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COMMENTARY

WORKPLACE SAFETY -

A MATTER OF DOLLARS AND SENSE

By Jimmy Sloop

Senior Operations Engineer, Midrex Technologies, Inc.



Workplace safety is a crucial part of any successful business but especially so in the iron and steel industry, where the potential for serious or even fatal injuries is very real and always present. It speaks well for our industry that iron and steel production facilities are safer workplaces, statistically speaking, than many other physical labor-intensive jobs like logging, fishing, and construction. The key to obtaining and/or maintaining a zero lost time accident safety program is to adopt a safety culture. Real on-the-job safety is more than just slogans and posters. When your team is trained, encouraged, and motivated toward a total commitment to your facility safety program, the phrase "Safety as a Culture" becomes a reality. It is up to everyone in the plant, shop, or office to be vigilant because safety is everyone's responsibility.

Before a plant is purposefully built to maximize production, it must be purposefully designed to be safe. MIDREX[®] Plants are a good example of this safetyby-design concept and have enjoyed an excellent safety record since the first start-up in 1969. The MIDREX Direct Reduction Process holds to basic design guidelines that have proven time and time again to provide the highest level of personal safety for plant operators while producing the most tons of DRI:

- Keep it simple
- Provide safety interlocks
- Develop procedures for safe operation
- Train plant personnel to understand the process and follow all safety procedures

A deep, personal commitment to the safety program must be instilled in the workforce from top to bottom; then, zero lost time accidents becomes the reality, not just the goal. It is important to note that achieving zero lost time accidents does not depend on zero mistakes. In fact, it is the proper recording, studying, and management of the mistakes that help shape safety procedures into a program that can provide zero lost time performance year after year. A lack of diligence and commitment to workplace safety is too costly to let happen. Direct costs for a major accident can quickly exceed seven figures, and the indirect costs can be much more over the long-term. Typically, the indirect costs of a major injury exceed the direct costs by a ratio of at least 4 to 1. Clearly, the best way forward for any industrial company is to invest in the ongoing improvement of an established safety program to provide the safest possible conditions for the workforce.

Safe operations contribute to the bottom line. Eliminating all risks is not possible but having a proper safety program can provide a safer, more prosperous, working environment. Excellence in health and safety performance leads to improved productivity and lower costs from less time spent dealing with worker injuries, accident investigations, and legal proceedings.

In the modern industrial environment, a company that does not actively invest in the ongoing improvement of its employee' health and safety is putting the entire corporation at risk. The more effective a plant safety program is, the more time there is to focus on company profitability and other performance goals.

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THE BASICS OF DRI PLANT SAFETY



By David Durnovich, General Manager - Midrex Global Solutions and Todd Miller, Midrex EHS Coordinator

INTRODUCTION

rom the earliest days, personal safety of plant personnel and protection of plant equipment have been of paramount importance in the design and operation of MIDREX[®] Direct Reduction Plants. After all, a MIDREX Plant is a chemical plant that processes iron oxide using combustible, explosive, and toxic gases at high temperatures.

The original purpose in our plant design was to provide the safest working environment possible. MIDREX Plants are good examples of this safety-by-design concept and have enjoyed an excellent safety record since the first start-up in 1969.

Midrex engineers are ever-mindful of the basic design guidelines that have proven time and again to provide the highest level of personal safety for plant operators while producing the most tons of DRI: keep it simple, provide safety interlocks, develop procedures for safe operation and train plant personnel to recognize hazards (*Figure 1*) and follow safety procedures.

When discussing plant design safety, three areas/operations within a MIDREX Plant deserve particular attention: gas handling, materials handling, and storage.

- Gas Explosion
- Fire
- Electrocution/Arc Flash
- Heat
- Burns
- Toxic gases
- Pressure component failure
- Dust Explosion

• Noise

• Falls

Asphyxiation

Radiation

- Rotating Machinery
- Corrosion

Biological

Direct Natural Draft

FIGURE 1. Potential hazards within a MIDREX Plant

GAS HANDLING

MIDREX Plants handle the following types of gases: natural gas, process gases, inert gas, and flue gas. For combustion to occur, the concentration in air of combustible gases must be within their flammable limits and a minimum percentage of oxygen must be present to generate sufficient heat. The flammable limits of

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GAS	Minimum %	Maximum %	Oxygen % (By Volume)
Hydrogen	4.0	74.0	4.0
Carbon Monoxide	13.0	74.0	6.0
Methane	5.3	14.0	12.0
Mixture	5.0	52.0	-

(Note: For practical purposes, a 4% concentration of a combustible gas or a mixture of combustible gases is considered non-flammable; therefore, dilution to 4% by any means is non-flammable.)

the gases used in the MIDREX Direct Reduction Process and the oxygen percentages necessary for combustion are shown above.

Ignition will occur when the auto-ignition temperature of a gas-air mixture is within its flammable limits and the oxygen level is more than the limit for the gas. The auto-ignition temperatures of the fuel gases used in the MIDREX Process are hydrogen, 570° C; carbon monoxide, 610° C; and methane, 630° C. Therefore, it is essential that no unburned flammable gas-air mixture is allowed to accumulate in the furnace, which could cause an explosion later. Purging the furnace to below 5% oxygen is a safe practice; however, a plant operator always should know the composition of the other 95% of gases present before proceeding.

The MIDREX Reformer is designed to ensure:

- 1. the reformer box is purged with air
- 2. the auxiliary burners have the proper gas-air mixture for ignition and to heat the reformer box
- 3. the main burners are ignited after the reformer box temperature exceeds 980° C (220° C above conventional furnace combustion practice)



Midrex engineers design the process gas recirculating system to be kept under pressure to avoid introducing any source of oxygen into the system. Therefore, the system should be purged with nitrogen prior to depressurizing it to atmospheric pressure.

Gas monitoring equipment plays a key role in protecting employees from harmful gases or environments while working in a MIDREX Plant. Whether it is during start up, commissioning, shut downs, or other maintenance activities, these personal pieces of equipment can and will save lives. All employees who wear a personal gas monitoring device must be trained in proper operations of gas monitoring equipment prior to entering a plant site.

Asphyxiation can occur when gaseous contaminants, called asphyxiates, displace the oxygen in breathable air. Chemical asphyxiation occurs when a contaminant, such as carbon monoxide, reacts with hemoglobin to prevent the blood from transporting oxygen. In low concentrations, asphyxiates do not present an immediate threat but in higher concentrations, they can displace the oxygen in the blood and result in loss of consciousness or eventual suffocation.

Gas leaks, whether from the process system or natural gas piping, must be detected and identified immediately. Large changes in gas pressure, temperature, flow, or analysis can indicate leaks in the gas system. Any gas leak that presents the chance for explosion must be repaired immediately. The determining factor in these cases should be safety - not economics.

Gas leaks can be detected by carbon monoxide (CO) monitors located at various points throughout the plant or by portable personal CO monitors. When a leak is detected, a local alarm is activated to warn personnel in the area, and a remote alarm notifies those in the control room. If the plant only utilizes portable CO monitors, it is the responsibility of the worker to advise the control room and others of the danger. If the plant does not utilize fixed monitors, all employees must be equipped with a portable CO monitor system.

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MATERIALS HANDLING

The natural tendency of all iron is to rust; i.e., to combine with oxygen in air (oxidize) and in water (corrode) to form iron oxides. This is intensified in the case of DRI. After all, DRI is the result of oxygen being chemically removed from iron oxide.

The tendency of DRI to oxidize or corrode is called reactivity. All types of DRI are reactive regardless of the production process or product form. Prolonged exposure of DRI to water reduces product metallization due to rusting (the product of corrosion). Any iron mass eventually will be entirely converted to rust given sufficient time, oxygen, and water.

Rusting also generates heat and in bulk scenarios, this heat can cause DRI to ignite if the heat becomes trapped inside a product pile. Excessive fines within a DRI pile also can pose a safety hazard, especially if the fines become wet and are buried in the pile.

To preserve product quality, care must be taken to varying degrees with each product. As a general rule, users should try to minimize any unnecessary handling of the product. A material handling system should be designed for the minimum number of transfer points required to move material from point A to point B and with the shortest drops. The easiest way to minimize the number of transfer points is to take material along the straightest path possible. However, care should be taken not to compromise metering and feed control in an attempt to eliminate all transfer points. Spillage from overloaded belts may lose more material than breakage through the extra transfer point of a feeder.

A typical DRI handling system associated with a captive DRI plant may include the operations shown in *Figure 2*.

A frequently quoted estimate for cold DRI (CDRI) breakage due to handling is 0.25% loss per 2-meter drop. This number can be much larger for weaker material, longer drops, or poorly designed transitions. Fines and chips generated during handling will oxidize much faster than whole DRI products. A conservative number is 15% loss for -6.35 mm fraction material after exposed (outdoor) storage for a month.

Hot DRI (HDRI) can be transferred from the DRI plant to the melt-shop by hot transport vessels, hot transport conveyors or pneumatic transport, depending on the distance between the DRI plant and the melt shop, or by direct gravity feeding in the case of a close-coupled reduction furnace and EAF. Hot transport vessel systems employ ladle-type insulated vessels that are transported on flat-bed trucks and can be (*next page*)

GENERAL GUIDELINES FOR DEALING WITH GAS LEAKS

 Always use properly calibrated gas monitoring equipment before entering a hazardous atmosphere.

- Priority must be given to warn plant personnel of any gas leak. The area surrounding a gas leak should be roped off and identified as a safety hazard.
- Any area where gas could accumulate in explosive proportions, such as under the reformer, should be repaired immediately. Personnel should be evacuated, and the area should be ventilated if at all possible.
- Leaks in the seal gas piping should be treated with caution and repaired as required to maintain safety and proper operation of the seal gas system. Remember, seal gas in an enclosed area can cause asphyxiation. If a leak develops where proper ventilation can not be ensured, the leak must be repaired immediately.
- Gas leaks in the feed gas, reformed gas, and bustle gas piping, as well as leaks from the furnace can burn without being seen. During daylight hours, leaks often can be located by a "hissing" sound. In the case of hydrogen, only very faint heat waves can be seen. Exercise extreme caution when trying to pinpoint the location of a leak. Never use your hand to feel for a leak.
- Any equipment or machinery that could be a source of ignition should be removed from an area where a gas leak occurs.
- Gas leaks within the analyzer building can cause a toxic buildup of combustibles. MIDREX Plants include a ventilation fan, which continuously forces fresh air into the analyzer building. It is imperative the ventilation system operates at all times and is kept in good working condition.
- Gas leaks from the cooling zone of the shaft furnace or product cooler may contain carbonyls. As with other gas leaks, the area surrounding the gas leak should be roped off and identified as a safety hazard.

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maintained at temperature if the melt shop is delayed in accepting the HDRI. Pneumatic transport systems use gas to blow DRI at high velocity through pipes to carry it to the EAF or to a product cooler. The high velocity and resultant turbulence can cause significant breakage and erosion of the HDRI, especially at bends in the pneumatic line. This method can result in fines generation of as much as 8-10%. Hot conveyor systems using enclosed conveyor buckets are less jarring and greatly reduce HDRI fines generation.

STORAGE

CDRI can be stored safely in open, well drained piles if it will not be moved until it is used in the melt shop. Rain only can penetrate the stack to a certain depth, typically less than a meter. Although the resulting corrosion will reduce the metallization, as described earlier in this article, the stack should not overheat unless additional material covers the wet area. This will insulate the wet iron and prevent the dissipation of the associated heat, which can cause the pile to overheat and lead to ignition.

HDRI is not intended for long-term storage but can retain much of its heat when needed to wait for a charging cycle or to be transported to a different nearby melting furnace. This is a temporary option when using hot transport vessels and not really an option with using pneumatic or conveyor bucket systems.

Hot briquetted iron (HBI) is normally stored outdoors in exposed piles built on a firm, well drained surface. Bulk piles of HBI tend to dissipate heat rapidly due to good thermal conductivity characteristics and a shape and form that create voids in the pile. HBI, like scrap also can rust. Rusting has been observed to reduce its metallization by less than 1% per month even in salt-laden, humid air and frequent, heavy rainfall conditions.

The following precautions should be followed when storing DRI products outdoors:

• Build pile on a firm base, such as concrete, and ensure proper drainage to prevent the intrusion of water under the pile. The base should provide protection from moisture in the ground. A sealant layout of tar, bitumen or some other material impervious to water should be laid down before the concrete is poured.

- Keep DRI away from corrosive chemicals, such as salt
- Avoid excessive fines content in the pile.

CDRI and HBI

- Conveying/transporting CDRI to storage silos
- Discharging/reclaiming CDRI from storage silos
- Conveying/transporting CDRI or HBI to short-term storage at EAF melt shop
- Reclaiming CDRI or HBI from short-term storage
- Conveying/transporting CDRI or HBI to EAF
- Charging CDRI or HBI to EAF



HDRI

- Discharging HDRI from reduction furnace to pneumatic transport system, insulated hot transport conveyor or insulated hot transport vessels
- Transporting/conveying HDRI from reduction furnace to EAF melt shop
- Charging HDRI to EAF from pneumatic system, insulated conveyor or transport vessels
- Direct gravity feeding HDRI from reduction furnace to EAF melt shop (if equipped)

FIGURE 2. Characteristics of DRI handling systems

• In the case of CDRI cover the pile to keep DRI dry and to prevent air stacking in the pile.

A DRI pile will warm up to about 60° C/140° F as steaming occurs but will cool down again to ambient temperature when the water is evaporated. Normally it is not necessary to take additional action if the pile is steaming as long as the temperature does not exceed 100°C/212° F.

In case of a pile of DRI overheating to temperatures in excess of 100°C/212° F, the overheated material should be removed from the pile and spread out on dry ground in a layer of about 0.5 meters using a track-equipped bulldozer or front-end loader, as shown in *Figure 3*. Another method is to bury the pile under sand or other suitable material to cut off the oxygen supply.

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Storage bins and silos are used to protect DRI products when there is a time delay between arrival and when the product can be used or shipped. Badly designed silos can create operational problems and a decrease of product quality. The design of silos should be determined on the basis of the material flow properties of the bulk solid(s) to be stored. The expenses for testing and silo design are small compared to the costs of lost production, quality problems, and retrofits that may be needed because of irregular flow patterns.

The precautions shown in *Figure 4* are recommended when storing DRI products.

All employees should be trained in the methods and procedures for proper storage and handling of DRI prior to starting their assignment. They should have access to Safety Data Sheets (SDS), which will provide them with important information on DRI storage, handling, and other safety precautions. All SDSs must comply with the Globally Harmonized System, which was adopted in 2013. All SDS records are kept and maintained for each MIDREX Plant.

OTHER SAFETY CONSIDERATIONS

Midrex also incorporates in its plant designs various fire and explosion protection features, such as:

- Non-combustible and low-combustible construction materials
- Site selection in an open, well-ventilated area
- Separation of plant sections to prevent "domino effect"
- Paved and/or concrete surfaces in fire risk areas
- Two (minimum) escape routes from every point in the plant
- Fire alarms which activate visual and audible signals in the control room
- Automatic shutdown in case of pressure drop (gas valves go to fail-safe positions and purge gas is supplied immediately)
- Carbon monoxide monitors and alarms
- Critical areas are well marked and signed

(Important Note: Water should not be sprayed on an overheated DRI pile under normal conditions. However, in case of a runaway fire, the pile should be inundated with a strong water stream. Firefighters should be prepared for violent steaming and hydrogen flashing resulting from such action.



FIGURE 3. Method for controlling hot material in a storage pile

PRECAUTIONS FOR STORING DRI PRODUCTS

- Any DRI at a temperature in excess of 65° C should not be sent to a storage bin or silo. It should be separated from all other material and piled no more than one meter high.
- Bins and silos should be purged with an inert gas from the bottom.
- Top slide gates should be closed except when DRI is being delivered.
- Bottom slide gates should be closed except when DRI is being discharged..
- Inert gas should be introduced into the top of the bin or silo during extended storage periods to ensure a slight positive pressure while the top and bottom slide gates are closed.
- Periodic gas analyses should be performed to ensure that oxygen level is below 3% and hydrogen is not being generated.
- Temperature within the bin or silo should be monitored.
 If high temperature (65-75° C) is observed, the bin or silo should be sealed and purged from the top until it cools.
 If the temperature rises to above 90° C, the DRI should be removed from the bin or silo.

FIGURE 4. Recommended precautions for storage bins and silos

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CONCLUSION

Workplace safety is a crucial part of any successful, well managed business and keeping people safe should be first priority. DRI plants and products can be potentially dangerous under certain conditions if the proper precautions are not taken. There are no cost savings worth the risks of shortcutting safety procedures when producing, handling, and storing DRI products. Loss of life, injuries, or destruction of property are costly on many levels. Direct cost to the company for a major accident include at a minimum: worker compensation claims, indemnity payments, and legal fees. Direct costs for a disabling on the job injury or death can quickly exceed seven figures.

The indirect costs are much more expensive over the longterm. The indirect costs of a lost time accident (LTA) will generally exceed the direct costs by a ratio of 4 to 1 or higher and compound into the millions of dollars in total cost over time. With the true costs of major injury accidents in mind, clearly the best way forward to stay with best industry practices and safety standards to help ensure safest possible conditions.

Midrex Technologies Inc. strives to be the worldwide leader in DRI production and we work just as hard to have the safest DRI plants in the world. Midrex provides each plant a detailed safety manual, and our employees go through rigorous safety training. We investigate all incidents, large or small, to identify causes and pinpoint potential hazards so corrective actions can be taken to ensure that every MIDREX Plant is as safe a working environment as possible.





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PROCESS GAS HEATER Proven Technology for Process Flexibility



INTRODUCTION

atural gas has fueled the growth of direct reduction of iron technology from its infancy in the mid-20th century to its role today as a source of vital feed materials for high quality steel production. This clean-burning energy source has been identified as a means to help facilitate the integration of the steel industry into the future global hydrogen economy. However, the availability and price of natural gas has posed challenges to its use for direct reduced iron (DRI) production and still does in some regions of the world. As a result, methods for producing a synthesis gas suitable for DRI production from coal gasification, coke oven gas treatment, and excess process gas have been introduced. Likewise, technology for the use of hydrogen as the reductant source for DRI production has been developed.

The MIDREX[®] Direct Reduction Process was conceived from the idea of reforming natural gas to produce a high-quality synthesis gas to reduce iron oxide pellets. The originators of the MIDREX Process applied their commercially proven combustion and heat transfer knowledge to create the proprietary design of a near-stoichiometric gas reformer and a gravity-flow, shaft-type reduction furnace. The current generation of Midrex engineers has adapted the world's most efficient gas reformer to design a Process Gas Heater (PGH) for use with a broad range of alternate fuels including hydrogen in the MIDREX Process.

BASIC PROCESS REQUIREMENTS

The block flow diagram of the MIDREX Process when using alternate fuels instead of natural gas is shown in *Figure 1*.



FIGURE 1. MIDREX Process alternate fuels diagram showing gas flow streams

The main process gas loop has several unit operations to clean, heat, and adjust the gas chemistry to the required properties suitable for the reduction of iron ore, which are summarized in *TABLE I (next page).*

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UNIT OPERATION NAME	UNIT OPERATION DESCRIPTION
Scrubber (Top Gas Scrubber)	 Reduces the top gas temperature to a suitable range for the downstream unit operations Removes particulates from the gas stream Condenses water. Generally, this is a packed bed cooler in which water is in direct contact with the gas stream.
CO ₂ Removal	 Removes carbon dioxide (CO₂) from the gas stream. CO₂ is an oxidant and must be removed to achieve the desired process chemistry for direct reduction.
Gas Heater (Process Gas Heater)	 Direct reduction requires high temperature as well as the correct gas composition in order promote the required reaction rate. After CO₂ is removed from the recycled gas stream, fresh syngas is added to the stream and the combined stream is heated to the required temperature for DRI production.

TABLE I. Major process gas loop unit operations and descriptions

TABLE II lists the general process requirements for streams 3 and 4 in *Figure 1*. Streams 1 and 2are not directly related to a discussion of the PGH and are shown only for comparison.

PARAMETER	STREAM 3	STREAM 4
Temperature (°C)	35 to 55	> 950
Pressure (barG)	~ 2	~ 2
Gas Quality	> 9	> 9
$(H_{2} + CO)/(H_{2}O + CO_{2})$		
CH ₄ Content (mol%)	> 3.5	> 3.5
H ₂ /CO	0.5 to 3.0	0.5 to 3.0

TABLE II. PGH process duty specifications

TEMPERATURE

The temperature of Stream 3 primarily depends on the type of the CO₂ removal that is applied and the chemistry of the makeup of the fuel (syngas or hydrogen). However, from the pointof-view of the PGH, the inlet gas temperature range of 35°C to 55°C does not have a significant impact on the required heat duty because the outlet gas stream needs to be heated to a much higher temperature. For direct reduction, the minimum required temperature is 760°C; however, the state-of-the-art is to operate at much higher temperatures. In most plants, it is desirable to heat the gas to the maximum possible temperature, which is primarily limited by the softening temperature of the DRI. In modern plants, it is reasonable to expect the outlet gas from the heater to be approximately 950°C.

PRESSURE

The operating pressure of the PGH is set by the requirements of the reduction furnace, which generally is around 2 barG but can vary depending on the specific site conditions. The pressure is an important parameter in designing the mechanical components of the PGH, but generally the heater does not set the limitation or requirement for the operating pressure.

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GAS QUALITY, CH₄ CONTENT, AND H₂/CO RATIO

The gas quality, methane (CH_4) content, and H_2/CO ratio are determined primarily by the composition of the make-up fuel (syngas or hydrogen) and also the type of the CO_2 removal technology that is applied. In any case, the commercial application requires the gas quality to be greater than 9. The gas quality requirement effectively sets a limitation on the amount of H_2O and CO_2 that can be present in the process gas.

TABLE II shows a CH_4 content of > 3.5 mol%. However, this is only the desired value and is dependent on the type and chemistry of the make-up fuel. For example, the operating range for CH_4 in a MxCōl° Plant in commercial operation has been as low as 0.5% and as high as 8%.

TABLE II also shows a range for the H_2/CO ratio. This value is established primarily by the type and composition of the make-up fuel to the process. In a MxCol Plant, the commercial operating range is from 0.5 to 3.0.

HEAT DUTY REQUIREMENTS

The primary process requirement for the PGH is to heat the gas from approximately 50°C to around 950°C. If we consider a gas with the composition shown in *TABLE III*, we can calculate the required heat duty.

The heat duty is a sole function of the enthalpy change due to increasing the gas temperature from 45°C to 950°C. For a reference plant producing 1.0 million tons per year of DRI, the total duty is in the range of 60 to 70 Gcal/h. This large heat duty requirement dictates that the PGH must be a significant unit operation when operating the MIDREX Process with alternate fuels.

CONSTITUENT	VALUE %
CO	37.4
CO ₂	3.0
H ₂	47.1
H ₂ O	3.0
CH ₄	4.2
N ₂	5.1
0 ₂	0
Others	Balance



DETAILED DESIGN CONSIDERATIONS Energy Efficiency

The required large heat duty also implies that the PGH can have a significant impact on the entire plant's OPEX. For instance, the fuel required for the burners would become too expensive to support the economical production of DRI if the efficiency is low. The key parameter that affects heater efficiency is the flue gas temperature leaving the heater box. *Figure 2* illustrates a typical calculation.





In *Figure 2*, the relative fuel rate is shown on the y-axis. The calculation is based on a fixed gas composition and flow that needs to be heated from a fixed inlet temperature to a fixed outlet temperature. The variable axis is the roof temperature of the heater, which also is the assumed exit temperature of the flue gas, and various combustion air preheat temperatures are shown as series.

Figure 2 shows that as the roof temperature is increased, the amount of fuel needed to achieve the same heat duty to the process stream increases. This is natural because if the combustion products leave the furnace at higher temperature, the combustion gas has less available energy to contribute to the process gas. As a consequence, more fuel (combustion products) is required for the same process heat duty. The trade-off in the design becomes a question of minimizing the roof temperature

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to reduce the fuel consumption versus having a high enough roof temperature to satisfy the final required process gas temperature and maintain sufficient heat transfer to produce an economical design.

Figure 2 also shows the impact of preheating the combustion air. If the combustion air is not preheated, as seen in the 50°C case, the relative fuel rate is increased compared to the cases where air preheat is considered. Therefore, it is necessary to have some type of preheat to achieve reasonably low fuel rates. The exact heat recovery configuration is vendor-specific.

TUBE MATERIAL SELECTION

The process conditions and duty also play a large part in the heater tube configuration and material selection. The first concern that needs to be addressed is the maximum allowable tube wall temperature for the heater tubes. Generally, the heater tube wall temperature is highest where the process gas is the hottest. The tube wall temperature can be calculated by balancing the radiation heat transfer from the combustion box with the conductive and convective heat transfer characteristic of the heater tubes. The equations and solution methods are commonly available in heat transfer technical references and are not presented here.

If we apply the typical example from this article where the roof temperature is 1150°C, the gas temperature is 950°C and the tube is made from a high-nickel alloy, then we find that the equations balance with a tube wall temperature of approximately 1050°C (roughly the arithmetic average of the process gas temperature and roof temperature). These tube wall temperatures are very high compared to the allowable temperature for even special, high temperature alloys that are typically used in these applications. Therefore, tube material must be selected to have enough temperature to withstand the process conditions.

The next point of concern related to material selection is gas chemistry. *TABLE II* has shown that the direct reduction reaction requires a high gas quality and additionally that the $H_2/$ CO ratio depends on the type and composition of the make-up syngas or hydrogen to the plant. When the $H_2/$ CO ratio is coupled with the gas quality constraint, the CO concentration can vary widely depending on the application. *TABLE IV* illustrates this point.

TABLE IV shows the effect that the H_2/CO ratio has on the gas composition within the range of ratios that has been applied commercially for MxCol Plants. The key point of concern is that

H ₂ / CO RATIO	CO CONCENTRATION IN THE GAS (MOL%)
0.5	55
1	41
2	27
3	20

TABLE IV. CO mole % for a gas with quality of 10 and various H_2/CO ratios

the typical process gas is a carbon-saturated stream and therefore can deposit carbon in certain temperature ranges. The two most important carbon depositing reactions are hydrocarbon cracking and Boudouard carbon deposition. The general forms of the reactions are:

CnHy -> nC + (y/2) H ₂	EQUATION (1)
2 CO -> C + CO ₂	EQUATION (2)

Equation (1) is the hydrocarbon cracking reaction, which is endothermic and is promoted at higher temperatures. Equation (2) is the Boudouard carbon reaction, which is exothermic and is promoted at lower temperatures. In terms of tube selection, the Boudouard carbon reaction normally is more critical since it typically occurs in the range of 550°C to 650°C. The deposited carbon, if not controlled, could easily promote metal dusting of the metallic tubes causing rapid degradation of the tubes and ultimately accelerated tube failures.

It can be seen in Equation (2) that increased CO concentrations and reduced CO_2 will favor the deposition of carbon from an equilibrium point of view. In *TABLE IV*, the CO_2 concentration already is quite low due to the requirement of having a reducing gas quality > 9. Thus, the effect of the H₂/CO ratio is apparent in that at very low H₂/CO ratios, the CO concentration can be greater than 50%. When compared to high H₂/CO ratios of 2 or 3, where the CO concentration is about 20%, the lower H₂/CO ratio gases have a significantly higher tendency to form Boudouard carbon. This is especially likely in the inlet of the heater tubes where the gas must be heated to through the critical Boudouard reaction zone.

There are various strategies for handling the material selection and carbon deposition issues, and the specific strategy is up to the individual heater vendor.

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FUEL TYPE

In general, there are several fuel options that can be used in the PGH. The most common fuels are Top Gas Fuel, which is generated within the MIDREX[®] Plant, and syngas or hydrogen, which is normally identical to the make-up process fuel. *TABLE V* shows typical heating values for common fuels and hydrogen.

FUEL NAME	LOWER HEATING VALUE RANGE (KCAL / NM3)
Top Gas Fuel	2,000 to 2,300
Syngas (from coal gasification)	3,200 to 3,600
Coke Oven Gas	4,100 to 4,300
Hydrogen	2,570

TABLE V. Typical heating values for MIDREX Process alternate fuels

Top Gas Fuel is normally the preferred fuel, as it is generated within the MIDREX Plant. Top Gas Fuel can be used directly within the PGH without additional compression or cleaning steps. The disadvantage is that Top Gas Fuel is not available during start-up conditions. Also, if there is an interruption in plant operation, the Top Gas Fuel quantity and quality will be affected. This means that the PGH must be designed to meet the heat-up duty and plant interruption cases with fuels other than Top Gas Fuel. Considering the difference in heating values listed in *TABLE V*, the specific design of the burners and combustion systems is not always straight forward.

OPERATING CONDITION CONSIDERATIONS

In addition to the normal operating conditions, the PGH also must be able to handle other special or transient conditions. A few of the conditions and their special concerns are noted in *TABLE VI*.

Special Plant Condition	Design Consideration
Plant Heat-up	 PGH must meet the start-up heat requirements with an alternate fuel since Top Gas Fuel is not available. PGH would need to be in stable operation for an extended period at lower temperatures than required by normal process duty alone if a heat ramp-up is required.
Start-up	 PGH would need to supply the energy required during initial start-up when the gas composition of the Process Gas loop will vary considerably from normal operation. PGH burner system must be designed to handle changeable Top Gas Fuel composition, as well as to be capable of transitioning from an alternate fuel to normal operating condition fuel.
Idle Operation / Plant Interruption	 PGH design must have adequate provisions to protect against unnecessary thermal cycling, which tends to dramatically reduce equipment life by introducing additional residual stresses into the heater tubes.

TABLE VI. PGH design consideration for special or transient conditions

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The Process Gas Heater is a critical unit in the operation of the MIDREX Process with fuels other than natural gas. Although several commercial designs are available that are suitable to the duty and temperature requirements, there are additional operational conditions that must be considered to achieve the required process conditions, expected operation costs, and long heater life. The Midrex PGH design is derived from the design of the MIDREX Reformer, which has proven to be the most reliable and efficient means of transforming natural gas into a high-quality reducing gas for producing DRI in use today in commercial MxCol Plants. When the supply of hydrogen becomes available in sufficient quantities to fuel DRI plants, Midrex will be ready with a process configuration powered by a PGH that provides added flexibility to the world's most preferred process for the direct reduction of iron.



JSPL MxCol[®] Plant in Angul, India

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MIDREX News & Views

ArcelorMittal Chooses Midrex to Design Demonstration Plant for Hydrogen Steel Production



Participants in the signing ceremony in Hamburg (from left to right): Vincent Chevrier, Todd Astoria, and KC Woody for Midrex Technologies, Inc. and Dominique Vacher, Dr. Uwe Braun, and Matthias Schad for ArcelorMittal.

(News release issued by ArcelorMittal on September 16, 2019)

rcelorMittal announced today that it has commissioned technology provider Midrex Technologies to design a demonstration plant at its Hamburg site to produce steel with hydrogen. Both companies have now signed a Framework Collaboration Agreement (FCA) to cooperate on several projects, ranging from research and development to the implementation of new technologies. The FCA will be governed by a number of Project Development Agreements, incorporating the expertise of Midrex and ArcelorMittal. The first Project Development Agreement is to demonstrate in Hamburg the large-scale production and use of Direct Reduced Iron (DRI) made with 100% hydrogen as the reductant.

In the coming years, the demonstration plant will produce about 100,000 tons of direct reduced iron per year initially with grey hydrogen sourced from natural gas. Conversion to green hydrogen from renewable energy sources will take place once available in sufficient quantities and at an economical cost. Energy for hydrogen production could come from wind farms off the coast of Northern Germany. The plant will be the world's first direct reduction plant on an industrial scale, powered by hydrogen.

"We are working with a world class provider, Midrex Technologies, to learn how you can produce virgin iron for steelmaking at a large scale by only using hydrogen. This project combined with our ongoing projects on the use of non-fossil carbon and on carbon capture and use is key to become carbon neutral in Europe in 2050. Large scale demonstrations are critical to show our ambition. However it will depend on the political conditions, how fast transformation will take place", comments Carl de Maré, Vice President at ArcelorMittal and responsible for technology strategy.

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ArcelorMittal Hamburg already produces steel using DRI technology. During the process, iron oxide pellets are reduced to metallic iron, the raw material for high quality steel, by extracting oxygen using natural gas. "Our site is the most energy-efficient production plant at ArcelorMittal", says Dr. Uwe Braun, CEO at ArcelorMittal Hamburg, adding that the existing Midrex plant in Hamburg is also the plant with the lowest CO_2 -emissions for high quality steel production in Europe. "With the new, hydrogen-based DRI plant we are now planning, we will raise steel production to a completely new level, as part of our Europe-wide ambition to be carbon neutral by 2050", Dr. Braun concludes.

"This commercial scale project will show the path for hydrogen based iron and steel making", commented Stephen C. Montague, President & CEO of Midrex Technologies Inc. "We are excited to work with ArcelorMittal as pioneers for using renewable energy in our industry."



ArcelorMittal Hamburg Plant

MIDREX News & Views

World DRI Production Exceeds 100M Tons

Midrex Publishes 2018 World Direct Reduction Statistics

A nnual global direct reduced iron (DRI) production surpassed the lofty milestone of 100 million tons in 2018, riding the crest of double-digit growth for the second consecutive year. According to the data and information published in the 2018 edition of *World Direct Reduction Statistics* for 2018, which is compiled annually by Midrex Technologies, Inc. and audited by World Steel Dynamics, global DRI production reached 100.5 million tons last year.

DRI output was up more than 15% over 2017 performance. From 2016 to 2018, world DRI production has increased by 38%, which is the largest increase in any two-year period since 1985. The sustained growth through 2018 was driven primarily by strong demand for natural gas-based DRI – an environmentally friendly and low residual metallic that is needed to produce today's premium steel products. Combined, India and Iran were responsible for more than half of total world DRI production in 2018. The top five DRI-producing countries last year were:

2018 Top 5 DRI Producing Nations

COUNTRY	PRODUCTION (Million Tons)
India	28.11
Iran	25.75
Russia	7.90
Saudi Arabia	6.00
Mexico	5.97

Source: World Steel Association, SIMA, and Midrex Technologies, Inc.

Over 11 million tons of last year's production was hot DRI (HDRI), which is fed directly to the EAF to reduce energy consumption and increase melt shop productivity. Hot briquetted iron (HBI), which is compacted DRI, accounted for 9 million tons of the 2018 total.

2018 World Direct Reduction Statistics is available for download on the Midrex website, **www.midrex.com**, as a resource for the global iron and steel industry.

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Nigel Phillips to Lead Midrex UK Operations



When Nigel Phillips takes over from Mike Jasper as Director – Operations, Global Project & ECA Finance, Risk Management of Midrex UK Ltd., he already will have a working knowledge of Midrex, its technology, and the direct reduction market. Phillips, who brings 30 years of experience in a variety of international trade and insurancerelated roles, has had a keen interest in Midrex Technologies Inc. (MTI) and its projects and marketing campaigns since Midrex UK was established in 2009, and has regularly met with senior Midrex executives in London to provide ideas and analysis of various financing scenarios.

Phillips has specialized in project and export finance with UK, Dutch, French, and Spanish financial institutions, arranging the finance for the cross-border sale of capital goods and services. He brings a wealth of knowledge of the market and financial structures, as well as risk mitigation provided by the private insurance market.

"The opportunity to lead Midrex UK into its second decade at this exciting time for Midrex and the DRI industry was one that could not be refused," Phillips explained. "With annual DRI production now exceeding 100m tons and the Midrex project pipeline containing several very tangible and sizeable projects, the importance of Midrex UK to the global MTI group has never been greater."

Mike Jasper is retiring after serving 10 years as the first and founding UK-based director of Midrex UK. ■

MIDREX UK LTD.

About Midrex UK Ltd.

Midrex UK was established in 2009 to provide Midrex clients access to the financing expertise and opportunities offered out of the United Kingdom and the City of London in the form of international project and commercial bank financing and ECA (Export Credit Agency) support through UK Export Finance (UKEF), formerly known as the Export Credits Guarantee Department (ECGD). Midrex UK provides access to the London insurance market to secure many forms of risk mitigation. Its strategic location in regard to EMEA (Europe, the Middle East, and Africa) allows it to support procurement, logistics, and expediting for new plant projects, as well as Midrex Global Solutions initiatives, tapping a developing UK and European vendor base that meets the high Midrex technical specifications.

The office is located at 39 Eastcheap, London, EC3M 1DE, and the phone number is 0044 (0) 207 089 1524.

Midrex UK was the first permanent overseas location established by Midrex to assist potential clients in developing and financing their projects. Midrex has since opened offices in Shanghai, China (2011) and near Delhi, India (2012), and is in the final stages of establishing an office in Dubai.

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The publication is distributed worldwide by email to persons interested in the direct reduced iron (DRI) market and its growing impact on the iron and steel industry.

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