HOW HBI IS MADE

(Based on the *Direct Reduction Fundamentals and Applications – Short Course* presented by Roy Whipp, President of Whipp Technology, Inc., and an HBIA Special Member)

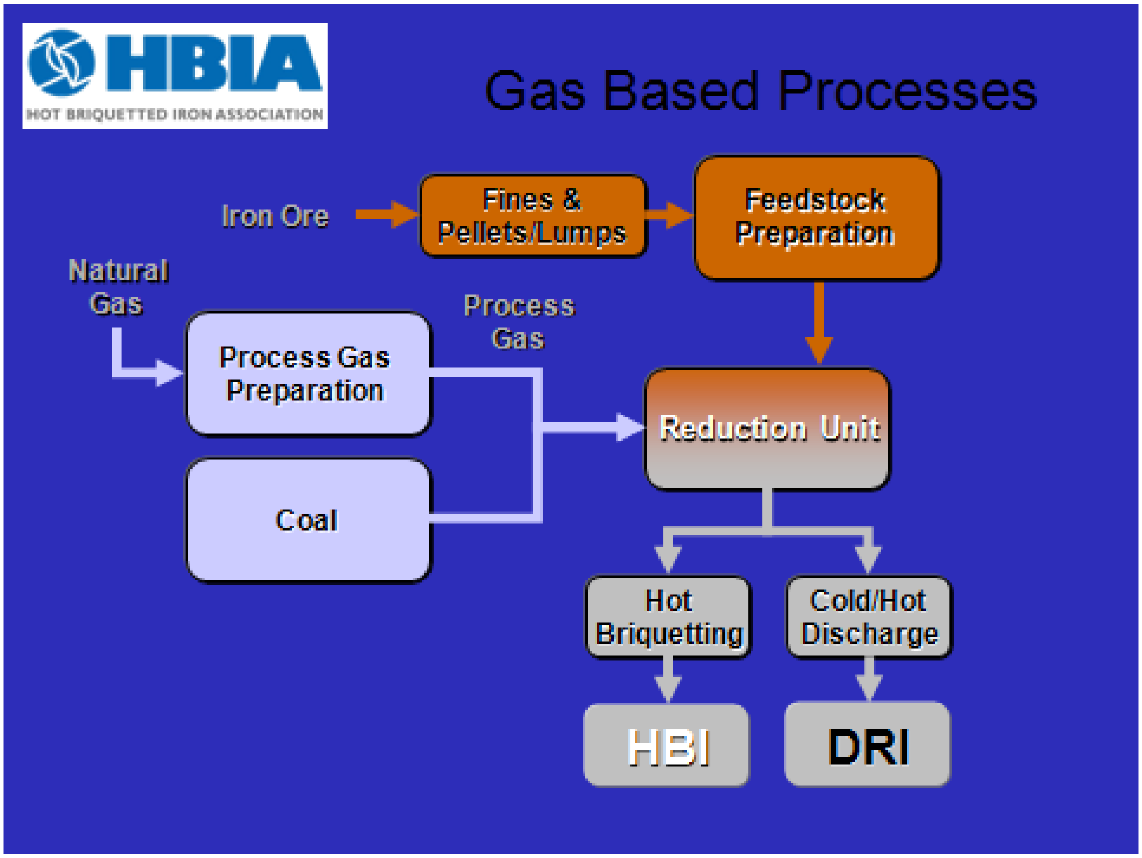
Gas-Based Processes

The majority of the direct reduction processes are gas-based; therefore, we will focus on them today.

The iron ore feed is either fines in fluid beds or pellets and lump in the other reduction furnaces. The feedstock is prepared to adjust the size to that required in the reduction furnace. This may require screening for separation or grinding to adjust the particle size downward.

The process gas is formed by different methods to generate H_2 and CO to remove the oxygen from the ore. Coal is also added in some processes to the process gas to actuate in the reduction. Natural gas enters the reduction furnaces and is heated to the required temperature for reduction of the oxide feed. We will look at the reduction furnaces in more detail in the following two slides.

Once reduced, the product is either briquetted while hot as HBI (hot briquetted iron) or cooled and discharged as DRI. In the hot briquetting process, the HBI must be cooled prior to storage in piles.



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Gas Based Processes

Iron Ore

Fines & Pellets/Lumps

Feedstock Preparation

Natural Gas

Process Gas Preparation

Process Gas

Coal

Reduction Unit

Hot Briquetting

Cold/Hot Discharge

HBI

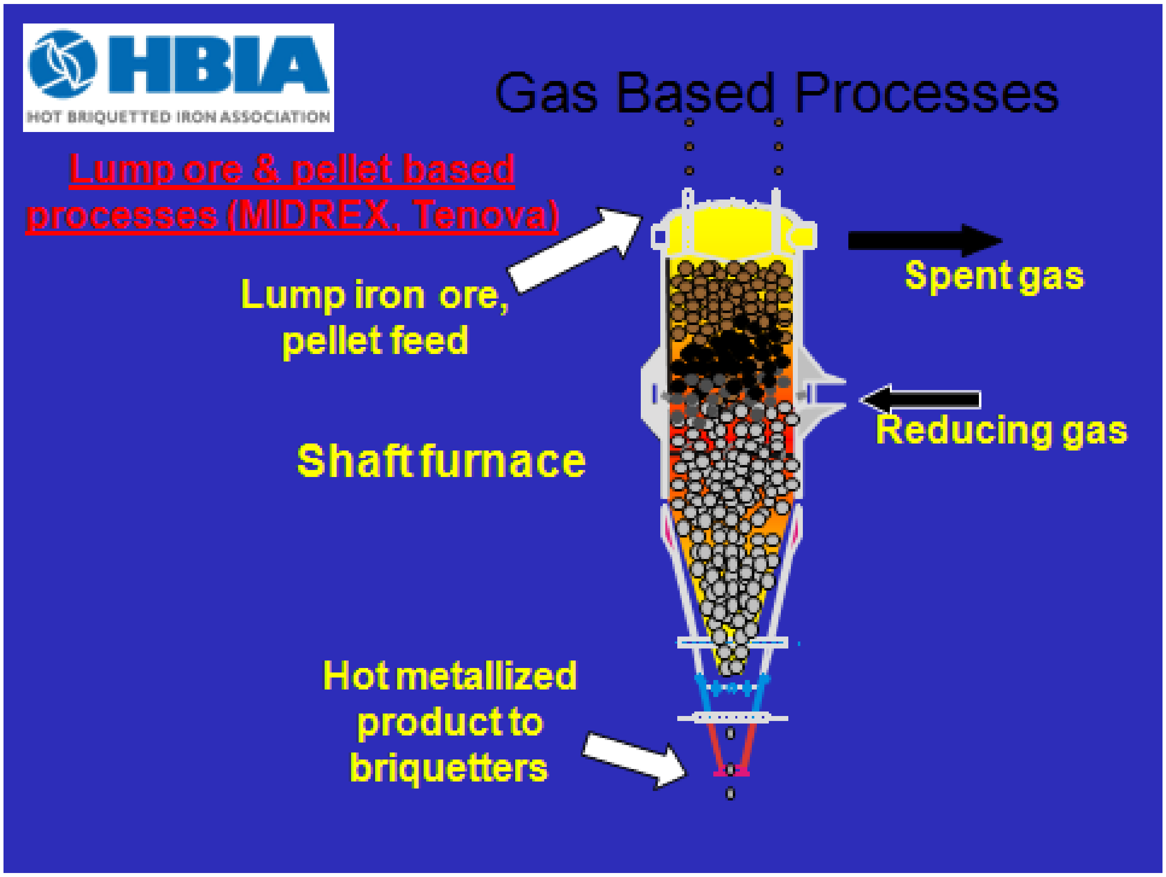
DRI

Gas-Based Processes - Lump and Pellet Feed

The principal shaft-based furnace operations are those of Midrex and Tenova/HYL, which together account for 98% of the gas-based processes. In these furnaces, the mixture of lump ore and pellets is introduced for reduction by different systems that we will clarify later. The ore flows by gravity downwards and is contacted by upflowing reducing gas. The ore is reduced and heated during the downward flow.

The hot reducing gas enters the shaft around the exterior diameter and flows upwards. In the upwards flow, the reduction of the Fe_2O_3 occurs. By the time the gas exits the reducing zone, it has been partially cooled by the heating of the incoming ore feed.

The shaft furnace can provide either hot product for briquetting or cooled final product.



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Gas Based Processes

Lump ore & pellet based processes (MIDREX, Tenova)

Lump iron ore, pellet feed

Spent gas

Shaft furnace

Reducing gas

Hot metallized product to briquetters

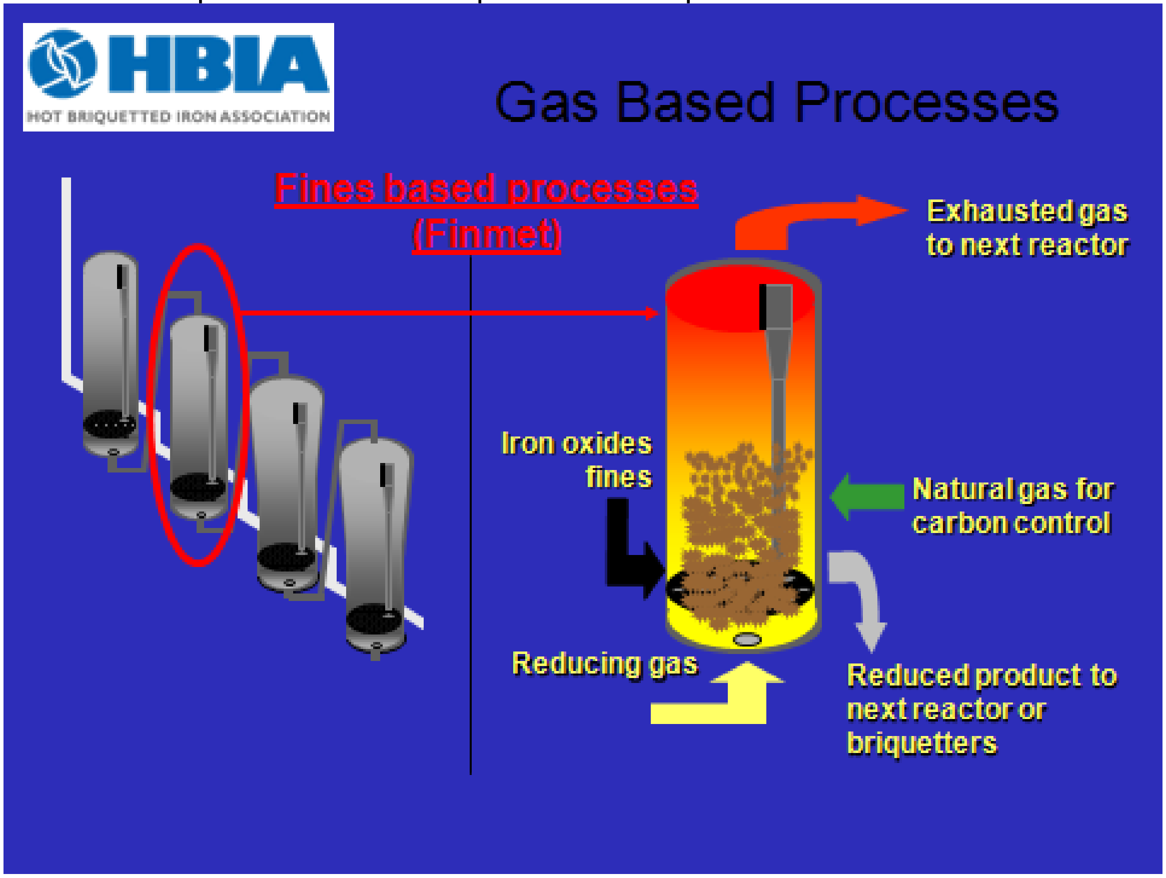
Gas-Based Processes – Fines Feed

The principal fines reactor-based furnace operation is that of FINMET, which is the only fines-based process in service at present. In the FINMET Process, the reactor layout is different from another fines-based process, CIRCORED, as we will see later. In all cases, the fines are maintained in a fluidized condition by upwards flowing reducing gas. In the FIOR and FINMET Processes, a total of four fluid beds are used. In the CIRCORED Process, two fluid beds of different conditions are used.

Between reactors, the ore flows by gravity downwards and is contacted in each by upflowing reducing gas. The ore is reduced and heated during the downward flow.

The hot reducing gas enters the reactors through fluid bed grids from the reactor bottom and flows upwards. By the time the gas exits the top, it has been partially cooled by the heating and reduction of the incoming ore feed.

The fines-based processes must briquette the final product.



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Gas Based Processes

Fines based processes (Finmet)

Exhausted gas to next reactor

Iron oxides fines

Natural gas for carbon control

Reducing gas

Reduced product to next reactor or briquetters

FINMET Process Flowsheet

There are four reactors in series, which are interconnected with gas and solids transfer lines. For a 500,000 t/y module, the reactors are 4.5 meters in diameter. Ore fines flow downward by gravity from the upper to lower reactor, while reducing gas flows upward in a countercurrent direction. This countercurrent flow improves the efficiency of the process, thus increasing the reduction over what can be achieved in a single reactor for given gas and ore flows.

The fine ore is heated in the first reactor to about 450º C by the partially spent reducing gas from the previous reactor, which enters into contact with the ore by way of a gas distribution grid. The gas leaves the fluid bed carrying entrained dust, which is removed in internal cyclones in the reactor, and this dust is returned to the fluid bed. The spent reducing gas passes out of the reactor to the gas handling system and is recycled to the process.

The gas required for reduction is supplied by a mixture of recycled top gas and fresh gas provided by a steam reformer. Because not all of the H_2 and CO in the reducing gas is consumed during reduction, this gas has to be recycled. To vent it or use it as fuel would make the process energy consumption excessively high.

The top gas is first quenched and scrubbed in a wet scrubber, where the gas is cooled and any remaining dust is removed. A small part of the scrubbed gas is removed to control inert gas build-up in the system, and this is used as fuel in the reducing gas furnace. The remaining recycle gas is compressed in a centrifugal compressor and returned to the process.

The gas required to make up that which is consumed in the process is supplied from a conventional steam reformer. The reformed gas stream, as well as part of the recycle gas is sent through a CO_2 removal system, and then the gas is preheated in the reducing gas furnace before being sent to the reactors.

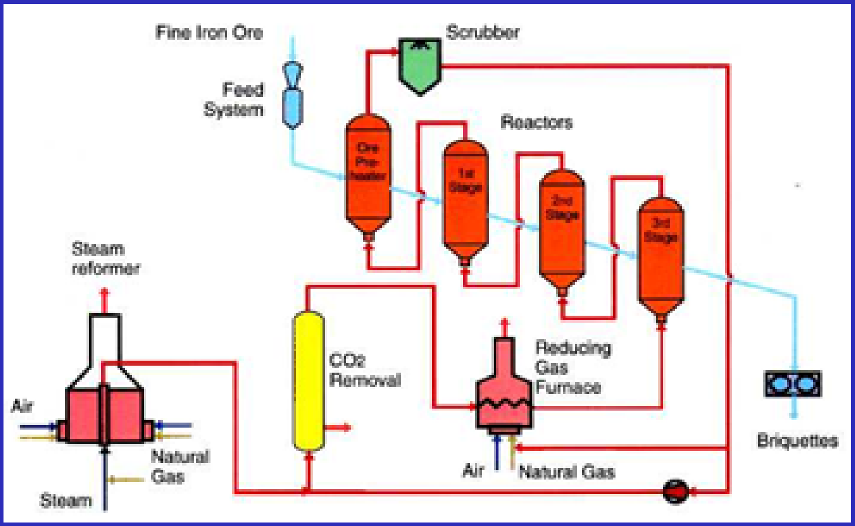
The ore flows down through the remaining reactors, becoming higher in metallic iron in each step due to the contact with progressively richer fluidizing gas. It reaches a metallization of around 91-92% in the last reactor. The operating temperatures of the reactors vary from about 450º C in the upper reactor to 780- 800º C in the lower one. The pressure of the reactors is between 11 and 13 bars gauge (barg). Carbon, in the range of 0.5-1.5%, also can be formed in the ore. This carbon is over 90% in the form of cementite, or Fe_3C, and is mostly formed in the last stage.

The fines are fed into double roll briquetting machines, where they are compacted to a density of more than 5 g/cc. The strings of briquettes exiting the machines are separated into individual briquettes in a revolving drum or trammel, which can be seen under the briquetter. Fines generated by the breaking process are separated from the product briquettes and recycled to the briquetting machines. The briquettes are then cooled on a forced air cooler and stockpiled.

FINMET Process

Feed	Fines 10 to 0.01 mm
Reductant	Reformed nat gas
Reactor Type	Fluid beds (4)
Pressure	12 bar
Temperature	450-800 C
Product	HBI
Use	Merchant
Plants (MIDREX Data)	2 (One is being demolished)
Production capacity	4.4 Mt/y
Production in 2005	1.3 Mt

FINMET Process Flowsheet



Tenova HYL Process

Tenova HYL has formed an alliance with Danieli & Co. for the development and supply of direct reduction technology and plants worldwide. This alliance, known as Energiron HYL, combines the long technological experience of Tenova HYL with the metallurgical plant and equipment design and supply capabilities of Daniel.

As a historical note, Tenova HYL, then known as HYL Technologies, built the first commercial DR plant in 1957.

Energiron HYL also offers reducing gas produced directly in the shaft reactor by means of in-situ reforming reactions in addition to other sources of reducing gas including reformed gas, natural gas, coke oven gas, syngas from coal, and exhaust gas from smelters.

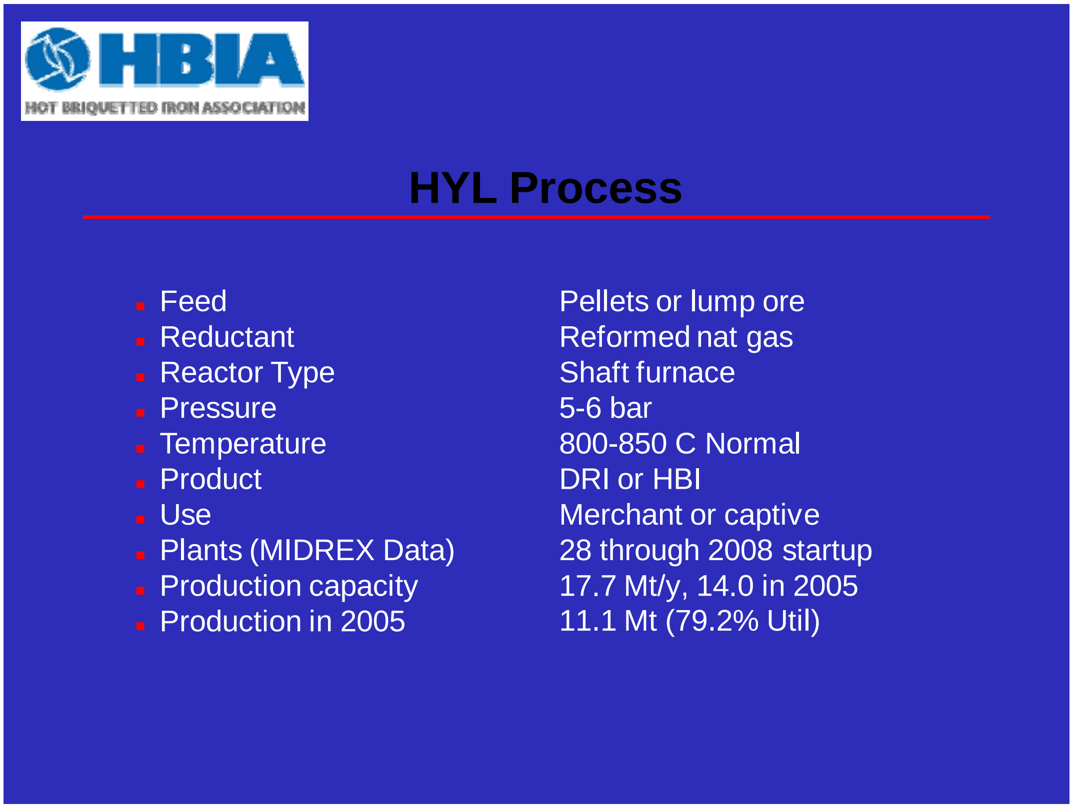
The reactor is a shaft furnace with internal lining. Energiron HYL has defined the reactor diameter size to be approximately 6 meters for 2 million t/y production.

The reactor internal pressure is normally 5-6 bars, which is higher than the MIDREX Process. In the latest process information, the gas pressure is listed as 2.5 to 6 bars.

Operating temperature mentioned in the standard HYL process flowsheet was 800-850° C in the past, but it was raised in the Tenova HYL ZR process. The Energiron HYL process info sets gas temperature at 950° C. Gas temperature quoted is 930° C from the heater with O_2 addition taking it above 1000° C to as high as 1085° C in the in-situ reforming.

Product from the systems is either DRI or HBI. Both merchant and captive plant configurations are offered. ENERGIRON HYL is quoting carbon from 1-4%.

According to published data, there will be 28 Tenova HYL plants through 2008 with a capacity of 17.6 million tons. Total production last year was 11 million tonnes with a utilization of 73.2% according to published figures.



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HYL Process

Feed	Pellets or lump ore
Reductant	Reformed nat gas
Reactor Type	Shaft furnace
Pressure	5-6 bar
Temperature	800-850 C Normal
Product	DRI or HBI
Use	Merchant or captive
Plants (MIDREX Data)	28 through 2008 startup
Production capacity	17.7 Mt/y, 14.0 in 2005
Production in 2005	11.1 Mt (79.2% Util)

Tenova HYL Process Flowsheet

Iron ore pellets, lump ore, or mixtures of both are transported by belt conveyor to the top of the reduction tower. An automated system of bins and pressure locks allows receiving the ore at atmospheric pressure in an open bin, pressurization in intermediate bins, and discharge to continuously feed the vessel.

The components included in the reducing gas circuit are: shaft furnace reduction zone, top gas quenching/scrubbing system, reducing gas recycle compressor, CO_2 removal system, and process gas heater. As an option, a heat recuperator can be included to recover energy from the reactor top gas stream.

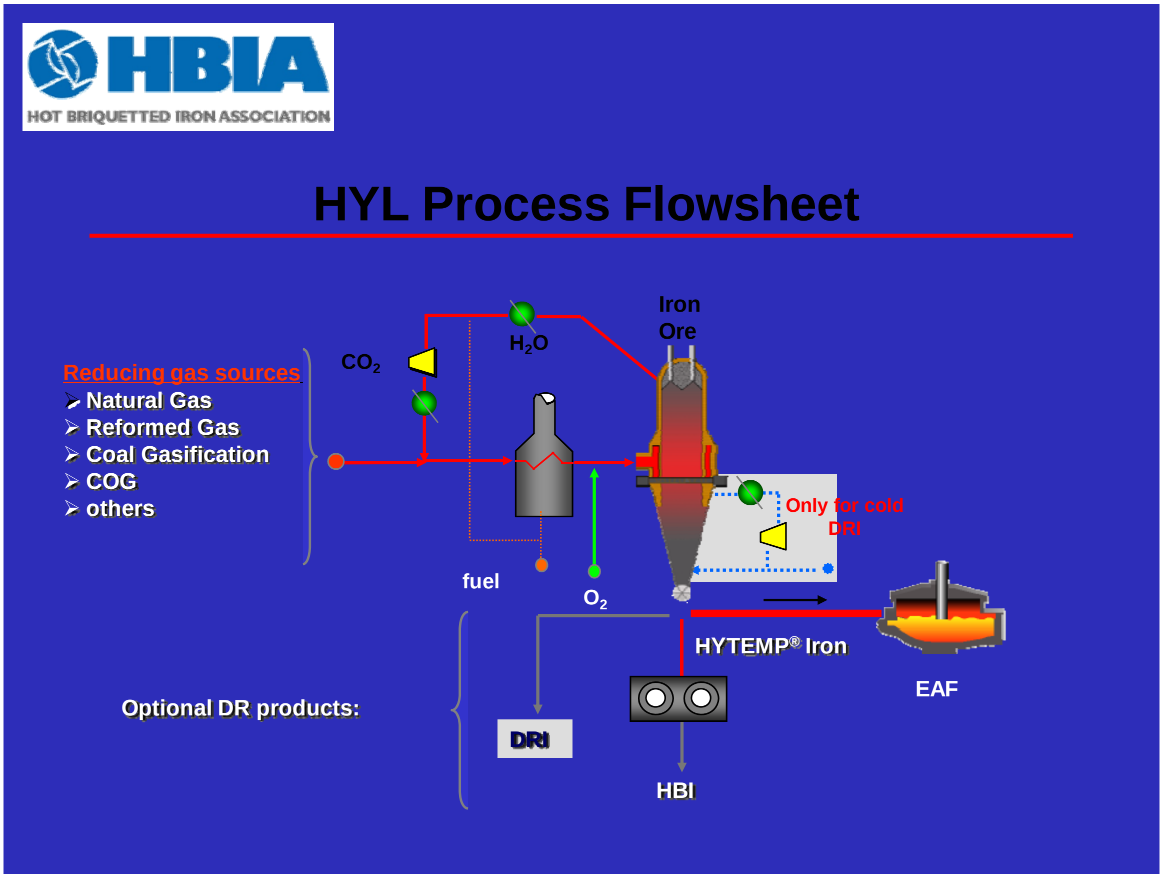
The reduction furnace operates at a pressure of around 6 bar absolute, allowing a high productivity of about 9 t/h x m^2 and minimizing dust losses through top gas carry-over. The natural gas stream (or reducing gas make-up) is mixed with the reducing gas recycle stream from the CO_2 removal system. This reducing gas stream is passed through the gas heater where it is heated up to 930-950° C.

Inside the shaft furnace, hot reducing gas is fed to the reduction zone and flows upward counter-current to the iron ore moving bed. The in-situ reforming and reduction reactions take place in this zone. The exhaust reducing gas (top gas) leaves the reactor at about 400° C and passes through the top gas heat recuperator, where its energy is recovered to produce steam or alternatively to preheat the reducing gas stream, and then it passes through the quenching/scrubbing system. Scrubbed gas is then passed through the process gas recycle compressor, where its pressure is increased. Compressed gas, after being sent to the carbon dioxide removal unit, is mixed with the natural gas make-up, thus closing the reducing gas circuit.

A rotary valve, located at the bottom of the vessel, regulates the continuous gravity flow of the charge downward through the reduction furnace. DRI is discharged by automated mechanisms consisting of pressurized bins and pressure locks.

For cold DRI, a cooling gas is fed to the lower conical part of the furnace at about 40° C, flowing upward countercurrent to the DRI moving bed. The gas distribution is uniform, and there is a high degree of direct contact between the gas and solid without physical restrictions to the flow of solids or gases inside the unit. The cooling gas exits from the upper conical part, at about 460° C, and is quenched/scrubbed by means of cooling water. Natural gas is injected as make-up to the cooling gas circuit for optimum efficiency and control of the cooling and carburization processes.

For hot product discharge and use, the cooling circuit is eliminated and hot DRI is continuously discharged at >700° C. For the HYTEMP pneumatic transport system, the product is transported by means of a carrier gas to the surge bins located at the melt shop for controlled feeding to the electric arc furnace. For production of HBI, hot DRI is continuously discharged at >700° C to the hot briquetting machines arranged below. The HBI is cooled in vibrating cooling conveyors using cooling water and then discharged to the HBI transport conveyor.



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HYL Process Flowsheet

Reducing gas sources
- Natural Gas
- Reformed Gas
- Coal Gasification
- COG
- others

Optional DR products:

Tenova HYL ZR Process Flowsheet

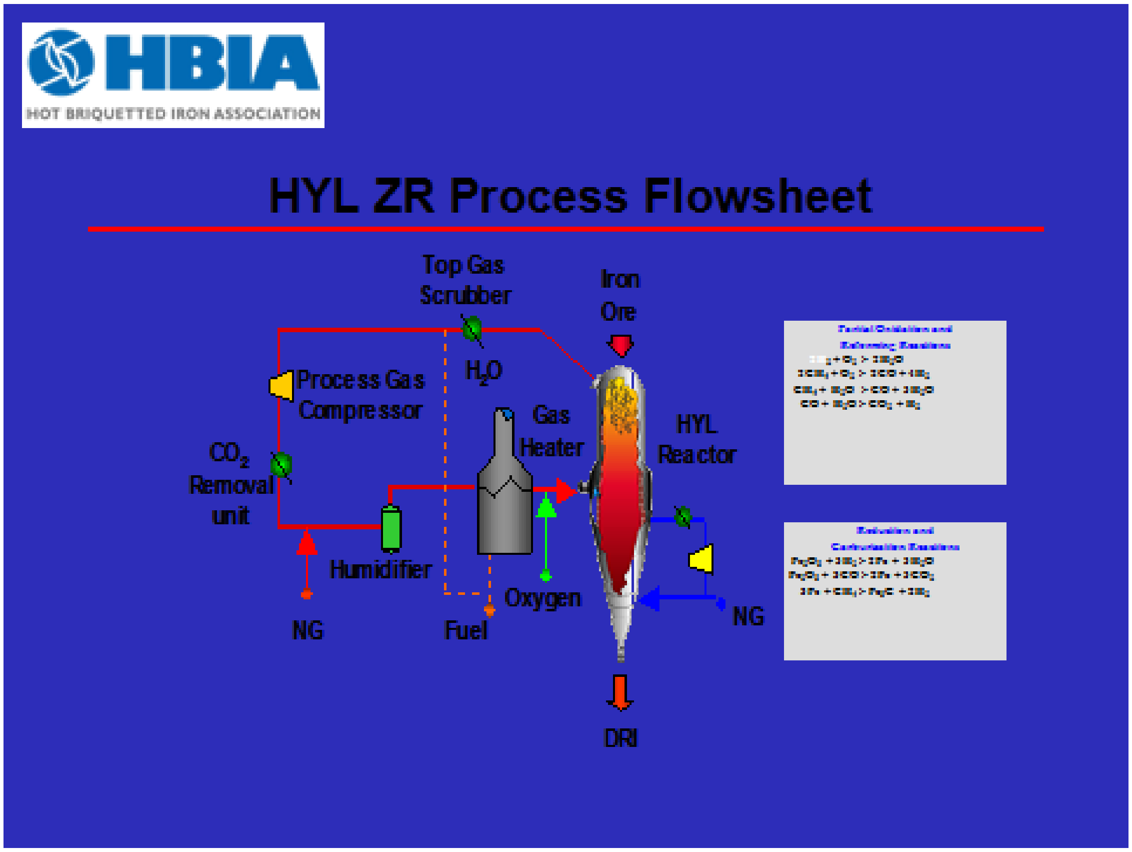
The ZR Process is based on the reduction of iron ores with reducing gases, which are generated from partial combustion and in-situ reforming of natural gas, taking advantage of the catalytic effect of the metallic iron inside the reduction reactor. The plant can be designed for production of cold DRI,hot DRI, or for direct charging.

Because of partial combustion, the reducing gas temperature at the reactor inlet is very high – above 1000° C. Due to the endothermic behaviour of the combined chemical reactions taking place inside the reactor, the resulting temperature at the reduction zone is below the potential condition for material cluster formation.

For the production of high quality DRI (94% metallization, 4% carbon), natural gas consumption is 2.25-2.3 Gcal/ton DRI and electricity usage is 60-80 kWh/ton DRI with low iron ore consumption of 1.35-1.40 t/t DRI, mainly due to high operating pressure.

The reactor operates at elevated pressure (6 bars absolute), allowing a high reactor productivity of about 9 t/h x m² and minimizing dust losses through top gas carry-over. This is reflected in low iron ore consumption, which keeps the operating cost low.

One of the inherent characteristics of the Tenova HYL Process scheme and of high importance for this application is the selective elimination of both by-products generated from the reduction process: water (H_2O) and carbon dioxide (CO_2) through top gas scrubbing and CO_2 removal systems, respectively.



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HYL ZR Process Flowsheet

MIDREX Process

In the 1st Qtr 2007 DIRECT FROM MIDREX, it was reported that since 1969, Midrex and its partners have built or are constructing 63 MIDREX® Modules (shaft furnaces plus reformers and associated systems) in 21 countries. To date, these facilities have produced over 500 million tons (Mt) of DRI and HBI, having a market value exceeding $70 billion. This record of plant sales, successful startups, and continued outstanding performance has resulted in a market share for MIDREX technology of 60 percent or more each year since 1987.

Feed is pellets or lump ore, with pellets normally the majority of the charge.

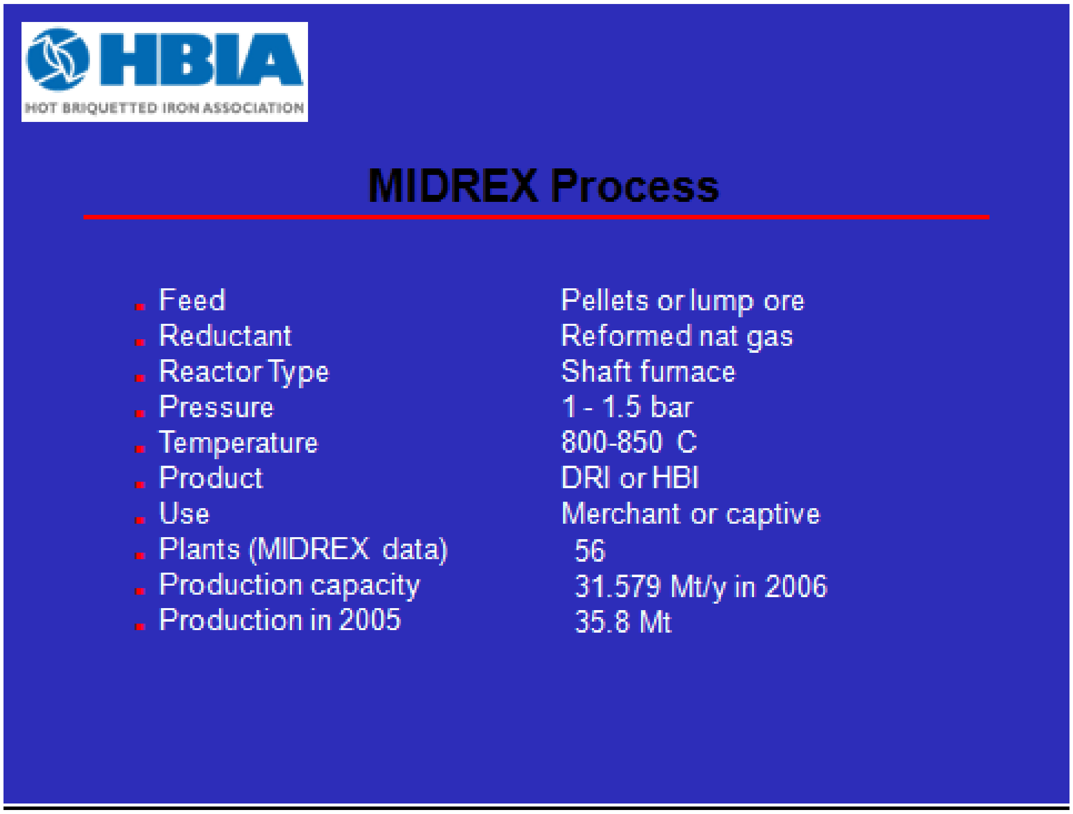
The reducing gas is reformed natural gas, but there is no cooling and treating and then reheating of the gas as is done in other processes. The H_2/CO ratio is lower than in HYL and FINMET. This is typically 1.5, but due to the different reforming systems, it can range from 0.5 to 3.5.

The reactor is a shaft furnace operating at a relatively low pressure (in the range of 0.4-1.5 bar overall). The largest diameter shaft furnace ever supplied is being installed at HADEED in Saudi Arabia (7 meter diameter).

Temperature has been increased with the process development and now exceeds 980° C in the new plants.

Both hot and cold DRI and HBI are produced for captive plant and merchant applications, respectively.

There are presently 51 operating plants and eight are in construction or commissioning at present. The production of the 51 operating plants was 35.71 million tons in 2006, including 3.9 million tonnes for 3 plants started up during the year. Midrex has reported capacity utilization as high as 131%.



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MIDREX Process

Feed	Pellets or lump ore
Reductant	Reformed nat gas
Reactor Type	Shaft furnace
Pressure	1 - 1.5 bar
Temperature	800-850 C
Product	DRI or HBI
Use	Merchant or captive
Plants (MIDREX data)	56
Production capacity	31.579 Mt/y in 2006
Production in 2005	35.8 Mt

MIDREX Process Flowsheet

The MIDREX Process consists of three major stages: 1) reduction, 2) reforming, and 3) heat recovery. Midrex claims that the plant is simpler in design as compared to other gas-based direct reduction processes.

Reduction

Iron oxide, in pellet or lump form, is introduced through a proportioning hopper at the top of the shaft furnace. At VENPRECAR in Venezuela, the feed mix is 65% pellets, 32% lump ore, and the rest is recycled remet.

As the ore descends through the furnace by gravity flow, it is heated and the oxygen is removed from the iron (reduced) by counterflowing gases, which have a high H_2 and CO content. In the VENPRECAR plant, the process gas is 60% H2 and 35% CO on a dry basis. These gases react with the Fe_2O_3 in the iron ore and convert it to metallic iron, leaving H_2O and CO_2.

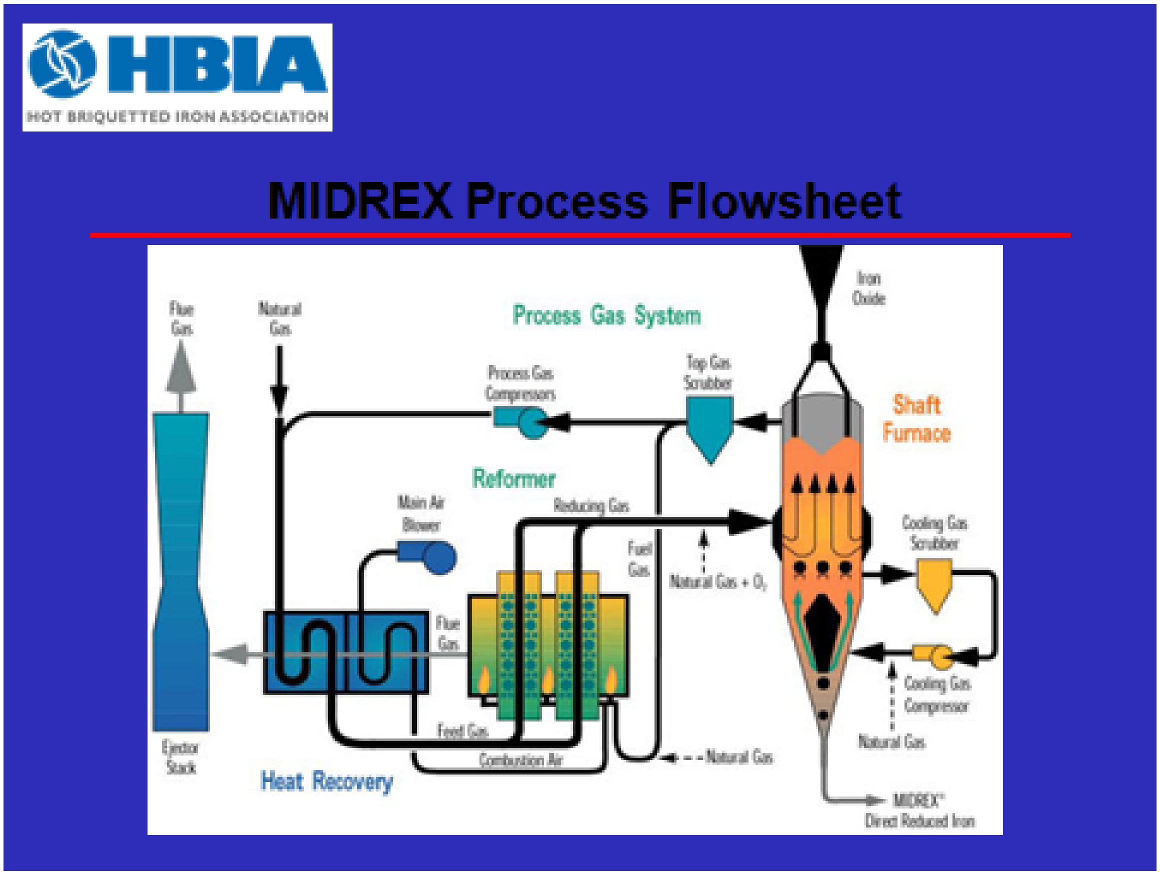
For production of cold DRI, the reduced iron is cooled and carburized by counterflowing cooling gases in the lower portion of the shaft furnace. The DRI also can be discharged hot and fed to a briquetting machine for production of HBI, or fed hot, as HDRI, directly to an EAF using the HOTLINK System or insulated transfer vessels.

Reforming

To maximize the efficiency of reforming, off-gas from the shaft furnace is recycled and blended with fresh natural gas. This gas is fed to the reformer, a refractory-lined furnace containing alloy tubes filled with catalyst. The gas is heated and reformed as it passes through the tubes. The newly reformed gas, containing 90-92 % H_2 and CO, is then fed hot directly to the shaft furnace as reducing gas. At VENPRECAR, the gas temperature exiting the reformer is 940° C and is cooled to 850° C to enter the shaft furnace.

Heat Recovery

The thermal efficiency of the MIDREX Reformer is greatly enhanced by the heat recovery system. Sensible heat is recovered from the reformer flue gas to preheat the feed gas mixture, the burner combustion air, and the natural gas feed. In addition, depending on the economics, the fuel gas also may be preheated.



HBI – Industrial Production

HBI is produced in the form of briquettes at high temperature and pressure with roller presses. Alternative briquette sizes and shapes have been tested in several plants. The typical volume of industrially manufactured briquettes is in the range of approx. 100 cm^3. So far, this is independent of the method used in the preceding direct reduction process.

Figure 1 represents the hot briquetting process for the production of HBI. The direct reduced iron is discharged hot form the reduction process. With a screw this hot feed is pushed into the nip between two counterrotating rollers. Pockets in the synchronously rotating rollers form the briquettes. This process occurs at high temperatures (typically approx. 700 °C) and high pressing forces (e.g. 120 kN per cm active roller width). The continuous string of briquettes leaving the rollers is guided by a heavy chute and is separated into mostly singles for example by a rotor with impact bars. Briquettes from fine material, produced in fluidized bed processes, may also be separated in a rotating tumbling drum.

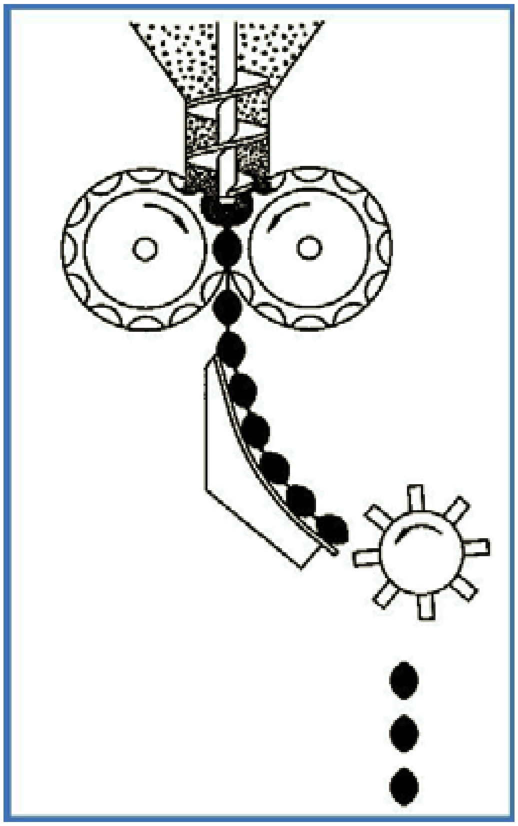


Figure 1: Typical schematic of hot briquetting

The key component in hot briquetting is a specially designed roller press. Figures 2 and 3 show the assembly bay of Maschinenfabrik KÖPPERN featuring modern machines for the production of HBI.

The entire plant for the hot briquetting of sponge iron typically consists of (Figs. 4 and 5):

- Briquetting press with screw feeder and material supply
- Briquette string separator (impact separator or tumbling dru
- Hot screen for the elimination of fines which occur during briquetting and separation
- Product cooler
- Bucket elevator for the recirculation of fines to the briquetting press
- Chutes and accessories

For hot briquetting of the total production of a direct reduction facility several of the above described "briquetting lines" are used. The layout of the briquetting plant is designed such that during the necessary scheduled maintenance on the machines and the system the overall availability of the plant is guaranteed.

In addition to the above mentioned industrially proven features, optimizations and new developments take place. For example, alternative concepts for briquette cooling are presently under consideration and larger machines are being designed to handle more effectively the higher output of future direct reduction plants.

Figure 2: Briquetting machine for DRI from pellets and lump ore, roller diameter 1,000 mm

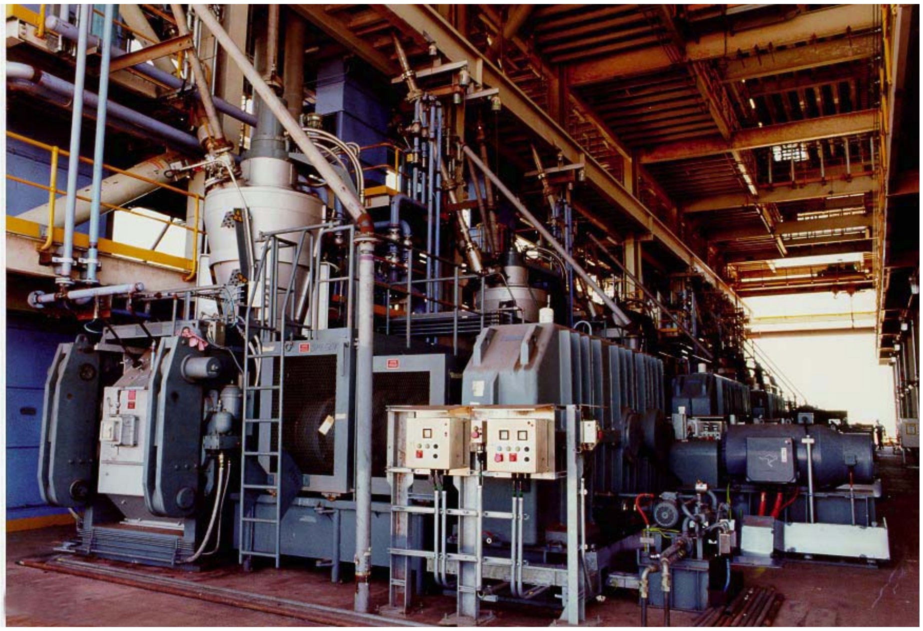


Figure 3: Briquetting machine for the production of HBI from fine ore, roller diameter 1,400 mm

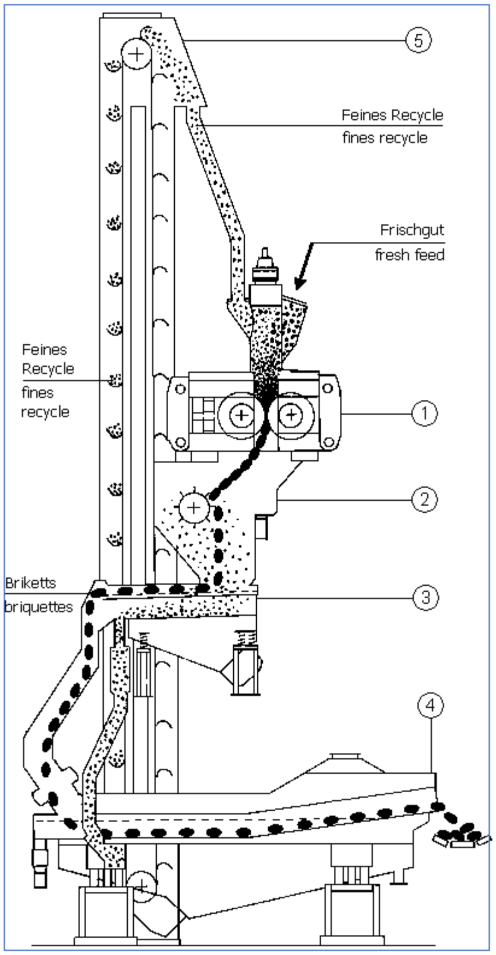


Figure 4: Briquetting line for hot sponge iron from lumps and pellets

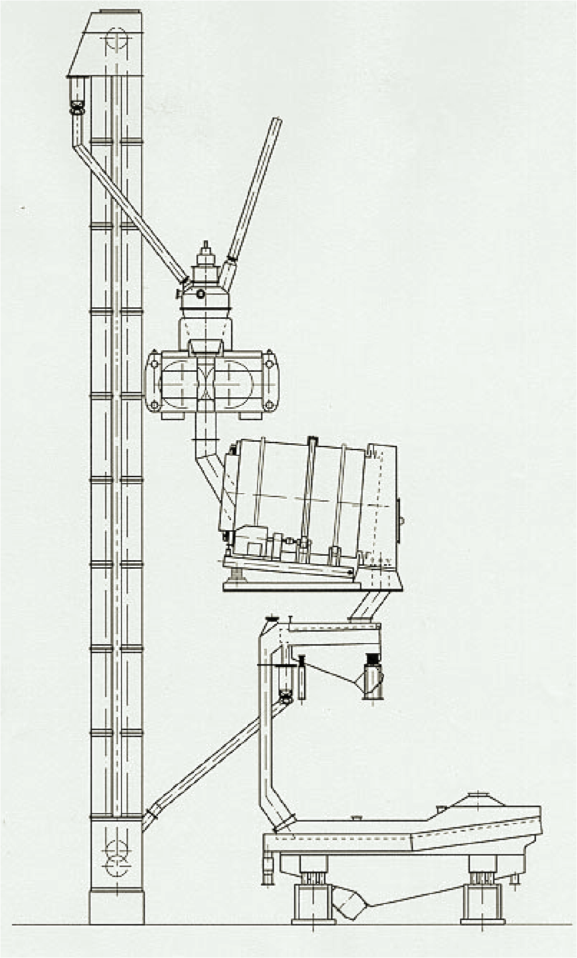


Figure 5: Briquetting line for hot sponge iron fines with drum separator

HBI – From Various DR Processes

Hot briquetting is applied both for products from pellets and lump ore (shaft furnaces) and from fine ore (fluid bed reactors). Particularly in the case of fine DRI from fluidized bed processes, in addition to passivation, it is a major task of hot briquetting to eliminate the inherent handling problems of this material. Both direct reduction technologies are based on gaseous reductants.

More recent investigations, including operation of a pilot plant, have shown that products from coal based processes (rotary hearth furnace) can be also briquetted hot at suitable conditions.

The mechanism of briquetting as well as the briquette structure and, consequently, details of the equipment used in the particular system, depend on the characteristics of the material to be briquetted.

The deformed pellets and lump ore pieces originating from a gas based shaft furnace technology are still visible in the briquette structure, while a more uniformly briquette results from the fine particles of a fluidized bed process.

The knowledge of briquette structure that depends on the properties of the particular feed from different reduction processes helps in optimizing the briquetting process (e.g. material feed systems, pressing tools, etc.)