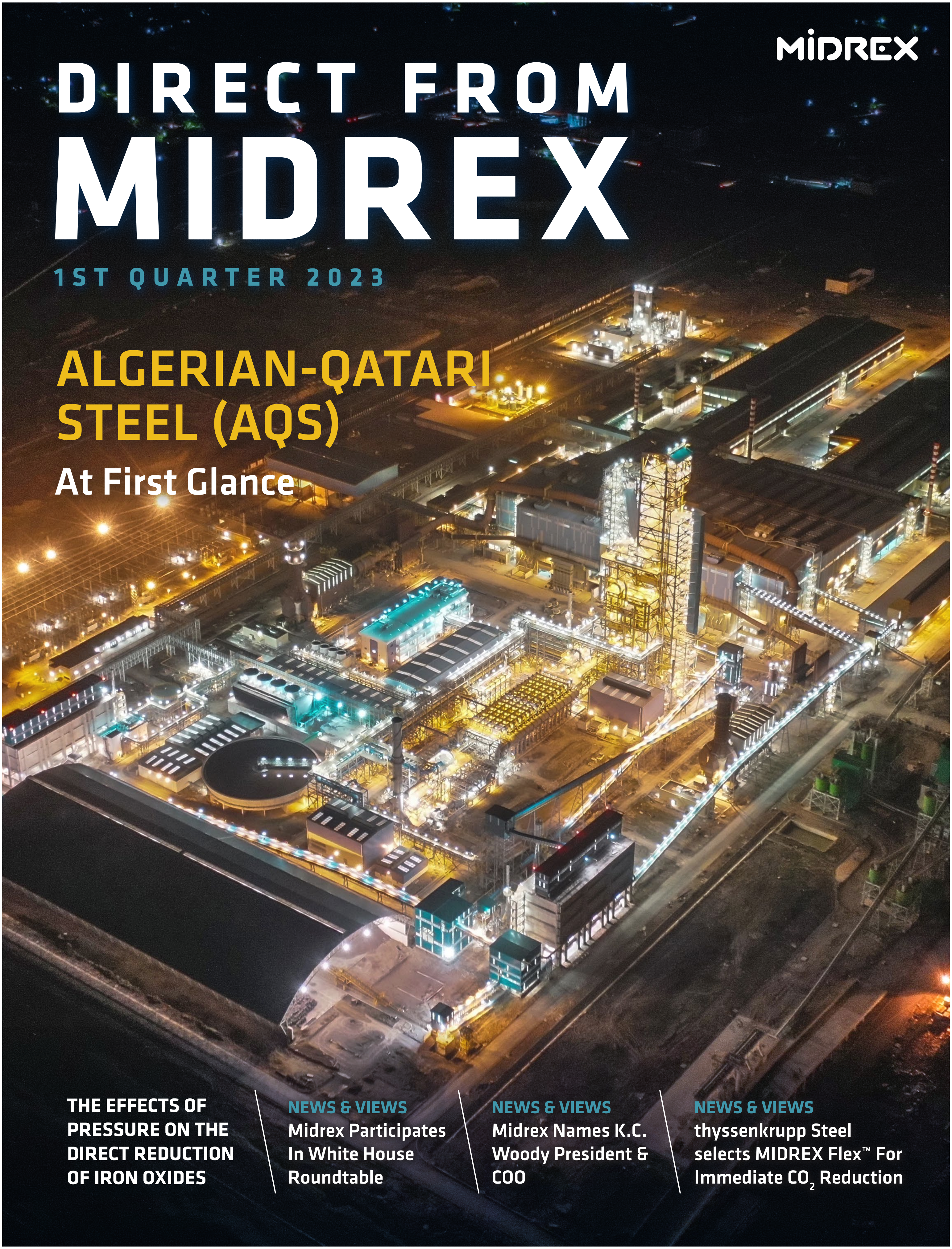
MIDREX

DIRECT FROM MIDREX

1ST QUARTER 2023



ALGERIAN-QATARI STEEL (AQS)

At First Glance

THE EFFECTS OF PRESSURE ON THE DIRECT REDUCTION OF IRON OXIDES

NEWS & VIEWS
Midrex Participates In White House Roundtable

NEWS & VIEWS
Midrex Names K.C. Woody President & COO

NEWS & VIEWS
thyssenkrupp Steel selects MIDREX Flex™ For Immediate CO_2 Reduction

COMMENTARY

WE ARE LIVING IN INTERESTING TIMES

By Stephen C. Montague
President & CEO

When I joined Midrex in 1987 as a summer intern, global production of direct reduced iron (DRI) the previous year had increased 15% to 12.68 million tons. In 2021, DRI production was nearly 120 million tons, and although we are still gathering the data for 2022, I am certain DRI production will continue to grow dramatically to meet the tremendous demand driven by decarbonization.

The direct reduction industry has come a long way in a relatively short time. Not just in the tons that are produced each year, but also in its role in the rise of electric arc furnace (EAF)-based steelmaking. You could say they have "grown up together," with the EAF capturing an increasing share of high-quality steel products thanks in great part to the diluent effect of DRI when used with scrap. Along the way, DRI has responded to the call for a better merchant product in the form of hot briquetted iron (HBI) and has harnessed the sensible heat from the reduction process with hot DRI (HDRI) to benefit EAF operations and productivity.

Today, the DR-EAF steelmaking route is generally viewed as the steel industry's "best bet" for reaching its decarbonization goals by 2050. Recently, Midrex participated in a US government-sponsored roundtable discussion on how to quicken the pace of industrial decarbonization and increase American competitiveness. The keys are electricity from renewable energy sources, "green" hydrogen from water electrolysis, and DRI from hydrogen-based DR plants.

We see opportunities to produce "green" iron at scale at mega-hubs in locations having the right energy and logistics profiles, such as North America, Middle East & North Africa (MENA), and Australia to be shipped to steelmakers around the world. We also believe that hydrogen DRI could replace merchant pig iron in EAFs. A lot of carbon dioxide (CO_2) could be eliminated by replacing the 6 million tons of pig iron that was imported in 2021 by EAF operators in the US.

How will these visions be realized? There are two full-scale "lighthouse"

COMMENTARY

> "Each year, MIDREX Plants produce approximately 80% of the world's low CO_2 iron. And that is "big" work that we are very proud of."

projects underway that are based on MIDREX® hydrogen technologies. Each of the projects is unique, yet they share in the unparalleled performance of the MIDREX Shaft Furnace.

- H2 Green Steel has broken ground in Boden, Sweden, on the world's first commercial-scale 100% hydrogen DR plant, as part of a totally "green" steel complex that will eliminate up to 95% of CO_2 emissions compared to traditional steelmaking. The 2.1 million metric tons per year (Mt/y) MIDREX H2™ plant will supply hydrogen-based DRI that will be mixed with scrap and melted in EAFs powered by "green" electricity. First product is expected in late 2025.
- thyssenkrupp Steel in Duisburg, Germany, is beginning to replace its traditional steelmaking by installing a 2.5 Mt/y DRI-electric melter combination that will avoid 3.5 Mt/y of CO_2 associated with its current blast furnace-basic oxygen furnace (BF-BOF) facilities. The MIDREX Flex™ plant can be operated immediately with reformed natural gas, which contains 50% or more hydrogen, and transitioned to 100% hydrogen operation as sufficient hydrogen becomes available. The DR plant is scheduled to be completed by the end of 2026.

When I am asked to describe Midrex, I say we are a small team doing big work, committed to loving and serving others. Some might think it is strange for a technology company in the iron and steel industry to have this focus but it is how we have designed and supplied plants since the 1970s that have produced well over 1 billion tons of DRI. Each year, MIDREX Plants produce approximately 80% of the world's low CO_2 iron. And that is "big" work that we are very proud of.

Yes, these are interesting times and I cannot think of a more capable team of people to tackle whatever the future holds than the men and women of the Midrex family and no better person to lead them than my friend and colleague for the past 13 years, K.C. Woody. That's why I've made the decision to retire in April 2024 to spend more time with my family and in ministry. K.C. will immediately add president to his current title of chief operating officer, and I will continue as chief executive officer until my retirement and will serve on the Midrex board thereafter. So, join me in saluting the good times that were and the even better times to come.

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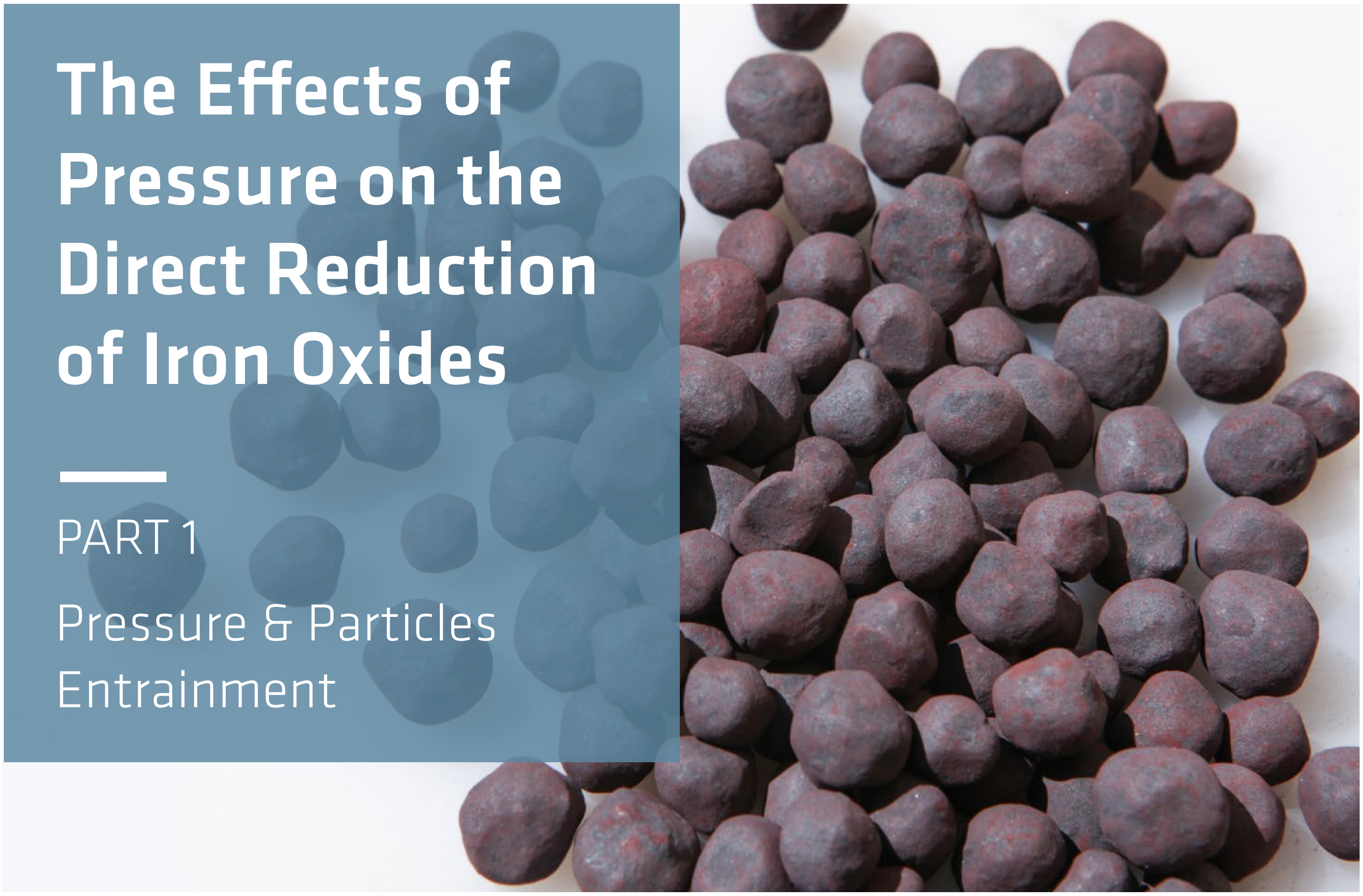
The cover article of this issue of *Direct From Midrex* provides a first glance from inside Algerian-Qatari Steel by DR Plant Acting Manager Eng. Mohamed El Sayed. The other feature article is a technical investigation of the effects on iron oxides of high pressure in direct reduction by a trio of Paul Wurth Italia engineers. News & Views includes the announcement of K.C. Woody as Midrex President and COO, the contract awarded by thyssenkrupp Steel to Midrex and Paul Wurth for the first commercial-scale hydrogen DRI-electric melter combination plant, the participation by Midrex in a White House Roundtable Discussion on industrial decarbonization, the hiring of Rogerio Valdejao as Director-Global Business Development, the promotion of Sean Boyle as Director-Plant Sales, and MIDREX Plants with first quarter anniversaries.



The Effects of Pressure on the Direct Reduction of Iron Oxides

PART 1

Pressure & Particles Entrainment

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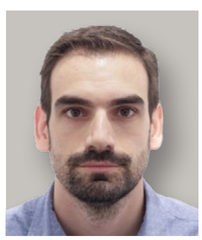

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Technology Director,
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Editor's Note: This article is the first of a two-part series on the subject of how pressure affects the operation of direct reduction processes. Part 1 focuses on the effect of pressure on particles entrainment, while Part 2 will describe the effects of pressure on iron oxide reduction kinetics

INTRODUCTION

The operating costs (OPEX) of each industrial plant are essential in analysing a company's economic performance and obviously, in having a successful business. This is generally true, especially in the competitive iron & steelmaking business. With focus on direct reduced iron (DRI) plants, many variables impact on the operating cost, such as raw materials and gas consumption, electricity consumption, and maintenance.

Yield, defined as the ratio between consumed iron oxide (IO) pellets and produced DRI, has a critical role in defining the plant OPEX performance. MIDREX® Direct Reduction Plants typically have a cut-point for the IO fines at 3mm, which contributes to an increase in the overall yield.

It should be noted that screening has a given efficiency and that some fines will be generated in the transport of oxide pellets from the screening station to the shaft furnace. As a result, some fines will find their way into the furnace. Any loss of such fines due to top gas entrainment will increase the overall material loss and consequently, worsen the overall yield.

One could be tempted to think that high pressure might be

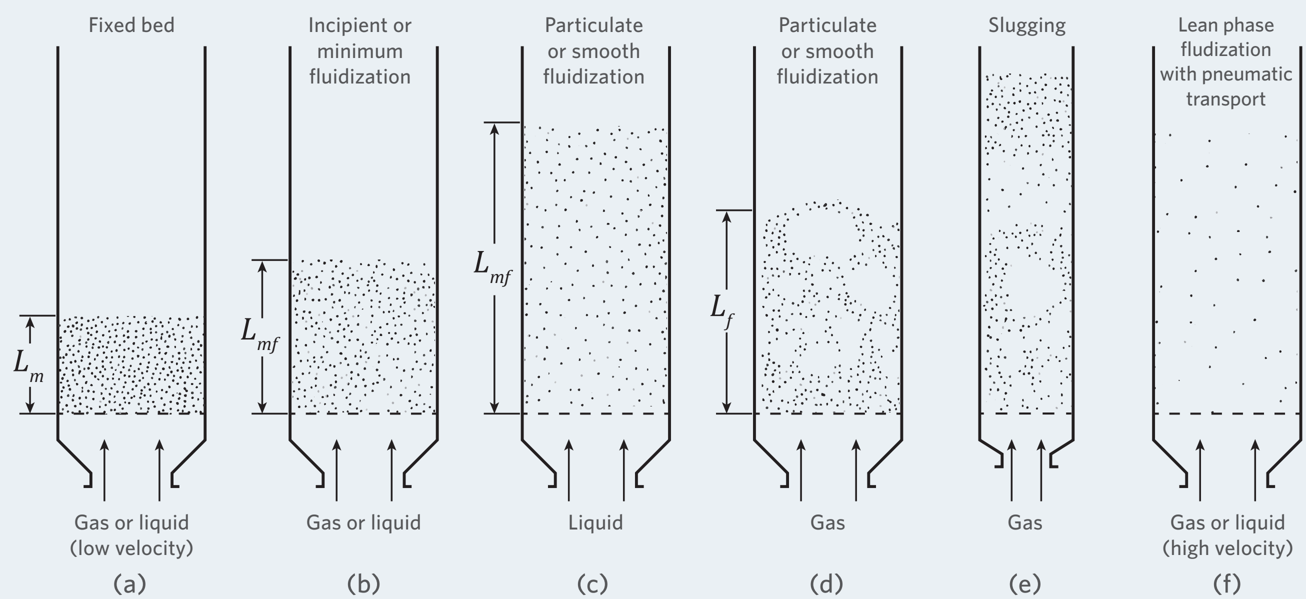

FIGURE 1. *Various forms of gas/solids contacting*

beneficial in reducing fines loss in the DRI plant's top gas thanks to a reduction in top gas velocity. Also, it is sometimes said that high pressure DRI processes perform better than the MIDREX Process with respect to fines entrainment. But is this true?

The following article *(Part 1 of a two-part series on the effects of system pressure on the operation of direct reduction processes)* analyses the theory of fines entrainment to assess how pressure affects the entrainment phenomena and to compare the performance of the MIDREX Process and high pressure DRI processes with respect to fines loss via the top gas.

THEORY OF PARTICLE CARRY-OVER

If a gas passes at a low flow rate upward through a fixed bed of particles, where the particles are solidly packed, it simply flows through the void spaces between stationary particles, as shown in ***Figure 1.a.*** [1]

If the fluid passes upward through a bed of particles with an increasing flow rate, the transition to an expanded bed occurs. In this condition, the particles move apart, a few vibrate and move in restricted regions. [1]

Finally, at even higher velocity, the fluidization, which is the condition where all the particles are just suspended by the upward-flowing gas, starts when the frictional force between particles and fluid counterbalances the weight of the particle bed: [1]

1) $F_D = W_B$

Where:

F_D = drag force is the frictional force imposed by the gas on the particles bed

W_B = weight of particles bed

A bed that respects the above conditions is considered to be just fluidized and is referred to as a bed at minimum fluidization, as shown in ***Figure 1.b.*** [1]

The corresponding superficial gas velocity at incipient fluidization condition is known as gas velocity at minimum fluidizing conditions (umf) and can be found by re-arranging equation 1, as shown by Kunii & Levenspiel , 1969 [1]:

If ε_{mf} and/or ϕ_s are unknown, Wen and You expression, as stated in Kunii & Levenspiel , 1969 (1), can be used to find u_{mf} .

$$2)\quad F_D = \frac{1.75}{\varphi_s \varepsilon_{mf}^{\ 3}}\left(\frac{d_P u_{mf} \rho_g}{\mu}\right)^2 + \frac{150(1-\varepsilon_{mf})}{\varphi_s^{\ 2} \varepsilon_{mf}^{\ 3}}\left(\frac{d_P u_{mf} \rho_g}{\mu}\right) = W_B = \frac{d_p^3 \rho_g (\rho_S - \rho_g) g}{\mu^2}$$

3) $$\frac{1}{\varphi_s {\varepsilon_{mf}}^3} \cong 14 \ and \ \frac{(1-\varepsilon_{mf})}{{\varphi_s}^2 {\varepsilon_{mf}}^3} \cong 11$$

Where:
ϕ_s= sphericity of a particle, dimensionless;
ε_{mf}= void friction in a bed at minimum fluidizing conditions;
d_p=particle diameter based on screen analysis, m;
u_{mf}=superficial gas velocity at minimum fluidizing conditions, m/s;
ρ_g= gas density, kg/m^3
ρ_s= particle density, kg/m^3
μ= viscosity of gas, kg/m-s

For larger particles (Re_p>1000) is obtained:

4) $$u_{mf}^2 = \frac{d_P(\rho_s - \rho_g)g}{24.5\rho_g}$$

When gas velocity increases right above the minimum fluidization velocity (umf) expansion of the bed starts to occur smoothly, as shown in ***Figure 1.c.*** A bed in this condition is called a smoothly fluidized bed or liquid fluidized bed because expansion of the particles bed occurs progressively with small instabilities and low bubbling phenomena. When gas velocity increases well beyond the minimum fluidization, bubbling and channeling phenomena start to occur causing large instabilities. In these conditions the bed, which is called aggregative fluidized bed or bubbling fluidized bed, does not expand much beyond its volume at minimum fluidization, as shown in ***Figure 1.d.*** [1]

When gas flowrate increases enough to exceed the terminal velocity of the solid particles (u0>uT), the upper surface of the bed disappears and entrainment becomes appreciable. This state is represented in ***Figure 1.f*** and is named disperse-, dilute-, or lean-phase fluidized bed where, pneumatic transport of solids phenomena occurs. [1]

All the above can be summarized, as shown in ***Figure 2.*** As mentioned in the introduction, the process of interest is the particles entrainment, as this can affect plant OPEX. The effect of pressure on particles entrainment, as well as a comparison of MIDREX Process entrainment versus high-pressure DRI process entrainment (on furnace top gas) is given in following paragraphs.

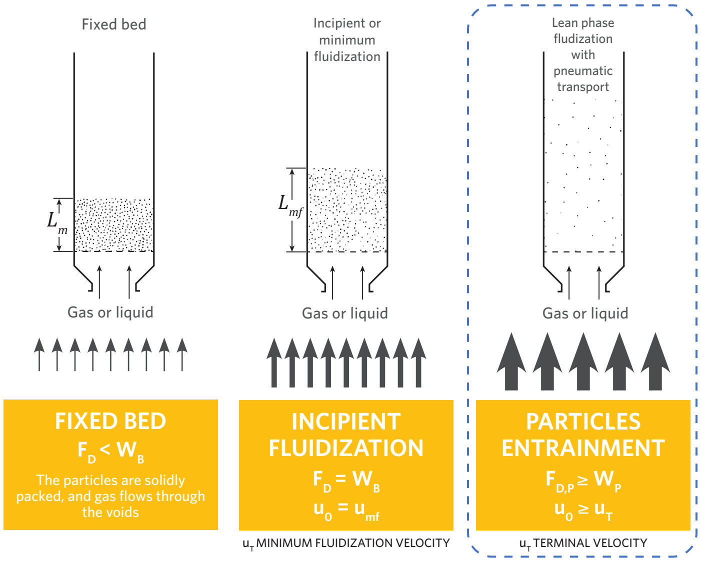

FIGURE 2. *Force balance on a single particle and Drag Force/ Gravitational Force relation for different beds (FD,P = Drag Force on single particle)* [2] [1]

PARTICLE ENTRAINMENT: TERMINAL VELOCITY

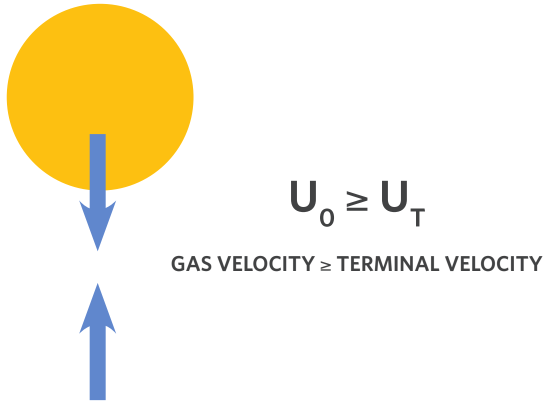

FIGURE 3. *Particle entrainment: Terminal velocity on a particle*

For a particle to be carried-over from a bed, the local gas velocity needs to exceed the particle's terminal velocity. This is defined as the lowest gas velocity that causes particles to start moving with the gas. By changing the reference system, the terminal velocity may be also defined as the speed at which a free-falling particle is no longer accelerating ***(see Figure 3)***. It is extremely important to remember that the terminal velocity is a property of the particle into its surrounding fluid environment! It is NOT a property of the moving fluid!

By going into the detail when a particle of size dP falls through a fluid, its terminal velocity can be estimated from fluid mechanics by the expression (1) opportunely referred to single particle. This leads to equations 5 and 6:

5) $$F_{D,P} = \frac{1}{2}\rho_G u_t^2 C_D A = \frac{1}{6}\pi d_P^3 \rho_P g = W_P$$

6) $$u_T = \left[\frac{4d_P(\rho_S-\rho_g)g}{3\rho_g C_D}\right]^{1/2}$$

One way to find u_T under the hypothesis of spherical particles is to use the following analytic expression for the drag coefficient CD:

7) $$C_{D,spherical} = \frac{24}{Re_P} \quad for\ Re_P < 0{,}4$$

8) $$C_{D,spherical} = \frac{10}{Re_P^{1/2}} \quad for\ 0{,}4 < Re_P < 500$$

9) $$C_{D,spherical} = 0{,}43 \quad for\ 500 < Re_P < 200000$$

Terminal velocity can then be calculated, replacing these values of CD in Eq.6:

10) $$u_{T,spherical} = \frac{g(\rho_S - \rho_g){d_P}^2}{18\mu} \quad for\ Re_P < 0{,}4$$

11) $$C_{D,spherical} = \frac{10}{Re_P^{1/2}} \quad for\ 0{,}4 < Re_P < 500$$

12) $$u_{T,spherical} = \left[\frac{3.1\ g\ (\rho_S - \rho_g)d_P}{\rho_g}\right]^{1/2} \quad for\ 500 < Re_P < 200000$$

In order to assess the effect of pressure on the terminal velocity, we assumed a typical MIDREX top gas composition and temperature, as well as typical IO pellet data (average size, sphericity, particle density, void fraction); we have calculated the resulting terminal velocity by varying pressure in the range between 2 bar-A and 7 bar-A . The result is shown in *Figure 4*.

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Note: ***Figure 4*** focuses on 2mm particles. As explained before, MIDREX Plants typically cut-point size is at 3 mm. ***Figure 5*** shows three different pellets particle size analysis where the percentage of particles below 5 mm is around 1%. By considering only the particles below 2mm and the screening efficiency, this value can be further reduced.

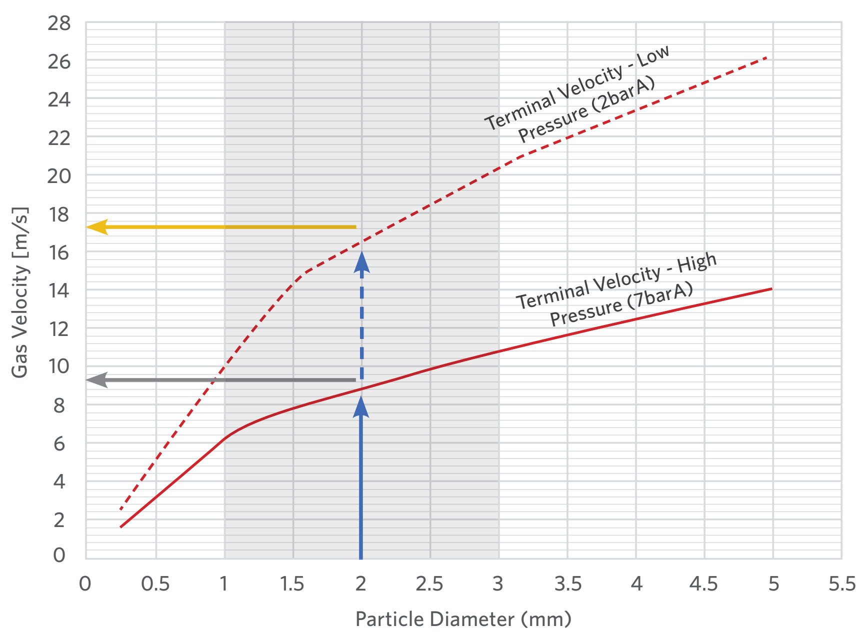

FIGURE 4. *Influence of pressure on Terminal Velocity at different particle diameters*

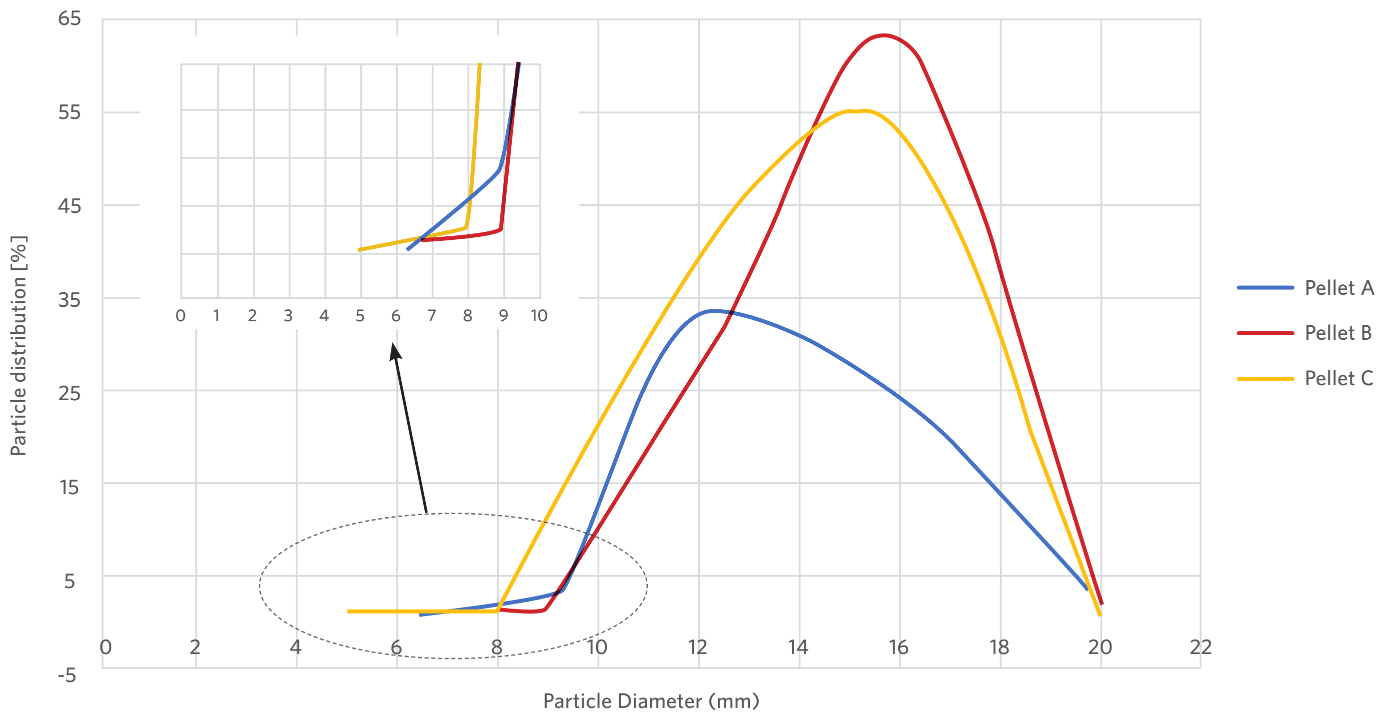

FIGURE 5. *Particle size analysis for three different pellets* [3]

Therefore, 2mm represents a sensible value to evaluate entrainment threshold.

As can be seen, particle terminal velocity decreases with a rise in operating pressure and this decrease becomes more significant for larger particles. The main reason behind this is due to increase of gas density with increase of pressure.

Terminal velocity represents the threshold that operators do not want to overcome, as overcoming means entrainment. Obviously the higher the threshold the lower the margin towards entrainment.

If one considers a reactor filled exclusively with 2 mm diameter particles, entrainment starts with a gas velocity of approximately 9 m/s when the reactor is operated at high pressure. In the same reactor, when it is operated at lower pressure level, the same 2mm particles are entrained at much higher gas velocity, approximately 17 m/s. It is then true that high operating pressure implies lower gas velocities. But it is also true that entrainment starts at lower terminal velocity. The process with high pressure (and lower gas velocity) must be compared with a much more stringent limitation (lower terminal velocity) as gas becomes denser.

Another important fact to be considered when comparing the entrainment of the MIDREX Process and the high pressure process is that they are characterized by different furnace diameters, different specific flowrates, and different gas compositions and temperatures. If we imagine two plants (one MIDREX, one using the high pressure process) with the same production level, the MIDREX Plant is characterized by larger furnace diameter, lower specific flowrates, and lower gas temperatures. This means that the reduction of gas velocity one might expect by increasing pressure level is actually much lower in the high pressure process due to reduction of furnace free section and increase of specific flow-rate.

Therefore, if we aim to compare the entrainment of the two processes, a comparison should be done by incorporating all involved variables (by keeping same production level).

It is of particular interest to compare the two processes by making use of the following ratio:

$$Gas\ Velocity\ Margin = \frac{Particle\ Terminal\ Velocity\ u_T}{Gas\ Mean\ Actual\ Velocity\ u_{0,mean}}$$

Gas velocity margin > 1 means that there is not carry-over of particles. The threshold for carry-over is at gas velocity margin = 1, so it is of interest to operate a plant well above 1.

By considering the actual top gas composition, temperature, specific flowrate, and furnace diameter for both MIDREX and the high pressure process, the following plot has been realized ***(see Figure 6).***

There are two immediate outcomes from the analysis of ***Figure 6.***

1. Both processes have gas velocity margin well above 1 for particles with diameter bigger than or equal to 2mm, which means that carry-over phenomena could be widely averted.
2. By looking closer to the largest particle that the two processes can entrain, it is noted that there are not significant differences for an industrial application ***(see Figure 7):***

Previous point number 1; i.e., the theoretical statement that MIDREX Process is designed with safe gas velocity margins for 2mm particles, is confirmed by a particle size analysis carried out on sample collection at the process classifier of one commercially operated MIDREX DRI Plant (as per construction features of the plant, the largest entrained particles are collected at the process classifier). The experimental data confirm the theoretical calculation: the size analysis result is that more than 92% of the particles of the sample are below 2mm in diameter, as confirmation of the above chart. Same values are confirmed by the article published by Lohmeiere et al. [4]. Nevertheless, a small fraction above 2mm is found to be entrained by the top gas. What is the reason behind this slight deviation between theoretical and experimental results?

We must remember that the theoretical analysis has been done considering a perfect, uniform gas distribution, considering the

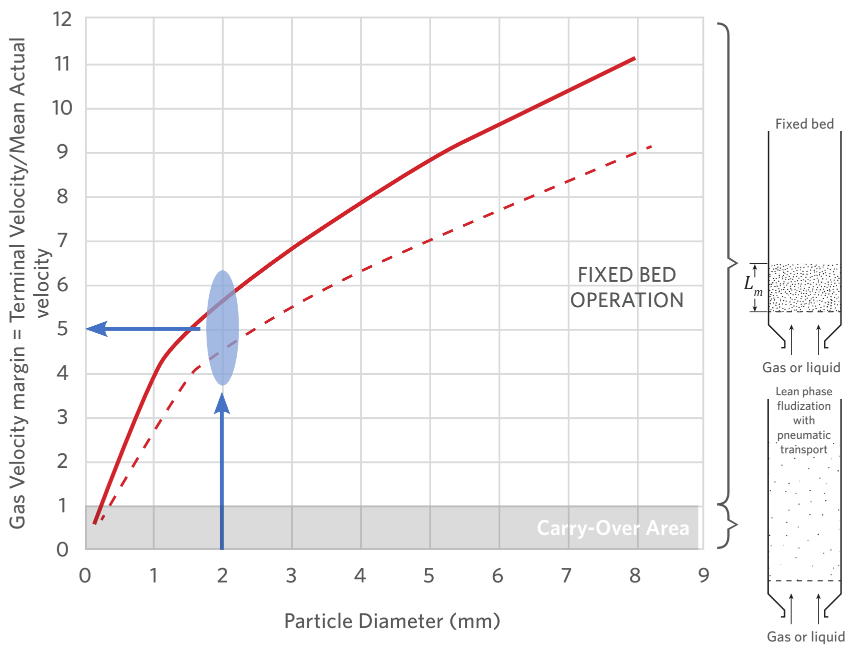

FIGURE 6. *Influence of pressure on particle carry-over at different particle diameters*

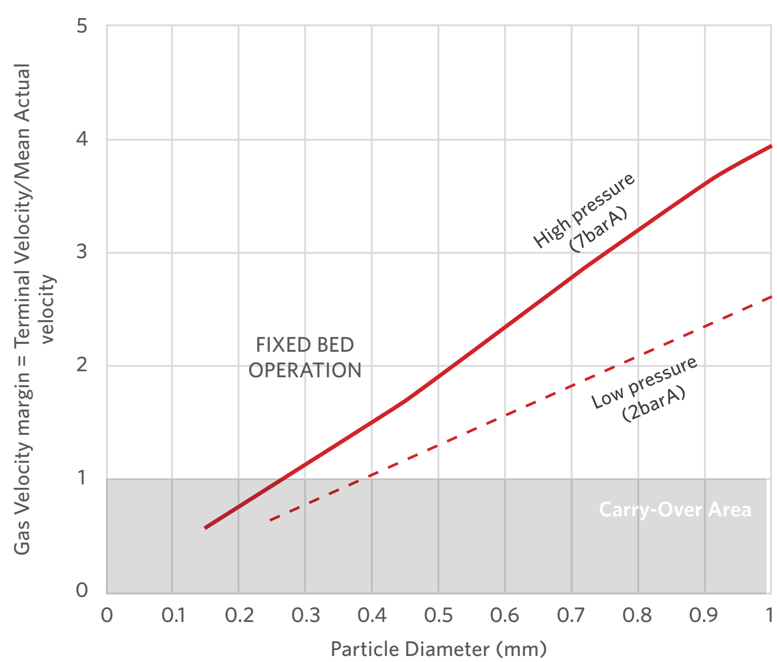

FIGURE 7. *Visualization of the largest particles that the two processes can entrain – negligible difference for an industrial application*

average gas velocity. In reality, gas velocities may be higher than the average superficial gas velocity due to inhomogeneous material distribution inside the furnace. If the material is charged inside the vessel in a non-homogeneous way, velocity peaks may occur. In the presence of velocity peaks, the particles entrained are larger than the ones theoretically entrained when considering the average velocity.

Figure 8 shows how the material charging system can qualitatively affect material distribution inside the furnace and gas velocity peaks formation.

MIDREX Shaft Furnaces, as explained in following paragraph, are characterized by an IO pellets charging system shown in the left side of *Figure 8:* material is homogeneously distributed inside the furnace and velocity peaks are therefore limited.

On the other side, the high pressure process uses mechanical sealing for pressurization/depressurization from atmosphere (see following paragraph), with a lower number of charging points.

The following conclusion can be reached:

1. MIDREX Process has limited deviation from ideal homogeneous gas distribution; velocity peaks are limited, and the largest entrained particle will be similar to the one calculated theoretically.
2. High pressure process is further to the ideal gas distribution. There are stronger velocity peaks, and particles entrained will be significantly larger than the ones theoretically calculated.

FINES GENERATION AT FURNACE CHARGING

As we have seen in the previous discussion, the two processes have comparable carry-over potential. Therefore, the key factor for fines losses will be fines generation, which might sound obvious but non-generated fines will not be entrained!

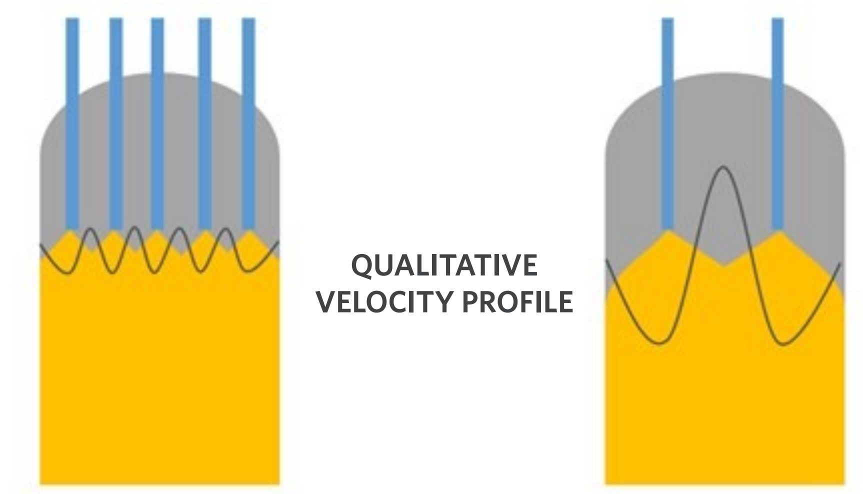

FIGURE 8. *Material charging system influence on gas velocity profile (MIDREX left, high pressure process right).*

Besides the intrinsic characteristics of the charged material, furnace charging and sealing systems play a major role on fines generation (***Figure 9)***.

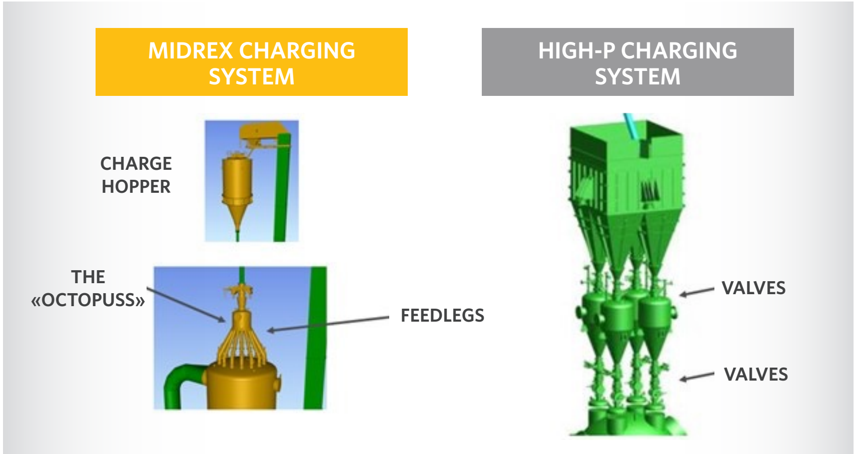

FIGURE 9. *3D view of a comparison between MIDREX charging system and high pressure charging system*

MIDREX Shaft Furnaces are characterized by IO pellets charging system where seal legs and feed legs connect the furnace charge hopper to the reduction furnace. These are designed to prevent segregation of material and to uniformly distribute the incoming material in the reduction furnace. Each feed leg receives an equal quantity of oxide and the multiple charging points guarantee even bed distribution. This feeding system has been proven extremely effective in ensuring uniform particle size distribution, uniform stock line profile, and in the end, an uninterrupted and gentle material descent from top to bottom. [5]

On the contrary, high pressure charging systems manage high operating pressure through use of mechanical sealing for decoupling from atmosphere. The high pressure lock hoppers lead unavoidably to a discontinuous material charge with uneven bed distribution because of the limited number of charging points. Additionally, because of the nature of the high pressure charging system, particles are subject to falls and interruptions that generate fines production.

Therefore, the MIDREX Process and its equipment guarantee a more uniform stock-line profile (lower velocity peaks, as explained before) and less intrinsic fines generation compared to the high pressure process.

REAL CUSTOMER EXPERIENCE

A comparison between MIDREX Plants and high pressure process plants, from real customer experience, is shown in ***Table 1.*** One overall fines comparison has been carried-out on the clarifier sludge annual quantity from two plants operated by the same owner/company, with the same iron oxide quality, one MIDREX, one the high pressure process.

	MIDREX® Technology	High Pressure Technology
DRI CLARIFIER SLUDGE [kg/tDRI]	20.4	28.3

TABLE 1. *DRI clarifier sludge data from two comparable plants (MIDREX vs high pressure)*

The results of the comparison leads to a 28% higher clarifier sludge quantity in the high pressure plant.

CONCLUSION

This paper treated the theory of particles entrainment, as well as discussed the different variables characterizing the MIDREX and the high pressure process with respect to particles entrainment.

Main takeaways:

- Increasing pressure reduces gas velocity but increases gas density. The apparent benefit of pressure rise is balanced as the terminal velocity lowers (or the drag force rises) due to gas density increase.
- The reduction of gas velocity, thanks to higher pressure, is offset in high-pressure process plants by:
  - Lower furnace section
  - Higher specific gas flow-rate
  - Higher temperatures
- MIDREX Technology is characterized by more favourable solids distribution in the furnace: uniform stock-line profile and lower chance of velocity peaks.

The MIDREX Process and the high pressure process have comparable entrainment capacity. However, MIDREX Technology has a much lower tendency to generate fines in the furnace charging section. By having the same entrainment capacity but a significant difference in fines generation at charging, the high pressure process is expected to lose more fines in the furnace top gas. This is confirmed by the plant data shown in ***Table 1***.

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ALGERIAN-QATARI STEEL (AQS)

AT FIRST GLANCE

By ENG. MOHAMED EL SAYED,
DRP Acting Manager

INTRODUCTION

Algeria, by its geographical location, is a gateway to Mediterranean Europe and the MENA (Middle East & North Africa) Region. Algeria enjoys natural benefits that include climatic diversity, mineral resources, and agricultural land, as well as specialized and skilled labor, which together provide investment opportunities in various sectors such as mining, medicine, tourism, industry, and agriculture.

Today, Algeria is home to the Arab Iron and Steel Union (AISU) and the location of the two largest capacity direct reduction (DR) plants in the world, both based on MIDREX® technology: Algerian Qatari Steel (AQS) in Bellara Industrial Zone (El-Milia) near Jijel in the east and Tosyali Algeria at Bethioua (Oran) in the west. Both companies are embarking on expansion projects that will include the installation of an additional direct reduction plant equipped for on-demand production of hot DRI (HDRI) and cold DRI (CDRI) plus an insulated conveyor system to transport HDRI to the EAF steel shop.

This article will take a closer look at what makes Algeria ideal for DRI-EAF steel production, the origin of AQS, the results of the first full year of DRI-based steel production, and future plans of AQS.

THE RISING STAR IN DRI PRODUCTION

The following main reasons make Algeria attractive for iron and steel investments:

1. Political stability boosts the confidence of foreign investors
2. Availability and pricing of natural gas and electricity, which are among the lowest in the world
3. Strong governmental policies favoring the industrial sector
   - Reserving natural gas for national industry development
   - Strong bilateral trade agreements and incentives

Moreover, after the Gara Djebilet iron ore deposit in Tindouf Province development, Algeria will be one of the lowest cost DRI producers in the world (iron oxide pellets typically make up 80 -90 % of DRI OPEX).

ALGERIAN-QATARI STEEL (AQS)

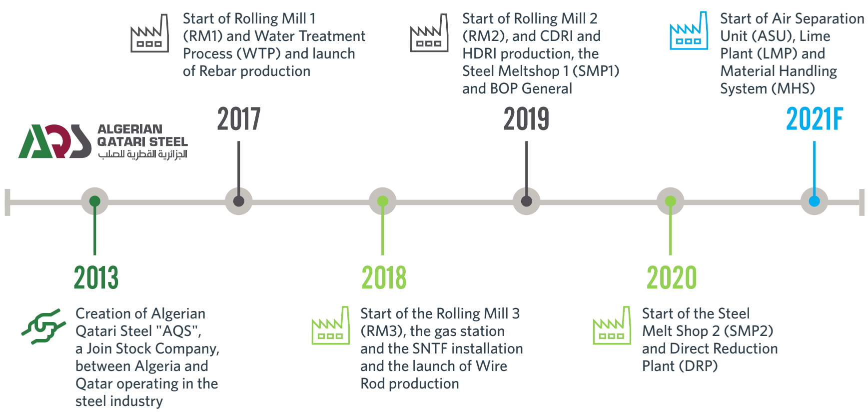
AQS was established in December 2013 as a joint venture between Qatar Steel International (49%), SIDER Investment Group (46%), and the Algerian National Investment Fund (5%). The relations between Algeria and Qatar are long-standing and growing, highlighted by decades of co-operation and synergy in economy and trade, industry, energy, mining, agriculture, and social and political initiatives.

AQS operates a 2 million metric tons per year (Mt/y) steel mill in the industrial zone of Bellara, in El-Milia, an administrative district of Jijel, located 400 km from the Algerian capital, Algiers. The steel complex occupies a total area of 216 hectares (> 553 acres) and includes these main production units:

- MIDREX Direct Reduction Plant – production capacity of 2.5 Mt/y HDRI and CDRI
- Two 120-ton EAFs – total production capacity of 2.2 Mt/y
- Three rolling mills – total production capacity of 2 Mt/y of reinforcing bars and wire rod

Supporting these production units are an industrial gas plant, lime production unit, station for receiving & transporting raw materials, water treatment plant, and electrical substation.

The AQS project was launched in March 2015, and the first rolling mill (for reinforcing bars) and the water treatment plant began operation in 2017. The complex continued to take shape in 2018, with start-up of a second rolling mill (for wire rods) and the industrial gas plant and SNTF (The National Rail Transportation Company) installation between the plant and Djen Djen international Port. In 2019, the third rolling mill and the first EAF were put into service. The second EAF and the MIDREX Plant were started up in end of 2020, followed in 2021 by the air separation plant, lime plant, and the materials handling system.



Timeline: AQS production units launching schedule

AQS MIDREX COMBINATION (CDRI-HDRI) PLANT

Midrex Technologies, Inc. and Paul Wurth were contracted in 2016 to supply a 2.5 million tons/year direct reduction plant (DRP) capable of producing both CDRI and HDRI.

Main Features:

- World's largest combination HDRI/CDRI plant
- 7.65 meters diameter MIDREX MEGAMOD® furnace
- 8 rows x 18 bays MIDREX Reformer
- 312.5 t/h HDRI transported by insulated metallic conveyor at 650° C
- Switch to 100% CDRI when HDRI is not required

First product was produced by the DRP in February 2021, HDRI was charged to the EAF in March 2021, and hourly design capacity (312 t/h) was achieved in September 2021. AQS was operating at 9% over design capacity by March 2022.

During 2022, 74% of total production (1.7 million tons) was HDRI, which had a remarkable positive impact on DRI costs, as will be discussed in the following section. DRI production (CDRI and HDRI) in 2022 was based on melt shop demand.

HDRI TRANSPORTING & FEEDING SYSTEM

The AQS DRP is equipped with an enclosed and insulated metallic conveyor capable of feeding HDRI at up to 312.5 tons per hour according to melt shop demand. The HDRI reaches the EAF at 650° C, and direct charging to the EAF ensures there are no fugitive dust emissions.

The transporting & feeding system is designed so HDRI and CDRI can be mixed at the discretion of the melt shop or HDRI can be diverted to a product cooler and stored as CDRI according to melt shop requirements. During 100% HDRI production, some "trickle discharge" is maintained to avoid static DRI at the product cooler.

Figure 1 shows the product discharge arrangements that allow AQS to produce HDRI and CDRI from the same shaft furnace.

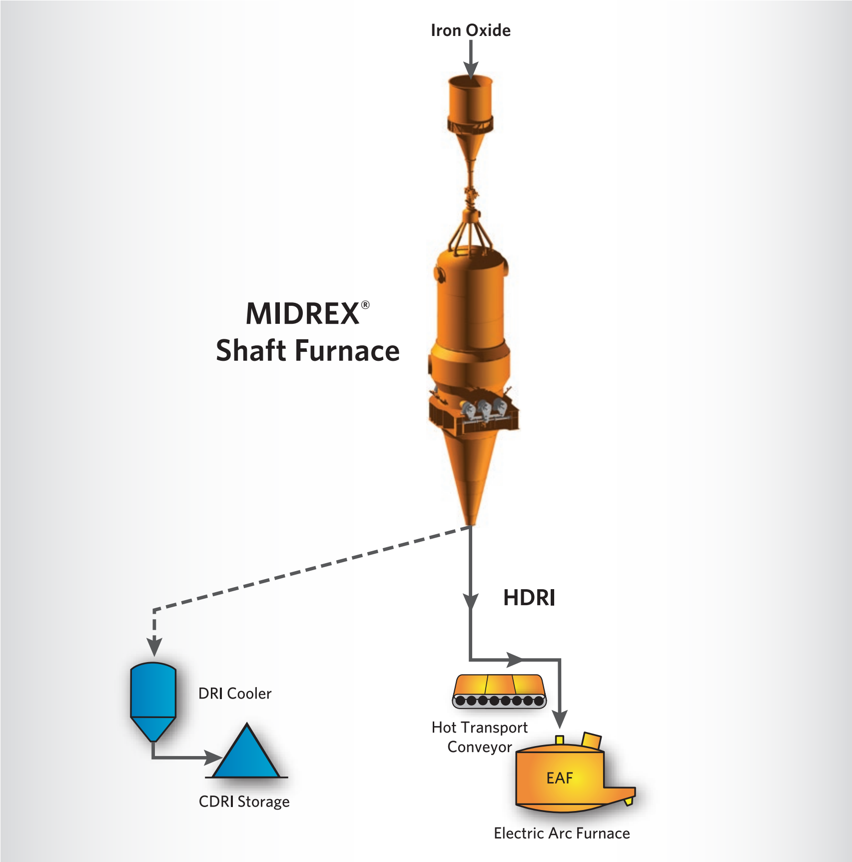


FIGURE 1. *Reduction furnace product discharge options*

GAINS ACHIEVED BY HDRI FEEDING SYSTEM – DRP

During Y-2022, AQS DRP increased plant yield by reducing the major raw material ratio (MRMR) due to the following, as shown in ***Figure 2***:

- No fines/dust carryover to the cooling gas system
- No losses from CDRI handling (product fines charged to EAF along with HDRI)

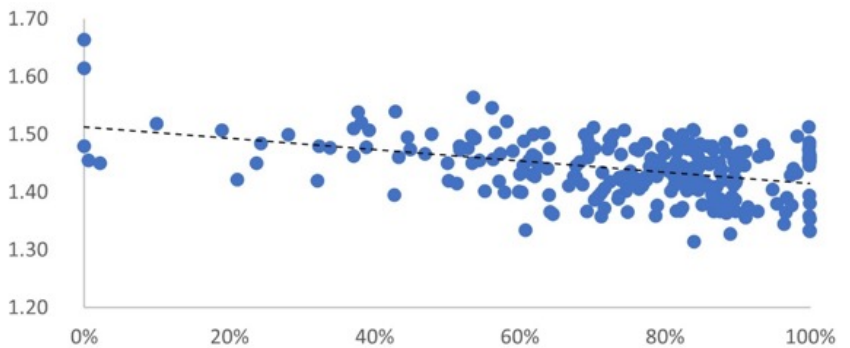


FIGURE 2. *Daily average MRMR (iron oxide/product) with different HDRI ratios*

During the same period, natural gas consumption was reduced due to stoppage of cooling gas recycle (no in situ natural gas), as shown in ***Figure 3***.

Daily average electricity consumption by the DRP was reduced because the cooling gas compressor and the CDRI handling conveyor and product screen were not needed (due to 100% HDRI charging), as shown in ***Figure 4***.

Ultimately, product quality was improved including a remarkable gain in carbon content compared to CDRI, as shown in ***Figure 5a*** and ***Figure 5b***.

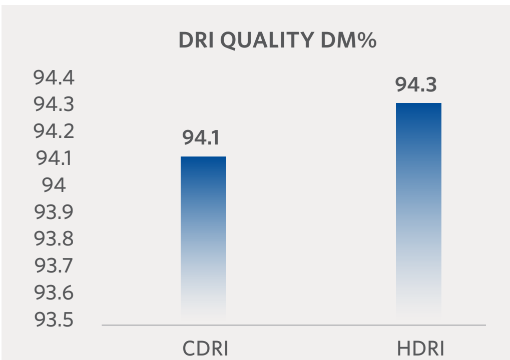


FIGURE 5a. *DRI % metallization HDRI vs CDRI*

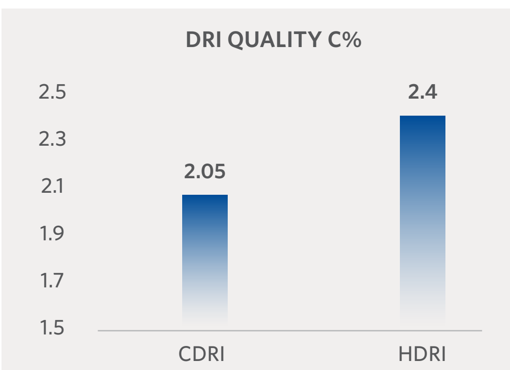
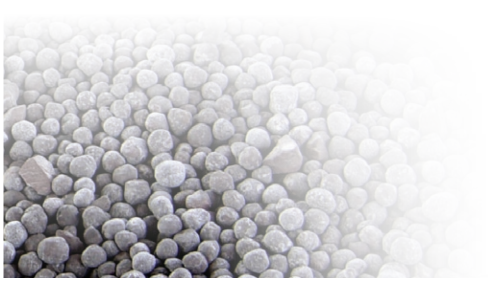


FIGURE 5b. *DRI % carbon HDRI vs CDRI*



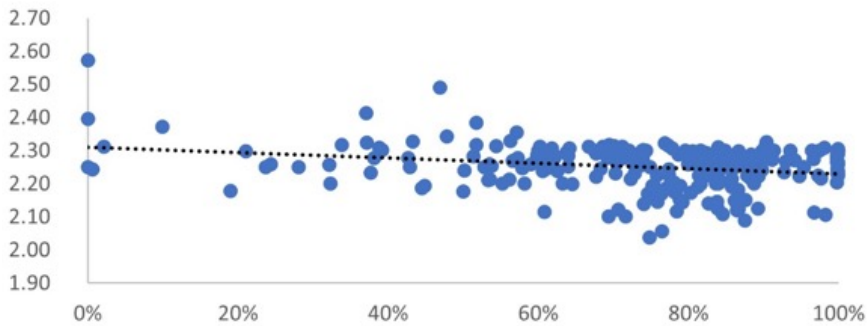


FIGURE 3. *Daily average NG consumption Gcal/TDRI with different HDRI ratios*

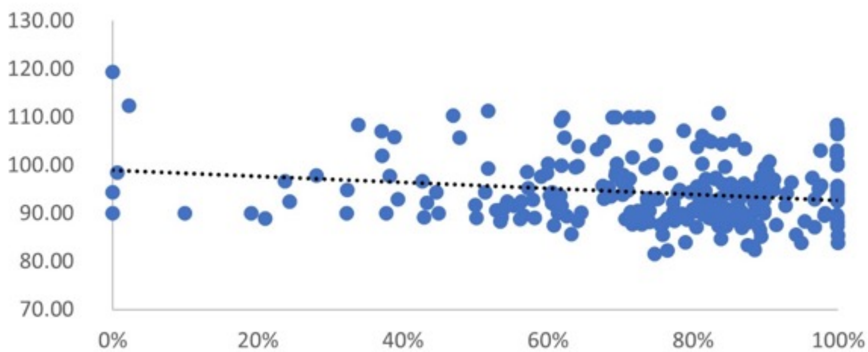


FIGURE 4. *Daily average electricity consumption Kw/ton DRI with different HDRI ratios*

GAINS ACHIEVED BY HDRI FEEDING SYSTEM – MELT SHOP

The AQS melt shop recorded significant operational gains attributed to the HDRI feeding system, as shown in ***Table I***):

- Lower specific electricity consumption, increased productivity due to shorter tap-to-tap times
- Less electrode and refractory consumption due to shorter overall melting cycle

The savings in electricity, natural gas, and raw material by the DRP and the Melt Shop were approximately 15 USD/ TMS, and the additional 360,000 tons of liquid steel when using 100% HDRI vs 100% CDRI .

EAF METALLIC CHARGE

	100%CDRI	100%HDRI
Power on time (min)	47	33
Energy consumption (Kw/ton)	580	439
Injected carbon (Kg/ton)	16	13
Oxygen consumption (Nm^3/ton)	27	22
Lime consumption (Kg/ton)	41	40
Dolomite consumption (Kg/ton)	50	49

TABLE I. *Comparison of operating with 100% HDRI vs 100% CDRI*

The savings in electricity, natural gas, and raw material by the DRP and the Melt Shop were approximately 15 USD/ TMS, and the additional 360,000 tons of liquid steel when using 100% HDRI vs 100% CDRI .

GUIDELINES FROM LESSONS LEARNED

Because the DRP operates continuously and the EAFs have a batch operating pattern, close coordination between the DRP and melt shop teams is essential to achieve the maximum benefits from feeding HDRI. A smooth switch between HDRI and CDRI discharge patterns to meet melt shop demands and maintain productivity rates. Also, long periods of inactivity in CDRI discharge allows the cooling gas scrubber packing to become fouled from scaling.

AQS has adopted the following guidelines from their operating experience:

1. When the melt shop can take entire HDRI production, CDRI is stopped and "trickle discharge" is directed to the product cooler to avoid a static bed inside the cooler, as follows:

DAY NO.	INTERVALS	DISCHARGE DURATION	DISCHARGE RATE	QUANTITY/DAY
First day	Each 4 hours			20 tons/days
Second day	Each 8 hours	5 minutes	40 ton/hr.	10 tons/days
Third day and cont.	Each 12 hours			6.5 tons/days

2. When the cooling gas compressor is stopped for an extended period, scale inhibitor and biocide doses to the cooling gas scrubber must be adjusted.

AQS EXPANSION PLANS

On November 1, 2022, the Emir of Qatar, Amir Sheikh Tamim bin Hamad Al-Thani, and the president of the People's Democratic Republic of Algeria, Abdelmadjid Tebboune, attended the official inauguration of the AQS steel plant. The intention to expand the steel complex to 4 Mt/y of steel and 5 Mt/y of DRI was announced during the ceremony.

AQS has started the expansion process by launching a tender for selecting an external consulting firm to prepare the feasibility study for extending the existing steel complex in the Bellara Industrial Zone (Phase II) and to determine whether AQS will launch any new steel products as part of the expansion project.

The expansion project is expected to be completed by the end of 2025 or early 2026.

Shown in the photo are the Emir of Qatar, Amir Sheikh Tamim bin Hamad Al-Thani, the president of the People's Democratic Republic of Algeria, Abdelmadjid Tebboune, as well as the AQS Board of Directors.

Midrex News & Views

The full news articles are available on **www.midrex.com**

Midrex Participates In White House Roundtable

On Friday, March 3, Midrex President & CEO Stephen C. Montague joined executives from the industrial private sector, labor leaders, and government officials to explore ways for the United States to take a leading role in expanding the global clean energy economy. The White House Roundtable Discussion focused on how public and private investments, when paired with new programs under the Inflation Reduction Act and Bipartisan Infrastructure Law can quicken the pace of industrial decarbonization and increase American competitiveness.

Montague said favorable government policies toward green electricity, hydrogen production, and carbon capture, utilization and storage (CCUS) provide unique opportunities to create American jobs by building new DR plants to produce green iron for use at home and abroad.

Midrex Names K.C. Woody President & COO

Midrex Technologies, Inc. (Midrex) has announced that Stephen Montague, current President and Chief Executive Officer (CEO) will retire in April 2024. K.C. Woody will be promoted to president effective immediately and maintain his current role as chief operating officer (COO). Stephen Montague will remain as CEO until his retirement and then continue to serve on the Board of Directors.

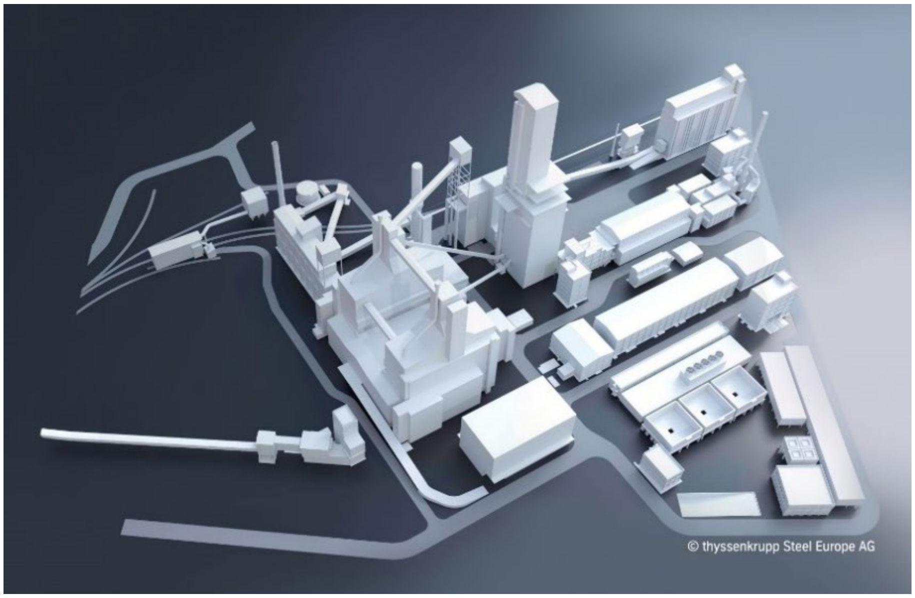
Woody joined Midrex in 2010 and has served in a variety of commercial roles including the first Managing Director of Midrex India Private Limited and Vice President-Commercial of Midrex Technologies, Inc. In 2020, he was named COO, leading all the commercial and operations activities for the company.

Woody is a graduate of the U.S. Military Academy at West Point and served on active duty as an officer in the US Army prior to Midrex.

Midrex News & Views

The full news articles are available on **www.midrex.com**

thyssenkrupp Steel selects MIDREX Flex™ For Immediate CO_2 Reduction



(Pictured left: 3D model of planned thyssenkrupp Steel Duisburg plant complex – courtey of thyssenkrupp Steel)

The hydrogen-based DRI plant is a major step in thyssenkrupp's conversion of its integrated steelworks to a climate-neutral production site.

Midrex Technologies, Inc. and Paul Wurth will partner to engineer, supply, and construct a 2.5 million tons/year MIDREX Flex™ direct reduction plant for thyssenkrupp Steel Europe AG at its Duisburg, Germany, site. The plant will initially operate on reformed natural gas, which contains 50% or more hydrogen (H_2) at the inlet to the furnace, until sufficient H_2 is available, at which time it will be transitioned to up to 100% H_2 operation. Furthermore, the direct reduction plant will be combined with advanced SMS group melting technology to significantly increase operating efficiency and reduce CO_2 emissions by more than 3.5 million tons per year. Plant start-up is planned for end of 2026.

MIDREX Flex technology provides the flexibility to operate on different ratios of natural gas (NG) and hydrogen (H_2), up to 100% H_2. It will allow thyssenkrupp to use natural gas, which already provides significant CO_2 savings over the conventional coke oven-blast furnace ironmaking route, until H_2 is available in sufficient quantities, which is expected in 2027.

Midrex News & Views

The full news articles are available on **www.midrex.com**

MIDREX® Plants with 1Q Anniversaries

Midrex is known for designing, engineering, and servicing reliable direct reduction plants, as well as for making certain that these plants have long and successful operating lives. This issue of *Direct From Midrex* recognizes the start-ups of Hadeed A (Saudi Iron & Steel Company) in Al Jubail, Saudi Arabia (40 years) and SULB in Hidd, Bahrain (10 years).

Hadeed A (Saudi Iron & Steel Company)

Started up 40 years ago in the 1st Quarter
Location: Al Jubail, Saudi Arabia
DR plant: MIDREX® (I of 4 modules)

- Start-up: March 1983
- Flowsheet: MIDREX NG™
- Product: CDRI
- Capacity: 0.4 M tons

Hadeed (Saudi Iron and Steel Company) is a fully-owned affiliate of Saudi Basic Industries Corporation (SABIC). It began operating in 1979 and added two MIDREX® DR Modules in 1982-83 (Hadeed A & B), a third in 1992 (Hadeed C), and a dual discharge HDRI/CDRI module (Module E) in 2007.

Hadeed A has produced more than 24.3 million tons of DRI since its original start-up. Although originally rated at 0.4 million tons/year, Hadeed A has averaged more than 0.6 million tons/year in its 40 years of operation. Two reformer bays were added in 1997, and thin wall refractory was installed in the shaft furnace in 2011.

Read more about Hadeed at:
http://www.hadeed.com.sa/

(Hadeed A & B shown in photo)

SULB

Started up 10 years ago in the 1st Quarter
Location: Hidd, Bahrain
DR plant: MIDREX®

- Start-up: January 2013
- Flowsheet: MIDREX NG™
- Product: HDRI/CDRI
- Capacity: 1.5 M tons

Foulath Holding Company BSC founded an iron ore pelletizing plant in Sidd, Bahrain, in 1984, and production started in 1989. A second pelletizing plant was added in 2010, and the name was changed to Bahrain Steel in 2013.

The decision was taken in 2009 to form SULB in cooperation with Yamato Kogyo Company Ltd (49% shareholder), as a steel production facility immediately adjacent to Bahrain Steel. Production began in 2012. SULB produces a range of steel products by the DRI-EAF (direct reduced iron-electric arc furnace) route and heavy and medium rolling mills.

SULB has produced almost 12 million tons of DRI since the MIDREX Plant was started up in January 2013. A hot DRI conveyor system was installed in August 2013. In 2021, SULB producing more than 1.5 million tons of DRI and operating in excess of 8100 hours.

Read more at:
https://www.sulb.com.bh/#!/home

Rogerio Valdejao Joins Midrex As Director– Global Business Development

ROGERIO VALDEJAO

Rogerio Valdejao has been hired as Director-Global Business Development to help build the team, processes, and business models to successfully grow new business for the long term. Valdejao has 30 years of international experience in sales, technical service, and product & market development in a variety of industries. His multi-cultural background has served him well in business assignments in the US, LATAM, and APAC.

Sean Boyle Promoted to Director – Plant Sales

SEAN BOYLE

Sean Boyle has been named to lead global plant sales for Midrex. Boyle, a mechanical engineering graduate of Virginia Tech, joined Midrex in 2013 and has served in various roles, most recently as Key Account Manager – North America and Europe. He was an integral part of the successful effort to secure the H2 Green Steel project.

Lauren Lorraine: Editor

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All references to tons are metric unless otherwise stated.

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