added.

The Midrex Technical Center fabricated a test stand to verify the concept and to perform experiments that provided the data needed to develop a commercial design (figure 4).
Design Features

A simplified flowsheet is shown in Figure 5 below. The ACT™ “bolt-on” unit starts by diverting a portion of the reformed gas, which is rich in $\text{H}_2$ and CO. All equipment used is well-proven and reliable.
Reformed Gas Cooler
All new MIDREX Plants, and most existing ones have a reformed gas cooler. The reformed gas cooler is used to control bustle gas temperature during plant start-up and occasionally during normal operation. There, a relatively small stream (less than 10% of the reformed gas flow) of cooled reformed gas at approximately 35 °C and 2 bar gauge from the cooler and is diverted to the ACT™ system.

Mist Elimination
The cooled reformed gas is the sent to a mist eliminator, similar in design to ones already used in the MIDREX® Plant, to remove excessive water and protect subsequent equipment.

Gas Compression
The gas is then compressed to approximately 14 barg by a well proven, oil lubricated screw compressor. This pressure is needed for the downstream membrane unit. The compressor package contains an inlet suction scrubber and the gas passes through two stages of mist removal before leaving the compressor package.

Gas Cooling
The gas from the compressor is hotter than needed for the downstream membrane unit. The gas is cooled by a syngas aftercooler and its mist is removed by a mist eliminator. This equipment is similar in design to equipment Midrex supplies in our current plants.
Membrane Separation
The gas, having been suitably compressed and cooled as needed by the membrane unit enters the membrane unit. This well proven technology uses a pressure difference to selectively allow some of the gas components in the feed stream to permeate across a membrane, separating the feed into two product streams. In this case, a CO rich stream (>80% CO) and a H₂ rich stream (>80% H₂) are produced. The CO rich stream is sent to the transition zone where reactions III –VI are employed to generate heat (and some carbon deposition), and reactions VII and VIII deposit carbon. The H₂ rich stream, the low pressure stream from the membrane unit, is recycled to the discharge of the process gas compressors. The gas entering the membranes is cleaned and suitably conditioned within the membrane system; and Midrex engineers ensured the features of the membrane system are tailored for the MIDREX® Process.

Controls and Logic
The amount of carbon added to the MIDREX® DRI Products is adjusted by the flowrate of gas to the membrane unit and the flowrate of transition zone natural gas. The necessary engineering for piping, controls, instrumentation, gas composition measurements, isolation, and control logic were performed by Midrex for normal operation, start-up, shutdown, and isolation of the ACT™ system.

Utilities
Utility-wise this new technology requires mainly:

- Electricity. Electrical consumption for the MIDREX® Plant will increase due to the compressor and the electric heater in the membrane unit.
- Machinery cooling water is needed for compressor cooling and the syngas aftercooler. The flow is relatively small compared to the other MCW users in the MIDREX® Plant.
- A small amount of nitrogen is needed intermittently for system purging
- A small amount of instrument air is needed for control valves.
CONCLUSIONS

MIDREX® ACT™ technology provides a means to increase the carbon level of MIDREX® Direct Reduced Iron for applications where higher carbon is desired. The amount of carbon added is controllable and the DRI discharge temperature is maintained. With this technology, MIDREX Plants will have the widest range of carbon available to them, from 0.5% up to 4.5%. With this technology, the DR plant will have the ability to:

- Produce CDRI with higher carbon content
- Produce HDRI with either higher carbon, higher temperature or both
- Produce HBI with higher carbon content without detrimental loss of temperature at the briquetter, insuring both HBI strength and high yield.
- Merchant plants (CDRI and HBI) can tailor their product chemistry and produce a value-added product to their end users.

Additional OPEX comes mainly in the form of added electrical consumption. The technology is a “bolt on” type design; the MIDREX® Plant can continue to operate without ACT™ and produce MIDREX® DRI Products at lower carbon content as they desire. The equipment used in this technology is proven and the design carries the same robust nature as all MIDREX® technologies.