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HBI – Hot Briquetting of Direct Reduced Iron

Technology and Status of Industrial Application

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Technology and Status of Industrial Applications

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Resume.

Hot briquetting is a reliable, fully developed industrial concept for the passivation of direct reduced iron produced with the various processes of direct reduction. Because, during hot briquetting, the large specific surface area of direct reduced iron is drastically reduced, the well known problems caused by reoxidation, overheating are avoided. Even the shipping instructions published by the International Maritime Organization (IMO) confirm that Hot Briquetted Iron (HBI) can be handled and shipped without special precautions.

From the mid 1970s until today, after extensive pilot testing of the technology, a number of industrial plants for the hot briquetting of direct reduced iron went into operation. Additional hot briquetting plants for already established but also for new direct reduction processes are under construction or in different stages of planning.

The paper describes the characteristics of HBI and its current industrial application for various Direct Reduction Processes.

Introduction.

Direct Reduced Iron has become a widely accepted source of premium iron units for steel making. Its advantages as a virgin iron product and diluent for impurities, introduced with scrap, are well documented.

Direct Reduction plants produce different materials that are based on:

- DRI (Direct Reduced Iron)
  or
- HBI (Hot Briquetted Iron)

Most of the early Direct Reduction Plants were built as part of integrated Mini Mills in which the DRI, after cooling, was fed to and consumed by electric arc furnaces in varying proportions of the total charge.

Today, an increasing number of Merchant Direct Reduction Plants operates in several locations. Others are in different stages of planning and construction. In these facilities, premium, "alternative" iron units are produced for export to the world's steel industry. Because of its much better shipping and handling characteristics, HBI gains an increasing importance for the supply of international markets.

In the following, the differences between the two types of products are discussed.
Hot briquetted iron will be particularly reviewed with regard to:

- Specific advantages and Characteristics of HBI
- Equipment and plants for the production of HBI
- HBI from different Direct Reduction Processes
- Development of the industrial application of HBI

HBI - Why?
Fundamentals.

During direct reduction, oxygen is removed from iron ore in solid state. This procedure results in a spongy structure of the product, thus "Sponge Iron", with a high porosity. Depending on the raw material and the reduction process applied, apparent product density is approx. 2 g/cm³ associated with a very high specific surface area. The latter is typically around 1 m²/g.

Due to the large specific surface area, DRI reacts very easily with water (particularly sea water) and/or oxygen. Since the reaction is exothermic, heat is produced. Owing to its spongy structure, DRI is also an excellent insulator. Therefore, the excess heat produced in a DRI storage pile by, for example, the reoxidation with water does not easily dissipate. This can cause overheating and meltdown of DRI in piles, silos, or - most dangerously - ship holds. The reaction with water also produces Hydrogen which yields explosive mixtures with air.

Since the beginning of Direct Reduction, methods for passivation of the product have been developed and tested. Hot briquetting has become the most reliable process for this task. By applying this technique, direct reduced iron is densified immediately after reduction at high temperatures and with very high pressures. Industrial facilities in connection with different Direct Reduction Technologies exist already for several years.

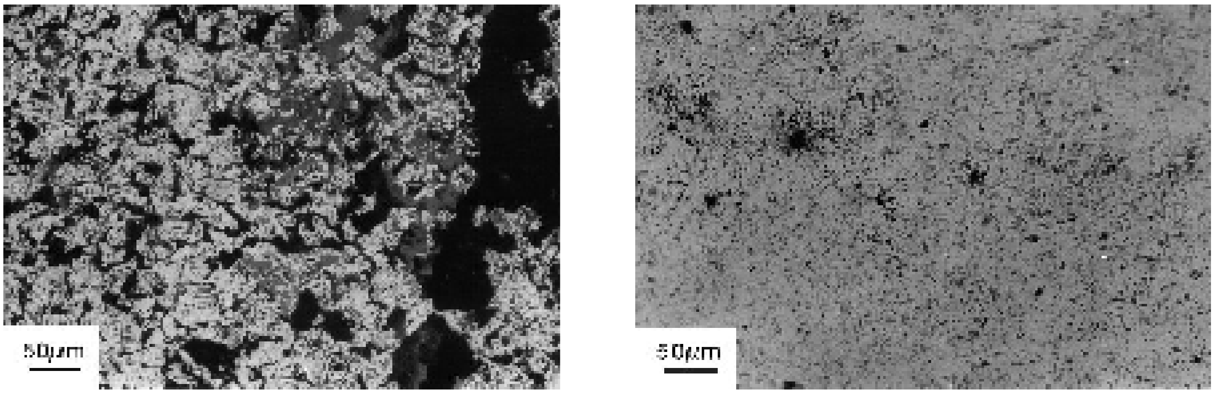


Figure 1: Comparison of the structure of DRI pellets (left) and HBI (right).

Hot briquetting of DRI closes internal pores, lowers the accessible surface, increases the apparent density, and improves thermal conductivity, all of which reduce reactivity (Fig. 1). Reoxidation and overheating of HBI is very unlikely. This results in considerable improvements of storage and transport characteristics. Additional advantages, such as higher density, improved handling, uniform product shape and size, as well as reduced fines production, are results of the physical characteristics of the HBI.

DRI from fine ores, reduced in fluid bed processes, is even more reactive and, even after cooling, cannot be safely handled in the open. In this case, hot briquetting not only passivates the product but also solves the inherent handling problems associated with the fine particulate material.

The reoxidation behaviour of HBI was tested in a production plant (MIDREX process) with a 600 t briquette pile [3]. Inspite of a tropical climate and high salt content in the atmosphere (coastal location) no heating occured and after open storage for one month only 0.8 % metallization was lost. Prior to the first transport by sea, tests were carried out using simulated ship holds where HBI was wetted with sea water. Again, the stability of the product was demonstrated [6]. Other trials evaluated the heating of briquetted material in an oxidizing atmosphere simulating the preheating of scrap. No loss of metallization was determined.

The characteristics of HBI constitute important advantages as compared with the results of other passivation processes. For example the passivation effect of aging is much less pronounced and disappears in the presence of water, particularly seawater.

For this reason, the advantages of HBI have become part of the IMO Shipping Regulation [4]. IMO distinguishes between DRI and "sponge iron which has been briquetted at temperatures of ≥ 650° C and has reached an apparent density of ≥ 5 g/cm³ (HBI). For the latter, in addition to considerably simplified shipping requirements, "open storage prior to loading" is acceptable.

As compared with DRI, the following punch list provides a summary of the most important specific characteristics of HBI:

- No change in the chemical analysis by the briquetting process.
- Only minimal loss of metallization even after long time storage.
- Open air storage both at the producer and user sites does not cause problems (no need for inertized silos as with DRI).
- Minimum risk of overheating during storage and transport (e.g. IMO allows "open storage prior to loading").
- Special inertization of ship holds is not required (no specially equipped ships).
- Little production of fines during handling.
- Handling similar to scrap (open air storage, transport with front-end loaders, magnets, belts, redlers, etc.); an additional advantage is the relatively small and uniform product size (charging of furnaces).
- High apparent and bulk densities.
- Low moisture saturation (max. approx. 3 % as compared with 12-15 % for DRI [3]).
- Efficient preheating for the EAF possible

For those reasons it is understandable that true merchant plants operating today are and most of the merchant facilities under construction or consideration will be producing HBI.

In this context true merchant plants are defined as producers of prime, alternative iron units by direct reduction for the general, open world market where traders and users do not maintain special handling and inertized storage or shipping facilities. Producers utilizing specifically equipped ships or barges to supply a dedicated user that implemented extraordinary receiving, intermediate storage, and feeding systems are not considered true merchant plants.

It should be mentioned that a lot of producers of DRI in integrated mini mills also operate briquetting systems. In these facilities a small amount of fines, that has been removed from the cold DRI by screening prior to feeding the EAF, is briquetted with a binder. Such briquettes have different uses in steel mills and foundries.

HBI - How?
Industrial Production.
Today, 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.

Figure 2: HBI Briquettes with different shapes and volumes

Figure 2 shows a selection of different HBI products. The typical volume of industrially manufactured briquettes is in the range of approx. 100 cm³. So far, this is independent of the method used in the preceding direct reduction process.

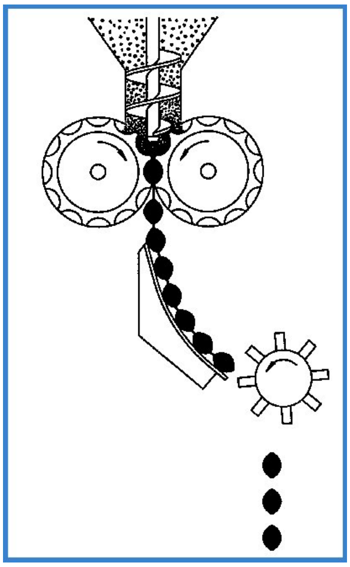


Figure 3 represents the hot briquetting process for the production of HBI. The direct reduced iron is discharged hot form the reduction process. With a screw this hot feed is pushed into the nip between two counterrotating rollers. Pockets in the synchronously rotating rollers form the briquettes. This 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 3: Typical schematic of hot briquetting.

The key component in hot briquetting is a specially designed roller press. Figures 4 and 5 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. 6 and 7):

- Briquetting press with screw feeder and material supply (1)
- Briquette string separator (impact separator (2) or tumbling drum (7)),
- Hot screen for the elimination of fines which occur during briquetting and separation (3),
- Product cooler (4),
- Bucket elevator for the recirculation of fines to the briquetting press (5),
- 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.

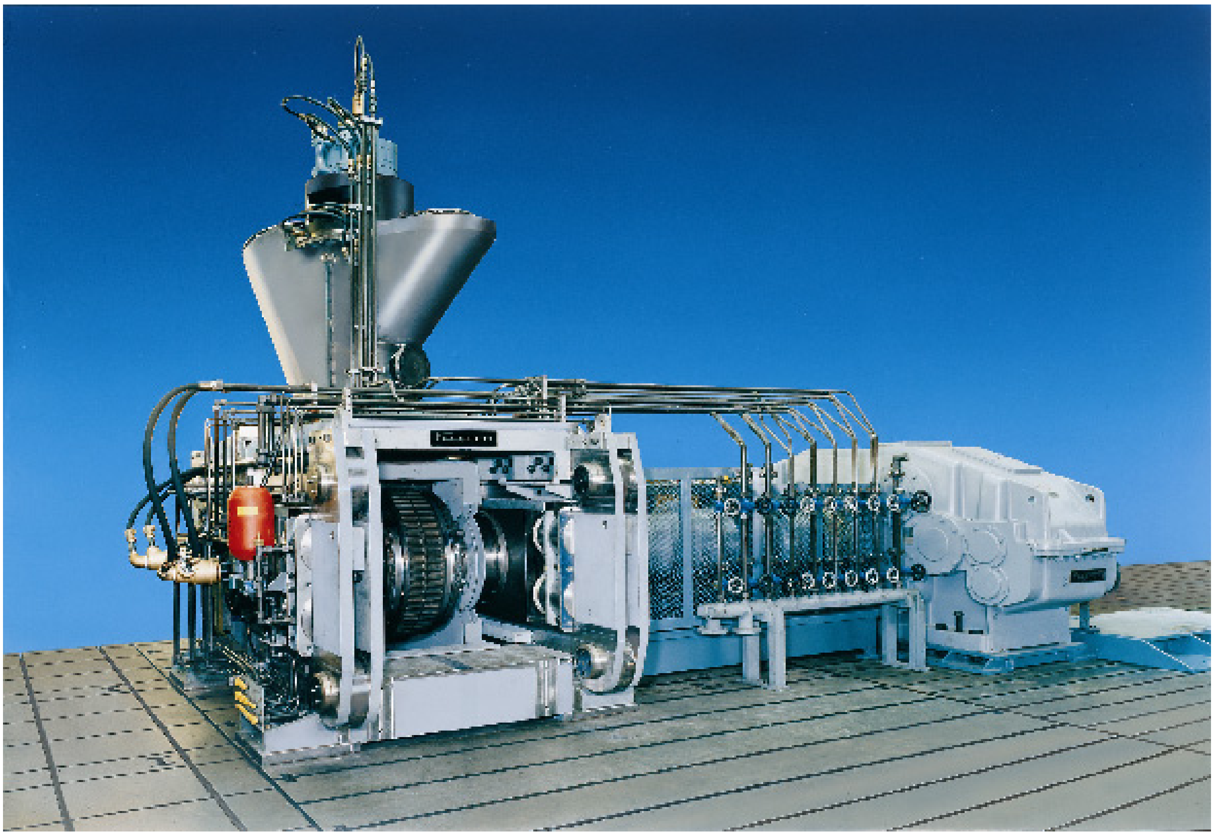


Figure 4: *Briquetting machine for DRI from pellets and lump ore*
Roller diameter 1,000 mm

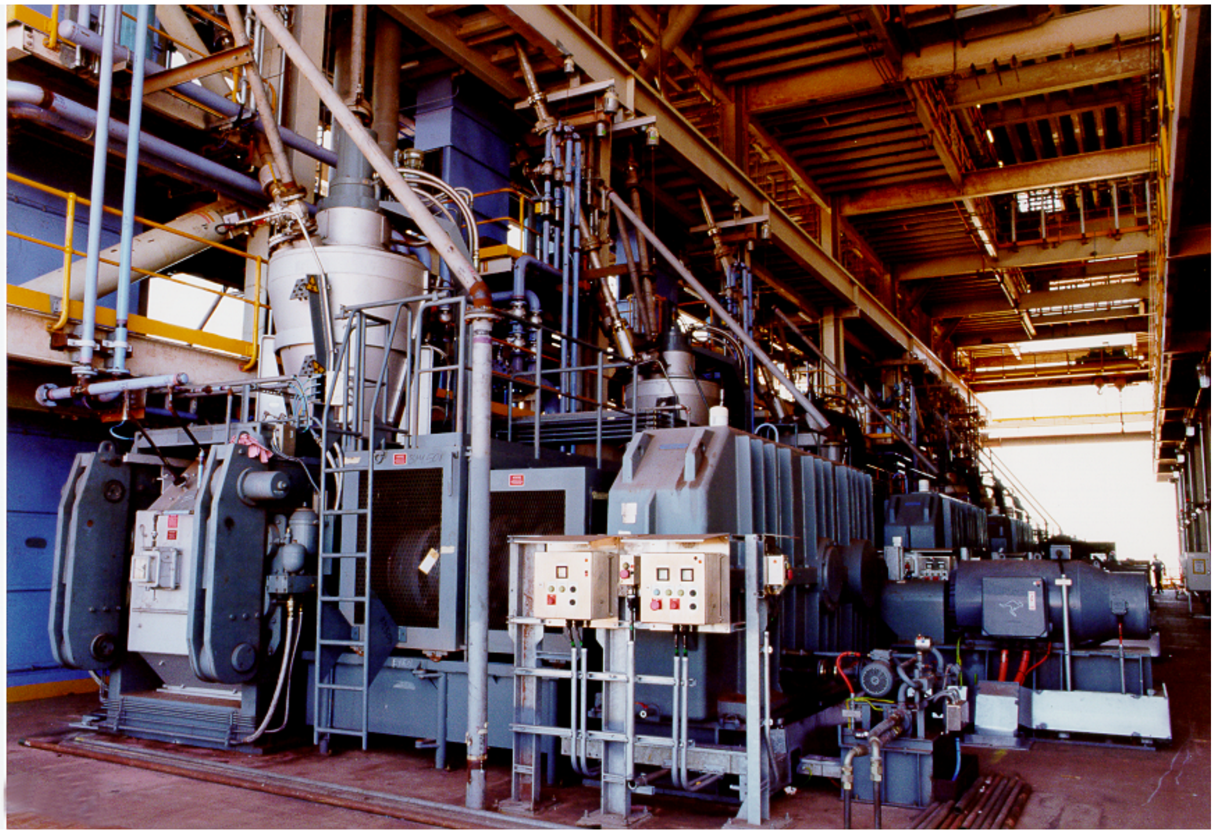
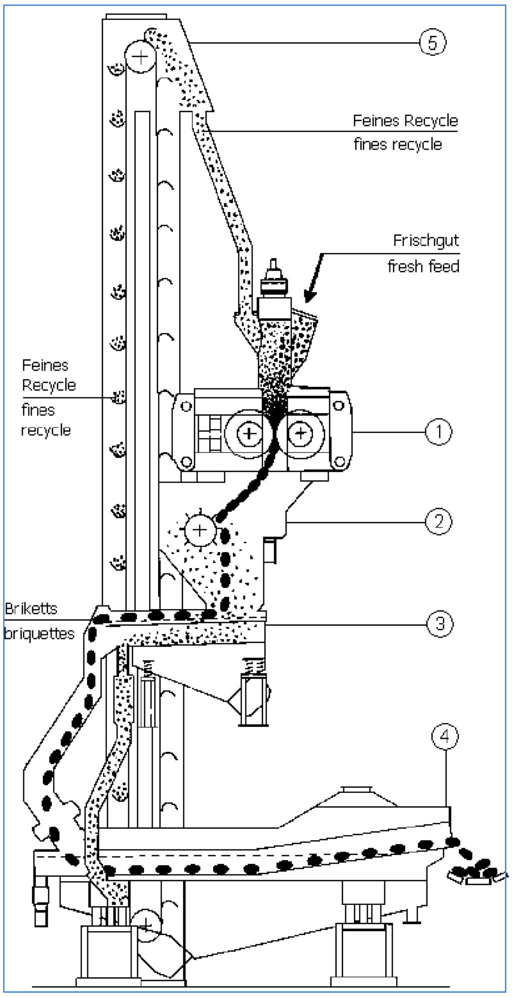


Figure 5: *Briquetting machine for the production of HBI from fine ore.*
Roller diameter 1,400 mm.



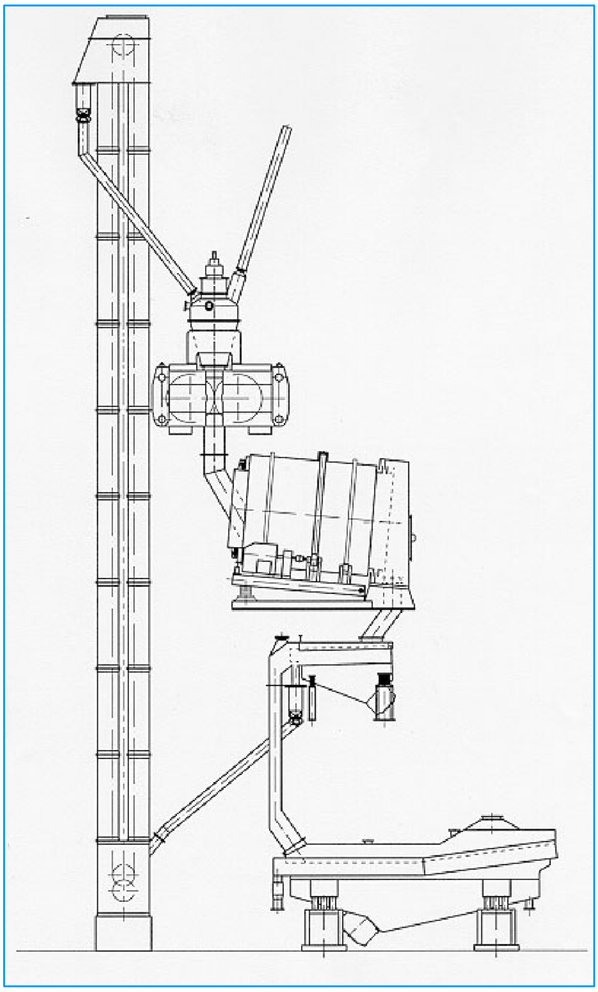


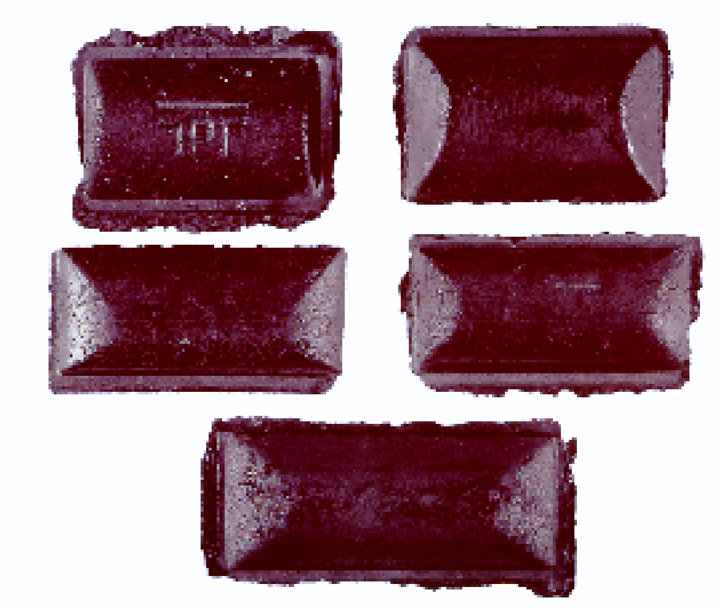
Figure 6: Flowsheet of a briquetting line for hot sponge iron from lump ore and pellets.

Figure 7: Briquetting line for hot sponge iron fines with drum separator.

HBI - Where?
Hot Briquetting for Different Direct Reduction 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 also eliminate the inherent handling problems of this material. Both direct reduction technologies are based on gaseous reductants.

More recent developments, including operation of one industrial plant, have shown that products from coal based processes (rotary hearth furnace) can be also briquetted hot at suitable conditions. The photographs in Figure 8 are examples of briquettes made of product from different direct reduction processes by hot briquetting.



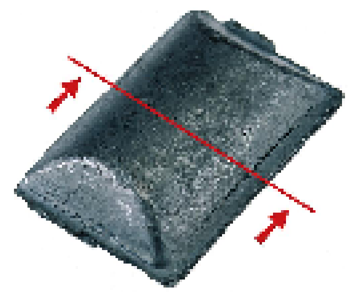
PUROFER FIOR/ FINMET

MIDREX HYL

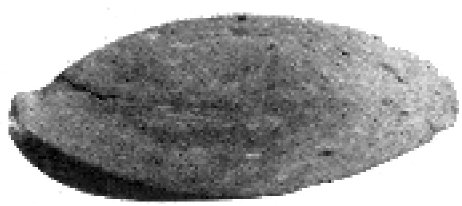
FASTMET

Figure 8: Briquettes made of product from different direct reduction processes by hot briquetting.

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. Some typical differences can be observed by evaluating the cross sectional cuts through briquettes from three different direct reduction processes (Figure 9).

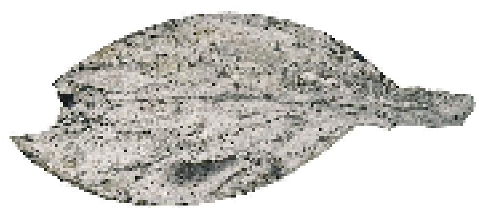


Depiction of the cross sectional cut and view



Fine ore (gas based reduction)

Pellets and lump ore (gas based reduction)



Pelletized fine ore (coal based reduction*)*

Figure 9: Cross sections through briquettes made with material from different direct reduction processes.

The polished and etched cross sections show in (9.3) that deformed pellets and lump ore pieces originating from a gas based shaft furnace technology are still visible in the structure while in (9.2) a more uniformly briquette results from the fine particles of a fluidized bed process. Photograph (9.4) depicts a briquette made from green pellets containing fine ore and coal as reductant that were reduced on a rotary hearth. Again, the outlines of the pellets are still visible and also their good deformability, particularly near and at the land area between adjacent briquettes. 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.)

HBI - Where to?
Status and Future Development.

The idea to convert iron sponge into a more valuable and, respectively, easier handlable product by mechanical densification is rather obvious and therefore, quite old. For example, in the January 1921 issue of the professional German journal "Stahl und Eisen" (Steel and Iron) an idea from 1857 of the Frenchman Chenot was mentioned. Quote: "The sponge featured a specific weight of 1.2 which was increased to 5 by pressing" [7].

However, a long and difficult time often passes from the first idea to the development of industrial methods and technologies. The fundamental work on the application of hot densification for direct reduced iron was first carried-out in the laboratory. Then, during the late 1960s and early 1970s the first pilot plants were built and operated. For example, the ESSO-FIOR technology was tested in a plant built and operated by McKee in Nova Scotia, Canada, and Thyssen's PUROFER process was evaluated in a semi industrial facility at Oberhausen, Germany.

Beginning in the late 1970s, the first sustained production runs of direct reduction plants with hot briquetting were accomplished using the FIOR process in Venezuela and a PUROFER plant in Iran. The final breakthrough of the technology occurred in the mid 1980s after the successful operation of the first MIDREX plant with hot briquetting at Sabah Gas Industries (today Amsteel) on the island of Labuan in Malaysia.

The present status of the technology is shown in Figure 10 which is a list of direct reduction plants with hot briquetting that are presently in operation or under construction. The distribution of these facilities in the world is depicted in Figure 11. Up to now a precondition for the economic operation of a merchant HBI plant was the availability of low cost natural gas. This fact can be easily recognized in the chart of Figure 11.

HBI Plants Worldwide

Startup	Plant	Location	Reduction Process	Capacity (Mt/y)	No. of Briquetting Maschines
1976	FIOR	Venezuela	FIOR (F)	0.4	3
1977	AHWAZ	Iran	PUROFER (PL)	0.33	3
1984	ANTARA STEEL	Malaysia	MIDREX (PL)	0.65	3
1990	ESSAR I+II	India	MIDREX (PL)	0.88	6
1990	OPCO (Minorca)	Venezuela	MIDREX (PL)	0.83	4
1990	VENPRECAR	Venezuela	MIDREX (PL)	0.72	3
1992	ESSAR III	India	MIDREX (PL)	0.44	3
1993	GRASIM	India	HYL III (PL)	0.75	3
1997	LISCO	Libya	MIDREX (PL)	0.65	3
1998	COMSIGUA	Venezuela	MIDREX (PL)	1.0	4
1999	VENPRECAR	Venezuela	MIDREX (PL)	Plant Expansion	1
~~1999~~	~~[BHP]~~	~~Australia~~	~~FINMET (F)~~	~~(2.0)~~	~~12~~
1999	LEBEDINSK I	Russia	HYL III (P)	1.0	4
1999	[ISG (CAL)]	Trinidad	CIRCORED (F)	0.5	3

[...] not operating (Status 2013)
~~[BHP]~~ dismantled

Coal Based = (C)
Fine Ore = (F)

Pellets = (P)
Pellets and Lump Ore = (PL)

HBI Plants Worldwide

Startup	Plant	Location	Reduction Process	Capacity (Mt/y)	No. of Briquetting Maschines
2000	MATESI (POSVEN)	Venezuela	HYL III (PL)	1.5	6
2000	ORINOCO IRON	Venezuela	FINMET (F)	2.2	12
2001	IRON DYNAMICS	USA	IRON DYN (C)	0.52	2
2006	ANTARA STEEL	Malaysia	MIDREX (PL)	Plant Expansion	1
2006/2007	ESSAR	India	MIDREX (PL)	0.75/1.5 (comb)	3
2006/2007	ESSAR	India	MIDREX (PL)	0.75/1.5 (comb)	3
2007	QASCO	Qatar	MIDREX (PL)	0.75/1.5 (comb)	3
2007	LEBEDINSK II	Russia	MIDREX (P)	1.4	2
2008	LION GROUP	Malaysia	MIDREX (PL)	0.9/1.5 (comb)	5
2010	SHADEED	Oman	MIDREX (PL)	0.7/1.5 (comb)	3
2011	SHADEED	Oman	MIDREX (PL)	Plant Expansion	1
2015	LEBEDINSK III	Russia	MIDREX (P)	1.8	7

Combined Plant HBI / DRI = (comb)

Coal Based = (C)
Fine Ore = (F)

Pellets = (P)
Pellets and Lump Ore = (PL)

Figure 10: HBI-Plants in operation and planned using pellets and lump ore (PL), pellets (P), fine ore (F) or coal-based rotary hearth [Status 2013]

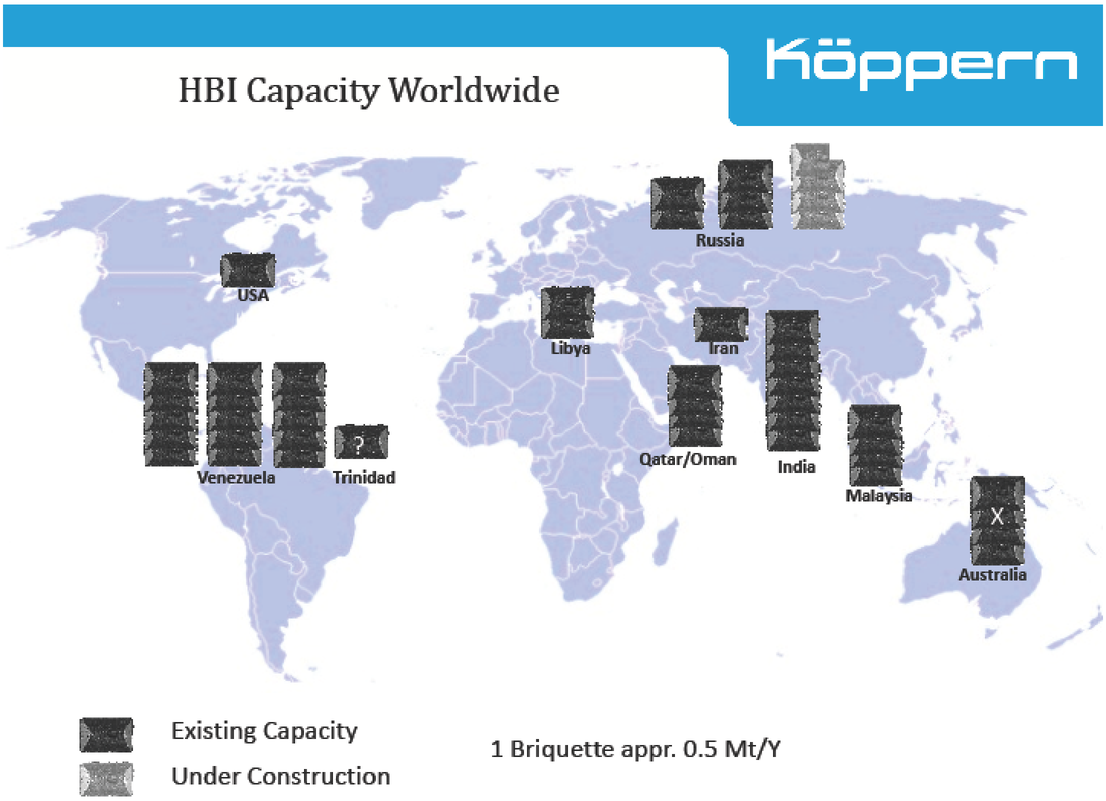


Figure 11: Locations and capacities of HBI facilities worldwide [Status 2013].

The years of start-up in the list of Figure 10 show that it took some time after the first successful operations until, in the 1990s, the production of HBI found a wider acceptance.

The a.m. figures are showing the status of 2013. An update about latest commissioning results will be given by Köppern in the presentation.

In the meantime hot briquetting has become the most reliable method for the passivation of direct reduced iron. This is true for materials from different kinds of direct reduction. Figure 12 illustrates the processes associated with the production of HBI using roller presses. Further developments which, at the present time, are still in the laboratory stage may add to this summary. The use of coal as a solid reductant (e.g. FASTMET) will result in the establishment of HBI merchant plants at new, alternative locations.

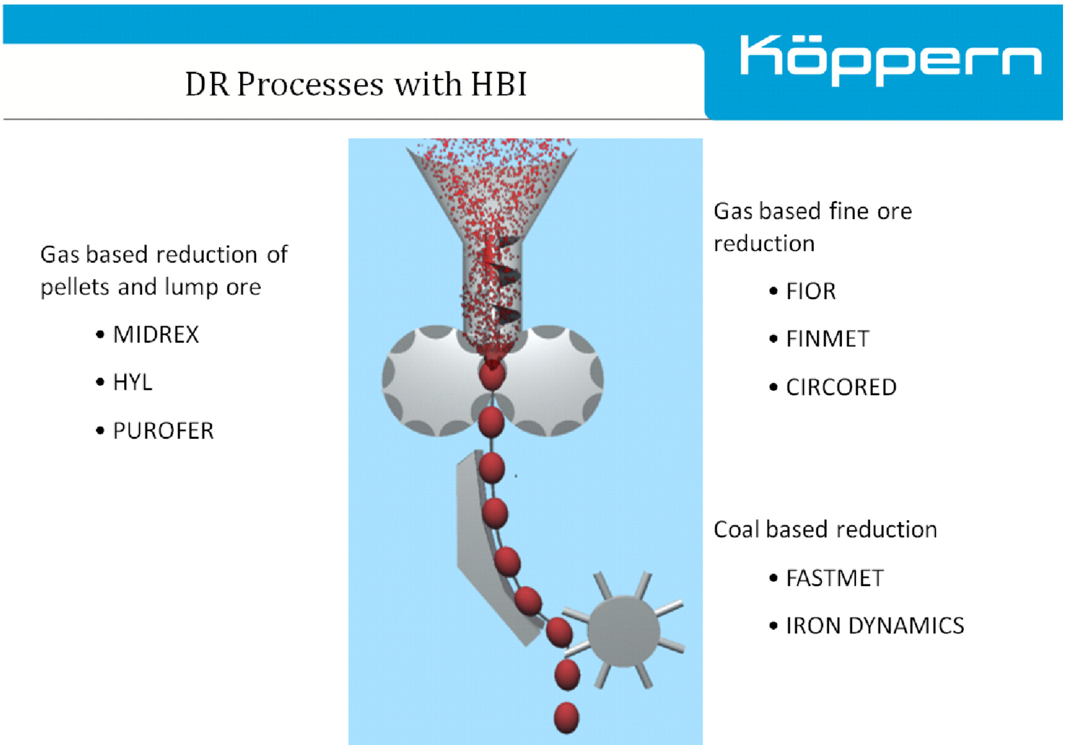


Figure 12: Direct reduction processes associated with hot briquetting.

Due to the worldwide recognition and acceptance of HBI as a reliable and predictable source of high quality iron units and a merchant commodity, considerable efforts are made to develop product standards. Test methods for quality control were first defined independently by the individual producers.
The evaluation of the briquettability of materials from different direct reduction processes and ores was developed by Maschinenfabrik KÖPPERN and compared with actual data from industrial plants [9].

In the meantime, an ISO committee is working on the establishment of internationally comparable standards for HBI (Figure 13) further confirming the increasing importance of this product for the international steel industry[10].

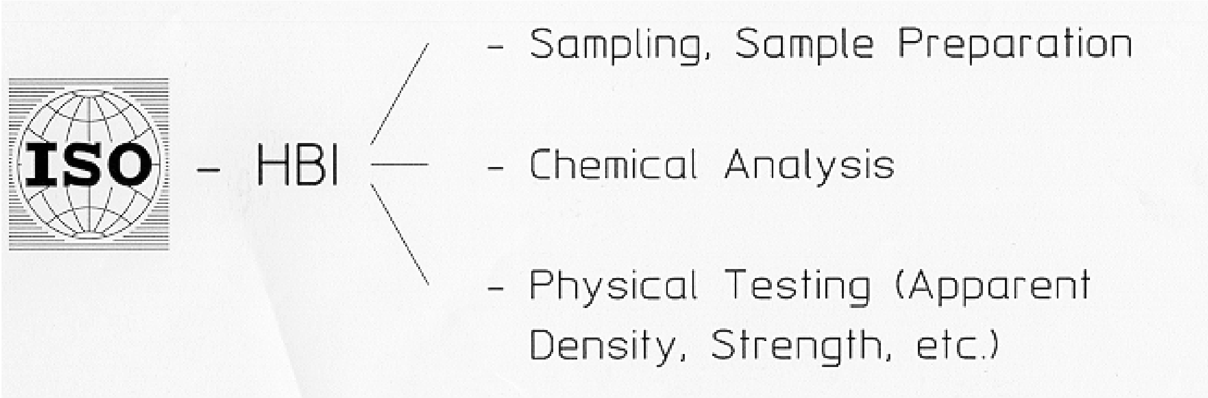


Figure 13: Areas of international standardization efforts for the characterization of HBI.

Conclusions.

Hot briquetting is the process of choice for the highest possible protection against problems associated with the tendency of sponge iron to reoxidize. The handling characteristics of HBI are similar to that of scrap. Additional advantages result from the consistent quality (clean iron units) and the uniform product size. Plants for the hot briquetting of direct reduced iron are successfully operating for many years and a considerable number of new plants is under construction.

New mini mill and EAF capacities were and are being installed in the world. A large percentage of the new installations will be dedicated to the manufacturing of flat products. Independently of whether the upper or lower limits of the capacity forecasts will be true, the necessary clean iron units will not be available from scrap only. This trend leads to the planning and realization of new DRI (not shown here) and HBI (see Figure 10) facilities.

Compared with DRI, HBI offers several advantages. In addition to the possibility to choose product size and shape, HBI does not require special conditions for storage, transport and handling. With DRI, even if ship holds and storage silos are inertized, a certain risk still remains.
Ship owners and insurance companies recognize and consider the widely demonstrated positive characteristics of HBI also in the relevant freight rates.
An EAF-based producer of steel who intends using direct reduced iron (typically 20 to 30 %) to improve the metallic charge by diluting impurities introduced by scrap, will not contemplate the installation of special handling facilities for DRI if safe HBI is available.

Therefore, HBI – as a safe product with easy handling and consistent quality will continue to be a preferred source of clean iron units for the open world market.

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