**HYL process for direct reduction of iron ore using an on-site nitrogen generator**

HYL process for direct reduction of iron ore

The HYL process is designed to convert iron ore (pellet/bulk ore) into metallic iron by using reducing gases in a solid gas moving bed reactor. Oxygen (O2) is removed from the iron ore by a chemical reaction based on hydrogen (H2) and carbon monoxide (CO) to produce highly metallized direct reduced iron (DRI)/hot briquetted iron (HBI). the HYL process is currently marketed under the "Energiron" trademark.

The HYL process for direct reduction of iron ore is the result of research work started by Hojalata y L.mina， S.A. (later known as Hylsa) in the early 1950s. After a preliminary evaluation of the concept， it was decided to install a process using a tunnel furnace， and several runs were made. The first one was carried out on July 5， 1950 by using an old furnace (an already built heating plate). A portion of crushed ore with a size of 12 mm to 25 mm was mixed with 40% coke and 15% limestone with the same granularity as the ore. This mixture was placed in a clay crucible and two iron tubes， each with a diameter of 100 mm and a length of 1 meter. Twenty kilograms of high quality DRI was produced.

The first gas-based plant， with a design capacity of 50 tons per day， was unable to achieve acceptable levels of metallization. During its 18 months of operation， it underwent several changes， including the installation of a gas reformer to improve the reducing gas. Finally， in early 1955， its operation was suspended. After this frustrating attempt， several experiments were conducted and a pilot plant was assembled to test new ideas. When this pilot plant was put into operation， it began successfully producing high-quality reduced iron at a rate of 30 tons per day. It soon reached a system production of nearly 60 tons per day.

With the successful production of direct reduced iron from the gas-based HYL direct reduction process， studies were initiated to design the first commercial plant with a capacity of 230 tons per day of DRI. The first industrial-scale direct reduction plant was commissioned on December 5， 1957.The Hylsa Monterrey 1-M plant was a fixed-bed reactor or intermittent process with an initial capacity of 75，000 tons of DRI per year.It continued to operate until 1991， just short of 35 full years of production.In 1978， the American Metals Council designated Hylsa 's HYL Process Plant 1-M as a historical milestone because it was the first successful industrial implementation of direct reduction ironmaking technology. However， the competitiveness of this technology was limited due to its batch nature.

By the end of 1970， total world DRI production in 1970 reached 790，000 tons， 680，000 tons of which were produced by the HYL process plant. However， HYL foresaw that the competitiveness of this technology would be limited due to its batch nature. For this reason， a research program was initiated in 1967 to develop a continuous (moving bed) process， and the first industrial plant was launched in May 1980 at Hylsa in Monterrey， Mexico， 23 years after the success of its first HYL plant. The new continuous vertical furnace process was called HYL III. The new process concept resulted in higher plant productivity， higher DRI quality， lower energy consumption and simpler plant operations.

The name HYL III was chosen to represent the third generation of HYL technology. The second generation (HYL II) is essentially a modification of the original fixed bed process designed to increase efficiency and reduce natural gas consumption. During the development phase of the process， two important modifications were made， namely (i) the use of high-temperature alloy tubes in the reduction gas reheater， allowing the gas to be heated to higher temperatures， and (ii) the reduction of the number of heater units from the original four to two. In the HYL II process， the reducing gas (rich in CO and H2) is produced by nickel-based catalytic reforming. However， the HYL II process was never commercialized because of the significant advantages offered by the advent of the HYL III process.

Since then， several improvements have been made in the HYL III moving bed process. 1986 saw the addition of a CO2 removal system to the reducing gas circuit， which led to significant improvements in productivity， energy consumption and DRI quality. The modification resulted in a reduction of gas consumption by about 50% and an increase in productivity of the shaft furnace by about 50%.

In 1995， partial combustion technology was incorporated into the HYL plant by injecting O2 into the transfer line between the reducing gas heater and the shaft furnace inlet. This option allowed a significant increase in reducing gas temperature and in-situ reforming. This reduced reforming gas consumption by about 25% and increased the productivity of the shaft furnace. in 1988， the total gas feed and O2 injection into the shaft furnace (reduction reactor) led to the "HYL self-reforming scheme" in which the reforming gas make-up was reduced to zero. This reformer less scheme was named HYL ZR process and was successfully applied at Hylsa 4M plant in April 1998 and at Hylsa 3M5 plant in July 2001.

The coating of spherical/bulk ore for direct reduction was introduced in 1988. 1993 saw the introduction of a pneumatic transport system (Hytemp technology) and hot DRI feeding to the EAF. 1994 saw the start of HYL production of high carbon (C) DRI with a C content of 3 to 5%. 1997 saw the commissioning of the world's first dual discharge (DRI and HBI) plant design.

During 2000， 100% of the lump ore was successfully used on a conventional basis. 2001 saw the introduction of a mini-module (200，000 tonnes/year) plant based on HYL's ZR (Zero Reformer) reformer-free technology. A HYL ZR process plant based on coal gasification and coke oven gas (COG) was also introduced. In addition， a single module DR plant with a design capacity of 2.5 million tons/year was offered during the year. Between the mini-module and the single module with a capacity of 2.5 million tons per year， modules with capacities of 500，000， 800，000， 1.2 and 1.6 million tons per year are also available.

The initial development work was done by Hylsa. in 1977， Hylsa established a new operating division (HYL technologies) for the purpose of formally developing and commercializing direct reduction technology. in 2005， Techint Technologies acquired HYL technologies. this division later became known as Tenova HYL In 2006， Tenova and Danieli formed a strategic alliance to design and build a gas-based direct reduction plant under the new "Energiron" trademark. Energiron is the innovative HYL direct reduction technology jointly developed by Tenova and Danieli， and derives its name from the unique DRI product that sets the technology apart from other existing processes.

Plant and equipment

The HYL direct reduction plant consists mainly of the following plants and equipment and their characteristics.

* A reduction shaft furnace housing a moving bed. This shaft furnace has a system for charging the iron charge and a product discharge system.
* A reducing gas circuit， consisting of a process gas heater， a top gas heat exchanger， a top gas quench/scrub unit， a reducing gas recovery compressor， a humidification tower and a knockout drum.
* The furnace is operated with minimal gas and water consumption and O2 injection.
* The product discharge system can have (i) a cooler for cold DRI production， (ii) a hot briquetter for HBI production， and/or (iii) a Hytemp pneumatic transport system to transfer the hot DRI directly from the shaft furnace to the electric arc furnace (EAF).
* An external cooling gas circuit， consisting of a quench/scrub unit and a cooling gas circulation compressor.
* A PSA (variable pressure adsorption) based adsorption system for the removal of carbon dioxide (CO2) from the reduction gas stream.
* Iron ore processing equipment， including iron ore sand silos， conveyors， screening stations， pellet coating systems， feed conveyors， and sampling and weighing units.
* DRI processing system， including conveyors and associated equipment for transporting cold DRI.
* Cooling towers， and filtration equipment and pumps.
* A process cooling water system， based on a closed loop to minimize water consumption， with clarifiers and settling tanks.
* A process control and instrumentation system， using distributed microprocessor-based controls.
* Substation， motors and lighting.
* An inert gas system usually based on nitrogen (N2).
* An air compressor

Process Description

The Energiron direct reduction process (HYL process) uses a shaft furnace reduction method to produce DRI. it is designed to convert iron pellets/bulk ore into metallic iron by using reducing gas in a solid gas moving bed shaft furnace. The O2 is removed from the iron ore by a chemical reaction based on H2 and CO to produce a highly metallized DRI.

The process flow diagram of the direct reduction method is shown in Figure 1.

Figure 1 Schematic diagram of the process flow of the direct reduction method

The main features of the HYL process include (i) utilization of H2-rich reducing gases with a ratio of H2 to CO exceeding 4， (ii) high reduction temperatures， typically exceeding 930 degrees C， and (iii) high operating pressures， typically between 5 kg/cm2 and 8 kg/cm2. Higher operating pressures have many characteristics including (i) lower gas velocities， (ii) lower drag forces， (iii) less dust carryover， (iv) lower ferrous material consumption， (v) higher plant capacity/size ratios， and (vi) lower power consumption due to lower compression factors. The high working pressure of the shaft furnace also leads to a productivity of the blast furnace of about 9 tons per square meter of area per hour.

The process can be flexibly produced in three different product forms， depending on the specific requirements of each user. The three forms of DRI are cold DRI， HBI or hot DRI ('Hytemp' iron). Cold DRI discharge is typically used in the melt shop of an adjacent steel mill close to the direct reduction plant. It can also be transported and exported as long as some procedures are followed and precautions are taken to avoid reoxidation. HBI is DRI discharged in hot condition， pressed into a block and then cooled. It is a commercial product， usually used for overseas export. Hytemp iron is DRI discharged hot， transported pneumatically from the DR plant to an adjacent steel smelter and fed directly into an electric arc furnace (EAF). Figure 2 shows the unloading scheme for these three products and the flow scheme for Hytemp iron.

Figure 2 Emission options for the three products and process scheme of the Hytemp iron system

The basic process configuration is characterized by the flexibility to handle different gas analyses. Reduction gas can be generated (i) directly in the shaft furnace by in situ conversion of natural gas; (ii) in an external natural gas/steam reformer; (iii) from the gasification of fossil fuels， biomass， etc. to produce syngas; (iv) from the exhaust gas of a smelting reduction process (e.g. Corex); or (v) from a coke oven gas (COG) source. In all cases， the process configuration corresponds to the same basic zero reforming scenario， adjusting the relative size of the equipment for the specific application. For the in-situ and steam reforming alternatives， gas analysis (heavy hydrocarbon content) is not a limiting factor. The "composition" gas can be a mixture of H2， CO， CO2 and hydrocarbons in any ratio.

One of the intrinsic features of the Energiron process is the selective elimination of by-products from the reduction process， namely water (H2O) and CO2， which are of great environmental importance. These by-products are eliminated by means of a top gas scrubbing and CO2 removal system， respectively. The selective removal of H2O and CO2 optimizes the recharge requirements. Water generated during the reduction process is condensed and removed from the gas stream， and most of the dust carried with the gas is also separated. The scrubbed gas is then passed through the process gas recirculation compressor， where its pressure is increased. The compressed gas， after being fed to the CO2 removal unit， is mixed with the natural gas make-up， thus closing the reduction gas circuit.

A key element of the HYL process is its pressurization operation. the use of O2 depends on the hydrocarbon content. the DRI metallization and C are independently controlled.

Three chemical reactions take place in this process. They are (i) partial oxidation and reforming reactions， (ii) reduction reactions， and (iii) carburization reactions. These reactions are described below.

Partial oxidation and reforming reactions

2CH4 + O2 = 2 CO + 4 H2

ch4 + h2o = co + 3 h2

2H2 + O2 = 2 H2O

Co2 + H2 = Co + H2O

Reduction reaction

Fe2O3 + 3 H2 = 2 Fe + 3 H2O

Fe2O3 + 3 CO = 2 Fe + 3 CO2

Carburization reaction

3 Fe + CH4 = Fe3C + 2 H2

3 Fe + 2 CO = Fe3C + CO2

3 Fe + CO+ H2 = Fe3C + H2O

The conversion of natural gas requires (i) a certain level of oxidants (H2O and CO2)， which must be carefully controlled， (ii) high temperatures as a result of partial combustion， and (iii) an active catalyst， which is provided by the metallic iron units of the iron ore that has been reduced. The oxidant produced by the reduction reaction is partially consumed by the reforming reaction. In this way， once in contact with the solid material in the shaft furnace， further methane reforming takes place in situ due to the catalytic effect of metallic iron (Fe). Under these conditions， the methane is always in contact with a new catalyst (metallic iron in the DRI)， as the DRI is continuously removed from the shaft furnace. Thus， the in-situ reduction of gas is generated and reduced in an efficient environment. This conversion process is highly endothermic and it continues until the temperature remains high enough. Once the temperature drops below a certain level， in situ reforming does not occur and only the reduction of iron ore takes place. Most DRI carburization is done by cracking methane (CH4) to produce iron carbide (Fe3C).

The Energiron ZR process reduces the size and increases the efficiency of the HYL direct reduction plant. The reduction gas is generated on-site in the reduction shaft furnace by feeding natural gas as make-up gas into the reduction gas circuit and injecting O2 at the shaft furnace inlet. in this process， optimal reduction efficiency is achieved because the reduction gas is generated in the reduction section. Because of this， an external reducing gas reformer is not required. Typically， the overall energy efficiency of the ZR process is above 80%， which is optimized by the in-situ reforming in the shaft furnace. The product absorbs most of the energy supplied to the process with minimal energy loss to the atmosphere.

The impact of eliminating the external gas reformer on plant size is significant. For a capacity of 1 million tons per year， the area required is reduced by about 60%. This also facilitates the location of the DR plant near the steel melting plant.

Another advantage of the ZR process is the flexibility of DRI carburizing， allowing for C levels of up to 5%. This is due to the increased carburizing potential of the in-shaft gas， which allows the production of mainly Fe3C. DRI with high Fe3C content is much less reactive than normal DRI due to the higher heat of dissociation required for Fe3C.

The Energiron process can also use the traditional steam reforming of natural gas that has characterized the HYL process since long ago. Other gases， such as H2， syngas obtained from the gasification of coal， petroleum coke and similar fossil fuels， and coke oven gas (COG) are also possible sources of reducing gas， depending on the circumstances and gas availability. This flexibility is available because the Energiron ZR process is independent of the reduction gas source and does not require recirculation of the gas to the reformer to complete the process chemistry cycle.

The hot reduction gases are fed in a vertical furnace in the reduction zone. These gases flow upwards against the moving bed of the iron charge. The gas distribution is uniform and there is a high degree of direct contact between gas and solids. The exhaust gas (top gas) leaves the shaft furnace at about 400 degrees Celsius and passes through the top gas heat exchanger， where the heat of the gas is recovered to produce steam. Alternatively， the heat from the exhaust gas can be used to preheat the reduction gas stream and then cool the exhaust gas through a quench/wash process.

For cold DRI， the cooling gas is fed into the lower conical section of the vertical furnace at about 40 degrees C and flows upward against the flow to the DRI moving bed. The gas distribution is uniform， with a high degree of direct contact between the gas and the solids， and there is no physical restriction on the flow of solids or gas within the furnace.

The hot DRI is discharged through a rotary valve in the shaft furnace， and through a diverter valve， the material is conveyed to a Hytemp system or other external cooler (for cold DRI production). Pneumatic conveying is usually done at the same rate as the production rate of the shaft furnace.

To produce HBI， the hot DRI is continuously discharged to the hot briquetter below at temperatures in excess of 700 degrees C. The HBI is cooled in a vibratory cooling conveyor using cooling water and then discharged to the HBI transport conveyor.

Hytemp iron uses a pneumatic system to transport the hot DRI to the electric arc furnace (EAF). It uses nitrogen (N2) or process gas as the transport gas. This is an environmentally friendly process because the DRI is closed from the time it is discharged from the reduction shaft furnace to the discharge into the electric arc furnace. The system has the flexibility to feed two EAFs from a single shaft furnace. At the bottom of the shaft furnace， the DRI is discharged into a pneumatic transport system where a hot gas stream from a gas heater circulates and is used to transport the DRI. to avoid degradation， the DRI is transported by an increase in pressure rather than the velocity of the gas. When the hot DRI reaches the storage bin at the top of the EAF， the DRI and the gas are separated. The gas is sent to a scrubber for cleaning and cooling. It is then compressed and heated for recovery. Before entering the gas heater， supplemental gas is added to compensate for the loss in separating the DRI from the transport gas. The hot DRI separated from the transport gas is sent to a transition bin to go from the pressure of the transport system to atmospheric pressure. From the transition bin， the DRI enters a storage bin and is fed by gravity to the EAF. hot DRI can also be sent from the shaft furnace to an external cooler when the steel melting plant is not ready to use or store hot DRI. The external cooler usually has the capacity to cool the entire DRI production.

In a typical HYL III process configuration， the sensible heat of the hot reforming gas and reformer flue gas is used primarily to generate steam. there are two end-users for the steam requirements of the DRI process plant， namely (i) steam from reforming， and (ii) exhaust steam from the CO2 absorption system in the reduction loop. The amount and pressure of steam produced is specified in order to achieve the best thermal and mechanical balance of the plant. Typically， steam is produced at high pressure (63 kg/cm2) in order to maximize the use of steam enthalpy to generate electricity in a single high-efficiency turbogenerator， which is then used for reforming and CO2 stripper reboiling. In this way， the total power demand of the plant can be generated within the plant. The capacity of the turbogenerator is approximately 90 kWh/ton in the case of cold emissions and approximately 105 kWh/ton HBI in the case of hot emissions， which is sufficient to meet the total power demand of the plant.

An important feature of the Energiron direct reduction plant is that the process can be designed with zero make-up water requirements. This is possible mainly because water is a by-product of the reduction reaction， as it is condensed and removed from the gas stream. Therefore， since a closed circuit water system based on a water heat exchanger is used instead of a conventional cooling tower， no fresh make-up water is required， and in fact a small stream of water is available at the cell limit.

Operating parameters and specific consumption

The typical characteristics of Energiron ZR process products are given in Table 1.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Tab 1 Typical characteristics for the product |  |  |  |  |  |
| Sl.No. | Item | Unit | DRI | HBI | Hytemp iron |
| 1 | Metallization | % | 92 – 95 | 92 – 95 | 92 – 95 |
| 2 | Carbon | % | 1.5 – 5.5 | 1.5 – 2.5 | 1.5 – 5.5 |
| 3 | Temperature | Deg C | 40 | 40 | > 600 |
| 4 | Bulk density | tons/cum | 1.60 | 2.50 | 1.60 |
| 5 | Apparent density | tons/cum | 3.20 | 5.00 | 3.20 |
| 6 | Nominal size | mm | 6 – 15 | 110 x 60 X 30 | 6 – 15 |
| 7 | Fe3 C | % | 25 – 60 | 25 – 30 | 25 – 60 |

Typical operating parameters and specific consumptions of the Energiron ZR process are given in Table 2.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Tab 2 Typical operating parameters and specific consumption for HYL ZR process |  |  |  |  |  |  |  |
| Sl. No. | Item | Unit | Cold DRI |  | HBI | Hot DRI |  |
| 1 | Carbon | % | 4.5 | 2.5 | 2.5 | 4.5 | 4.5 |
| 2 | Metallization | % | 93 | 93 | 93 | 93 | 93 |
| 3 | DRI temperature | Deg C | 40 | 40 | 700 | 700 | 700 |
| 4 | Iron burden | tons/ ton | 1.36 | 1.39 | 1.41 | 1.36 | 1.39 |
| 5 | Natural gas | Gcal/ton | 2.25 | 2.20 | 2.23 | 2.35 | 2.25 |
| 6 | Electricity | kWh/ton | 65 | 65 | 80 | 65 | 65 |
| 7 | Oxygen | N cum/ton | 42 | 53 | 53 | 48 | 53 |
| 8 | Water | Cum/ton | 0.8 | 0.8 | 1.1 | 0.8 | 0.8 |
| 9 | Nitrogen | N cum/ton | 12 | 12 | 19 | 18 | 18 |

Typical emissions from the Energiron ZR process are given in Table 3.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Tab 3 Typical emissions from HYL ZR process |  |  |  |  |
| Sl. No. |  | Emissions | Unit | Value |
| 1 | NOx with ultra-low NOx burners |  | mg/N cum | 50 – 80 |
| 2 | NOx with selective catalytic removal |  | mg/N cum | 10-50 |
| 3 | CO |  | mg/N cum | 20-100 |
| 4 | Dust from heater/reformer stack |  | mg/N cum | 1 – 5 |
| 5 | Dust from material handling dedusting |  | mg/N cum | 5 – 20 |