FINMET®
ADVANCED FINE ORE REDUCTION TECHNOLOGY

WOLFGANG HILLISCH *
ANTON EBERLE **
DR. LAWRENCE GOULD ***

SYNOPSIS :

FINMET® is a recently introduced fluidised-bed direct-reduction process which is based on the use of non-agglomerated iron ore fines as the feedstock and natural gas for the generation of reducing gas. Jointly developed by FIOR de Venezuela (now called rDI) and VOEST-ALPINE Industrieanlagenbau GmbH and Co (VAI) of Austria, this process features a number of decisive advantages in comparison with conventional pellet-based direct-reduction technologies. To date, two FINMET® plants are in operation; 1) BHP DRI, Port Hedland/Australia and 2) Orinoco Iron, Puerto Ordaz, Venezuela.

This paper presents a brief overview of the process and its advantages as well the status of plant operations at BHP DRI and Orinoco Iron.

* Product Manager, FINMET® Technology, VAI, Linz, Austria
** Senior Vice President Mineral and Reduction Technology, VAI, Linz, Austria
*** Exploration Geologist, VAI, Linz, Austria

INTRODUCTION

The ever-increasing global demand for metallic input materials of high quality and the shortage of suitable scrap grades calls for an increased production of scrap-substitute materials such as direct reduced iron (DRI) and hot briquetted iron (HBI).

Direct-reduced iron is predominantly produced in shaft furnaces where pellets or lump ore is reduced to metallic iron by a natural gas based reducing gas. In 1976, a new technology, named FIOR, was introduced in which iron ore fines are reduced to metallic iron in a cascade of fluidized bed reactors. The direct-reduced iron is compacted to hot-briquetted iron which is suitable for long-term storage. A drawback of FIOR technology is that it is characterized by relatively high energy and other consumption figures which means that its application is geographically limited to areas with extremely low gas prices. FIOR de Venezuela (rDI) has successfully operated this process at Puerto Ordaz, Venezuela for 25 years during which time more than 6 million tons of iron briquettes were produced.

In 1991 VAI and rDI decided to proceed with the development of an improved fluidized-bed process named FINMET®. The goal of this technology was to also utilize low-cost iron ore fines to produce HBI, however at similar energy and other consumption figures as in other pellet-based DR processes.

Two FINMET® plants are now in operation at Port Hedland, Australia and Puerto Ordaz, Venezuela. Production at BHP DRI's Port Hedland plant is gradually being increased to its full capacity of more than two million t/a. The FINMET® plant for Orinoco Iron at Puerto Ordaz is currently in the commissioning phase.

PROCESS DESCRIPTION

The FINMET® process (**Figure 1**) uses iron ore fines with a grain size of less than 12 mm which have to be dried to the point where they will freely flow through storage bins. This is done in fluidized bed dryers where the ore is heated up to approximately 100 °C which reduces the free water content to 0.1 to 0.2%. The dried ore is then transported to the top of the reactor structure by bucket elevators into a lock hopper system where the pressure is increased to the reactor pressure of approximately 10 bar(g). Four fluidized bed reactors are interconnected with gas and solids transfer lines. Ore fines flow downward by gravity from the upper to the lowermost reactor while reducing gas flows upwards in a countercurrent direction. This countercurrent flow of a multistage process improves the reduction efficiency in comparison with a single reactor process. The fine ore is heated in the first reactor (R4) to a temperature between 400–550 °C by the partially spent reducing gas from the previous reactor. The dust-laden gas from the fluidized bed is cleaned by internal reactor cyclones and returned to the fluidized bed via the cyclone diplegs.

The ore flows in a downward direction through the next reactors of the series and the degree of metallization continually increases at each step due to the reaction with progressively richer reducing gas. In the final, lowermost reactor (R1) temperatures in the range of up to 800 °C prevail.

The carbon content – over 90% in the form of iron carbide (Fe_3C) – of the metallised product can be adjusted to between 0.5 and 3% in the final reactor.

A mixture of recycled top gas and fresh gas generated in a steam reformer provides the gas required for reduction. The top gas exiting the uppermost reactor is first quenched and scrubbed in a wet scrubber. A small portion of the dedusted gas is removed to control the inert gas build-up in the system. This gas is mainly used as a fuel in the reducing gas furnace. The remaining recycle gas is returned via a recycle gas compressor to the process. The reformed gas stream as well as the recycle gas stream (or a portion thereof) are sent through a CO_2 removal system. The gas is then preheated in the reducing gas furnace up to approx. 850 °C before being sent to the reactors..

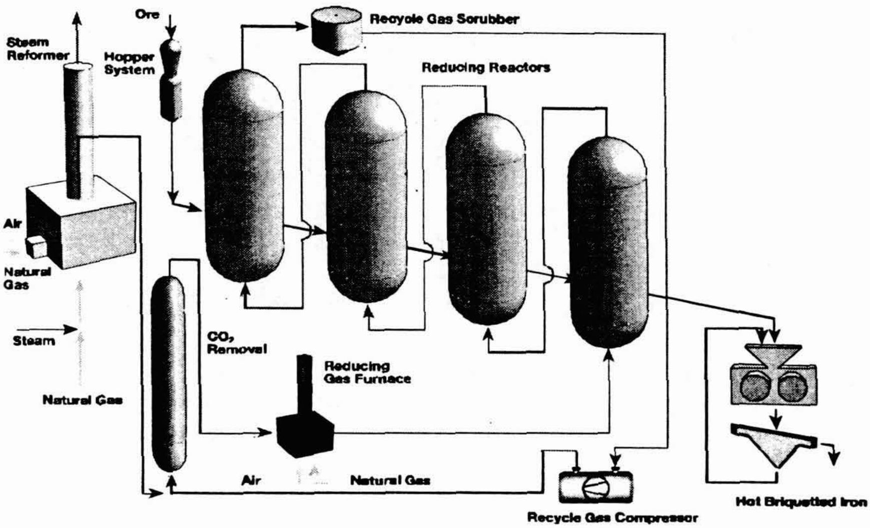

Figure 1 : FINMET® Process Flowsheet

The hot DRI fines are transported by a pneumatic lift system (riser) to the briquetting area into an insulated bin. From there the fines flow by gravity into double-roll briquetting machines where they are compacted to a density of over 5 kg/dm³. The briquette strings exiting the machines are separated into individual briquettes. Fines generated in the breaking process are screened and recycled to the briquetting system. The HBI product is then cooled and transported to the briquette storage area.

ADVANTAGES OF FINMET® TECHNOLOGY

Low-Cost Iron Ore Raw Materials

One of the essential advantages offered by FINMET® technology is that it can directly process widely available low-cost iron ore fines (**Figure 2**) in a series of fluidized bed reactors without the need for prior pelletizing.

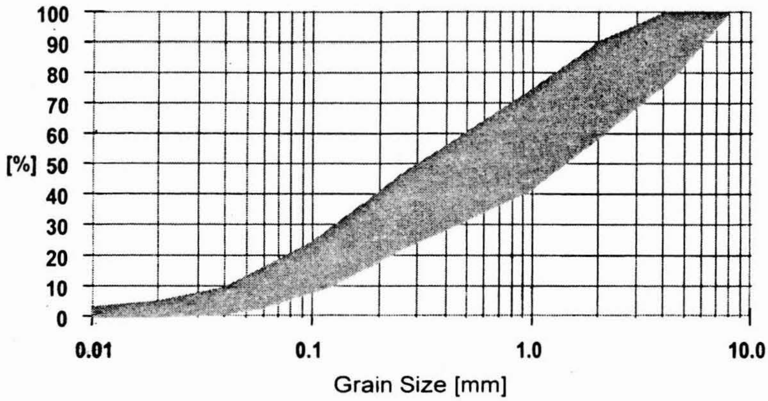

Figure 2 : Typical FINMET® Grain Size Distribution

The main requirement for the iron oxide raw materials is that the iron content should be as high as possible with a minimum of gangue content due to the fact that as in all direct-reduction processes the gangue will remain in the final product.

With the usage of low-cost iron ore fines savings of around 40% for the ferrous raw materials can be achieved at similar energy consumption levels compared with pellet-based DR-technologies. This allows for an attractive production cost reduction in the range of 20–25% (**Table 1**).

Superior Properties of FINMET® HBI

Product Description

FINMET® briquettes are uniform in size, easy to handle and transport and can be stored under open air conditions without the need for further treatment or passivation. They have a high degree of metallization, high density and the carbon content can be adjusted within a certain range in accordance with EAF steelmaking requirements (**Table 2**).

Table 1 : Production Cost Comparison FINMET® versus Conventional DR Processes

	unit	USD/unit	FINMET® Consumption per t HBI	FINMET® USD/t HBI	Typ. Conv. DR Process Consumption per t HBI	Typ. Conv. DR Process USD/t HBI
Material Cost						
Pellet	t	43,00	0,00	0,00	1,05	45,15
Lump Ore	t	38,00	0,00	0,00	0,45	17,10
Fine Ore	t	26,00	1,50	39,00	0,00	0,00
Total Material Cost				**39,00**		**62,25**
Energies & Utilities						
Natural Gas	GJ	0,68	13,30	9,04	10,50	7,14
Electricity	kWh	0,02	165,00	3,30	120,00	2,40
Water	m³	0,50	2,00	1,00	1,50	0,75
Total Energies & Utilities Cost				**13,34**		**10,29**
Other Operating Cost						
Labour				1,50		1,00
Maintenance & consumables				7,50		6,00
Total Other Op. Cost				**9,00**		**7,00**
Production Cost per t HBI				**61,34**		**79,54**

Table 2 : Typical Specification for FINMET® HBI

Total Iron (Fe)	91–94 % (depending on ore input)
Metallic Iron	84–86 % (depending on ore input)
Metallization	91–93 %
Carbon	0.5–3.0 %
Briquette Density	> 5.0 t/m³
Bulk Density	2.8 t/m³

Fines Generation and Physical Strength

Compared to pellet/lump ore-based HBI, FINMET® HBI is denser and more uniform and compact, i.e. without voids and cracks which can lead to breakage, fines generation and internal oxidation.

This means that FINMET® HBI offers other significant advantages for steel producers as it

- Can be stored in the open with minimum loss in metallization
- Improves the loading efficiency (i.e. fewer scrap-bucket charges) because of its higher density
- Can be continuously charged to metallurgical vessels, etc.

Due to its homogeneous composition and compact nature, handling, loading and discharging of FINMET® briquettes generates only approximately 2% fines compared with 7% for other HBI products. This means an increased overall production yield.

Tumble tests conducted on 15-kg samples of conventional HBI and fines-based HBI showed a much better size stability for the FINMET® briquettes.

The benefits of stronger briquettes are also evidenced at BHP DRI's plant in Western Australia where following a 7.2-km transport via overland conveyor from the FINMET® plant to the harbor's ship-loading facilities the fines content of the product is only around 1%, despite numerous conveyor take over points.

A high fines percentage frequently leads to handling, feeding and operational problems as follows:

- Fines have a far greater tendency to self-combust during transit and storage.
- Fines oxidize more easily than whole briquettes and exhibit a 20% reduced metallization level in comparison with whole briquettes after only 30 to 40 days in open storage.
- A high percentage of fines charged to the EAF is extracted with the offgas meaning a loss in metallic charge and potential damage to the downstream bag filters.

CURRENT FINMET® PROJECTS

BHP DRI, Port Hedland, Australia

Project Background

With a nominal plant capacity of 2,000,000 t/a the FINMET® plant is the largest merchant HBI plant in the world. Completed early 1999 by BHP and VAI, the plant is located on the 120-ha Boodarie pastoral lease, about 20 km south of Port Hedland, Western Australia. The operating company was named BHP DRI and the product was branded "Boodarie Iron". A number of auspicious factors exist for a successful DR iron business, including :

- Availability of quality iron ore (Mount Newman iron ore fines)
- Competitively priced energy
- Production technology know-how
- Availability of a qualified workforce
- Good port facilities
- Proximity to regional consumers

The total project investment comprised the following:

- Two FINMET® production modules, each with two reactor trains
- Two gas-reforming plants
- A 5.5 million t/a beneficiation plant to upgrade the iron ore
- An on-site iron-ore stockpiling area with stackers and reclaimers
- A briquetting plant consisting of 12 briquetting presses
- A briquette stockpile and handling facility on Finucane Island
- A 1.1 km under-harbor tunnel to supply ore from the Nelson Point blending yards
- A 7.2 km overland conveyor belt for carrying ore to the plant as well as Boodarie Iron back to the Finucane Island shiploader for export

Start up and initial production situation

Following completion of construction activities, cold and hot testing of the plant facilities were carried out. The FINMET® plant was then started up and the first briquette produced on February 18, 1999. Each of the four production trains was subsequently put into operation.

Contrary to the original observations based on laboratory and large-scale tests, the iron ore in the uppermost Reactor 4 of the FINMET® plant was converted to a highly dense magnetite structure with minimum porosity. This caused a topochemical reduction of certain iron ore fractions which impeded complete reduction of the inner particle volumes in the next reactor stages (**Figure 3**).

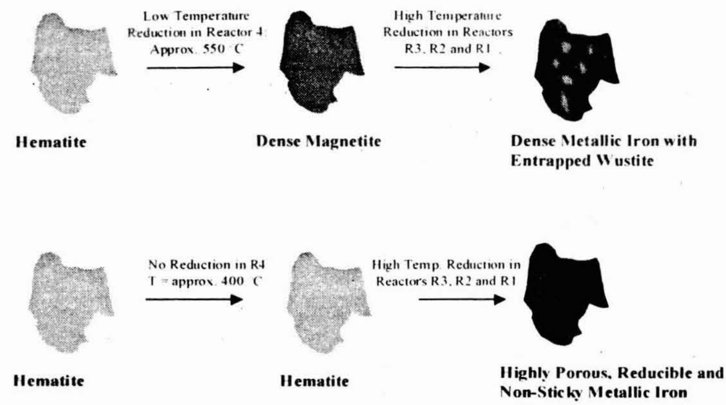

Figure 3: Topochemical vs. homogeneous reduction behaviour of Mt. Newman iron ore fines

Because the particle surfaces were highly metallised, increased sticking was observed which caused blockages during material transfer from one reactor to the next. Additionally, the desired degree of metallisation could not be consistently achieved at the originally anticipated process parameters, i.e. reactor temperatures and reformed gas flow rates.

Process Improvements

On the basis of plant observations BHP and VAI assumed that the prevailing Reactor 4 conditions at approx. 550 °C were the primary cause of the topochemical reduction behaviour. Specific laboratory reduction tests were then conducted with the aim to determine the optimum operating regime for Reactor 4 with respect to temperature and ore residence time in order to overcome the encountered problems.

The transformation of hematite into magnetite is in general thermodynamically favoured under Reactor 4 conditions (**Figure 4**), but can be suppressed by lowering the reactor temperature to approximately 400 °C with the correspondingly slower reaction kinetics (**Figure 5**). At the lower R4 temperature no topochemical reduction behaviour takes place in the next reactors of the series where higher temperatures and more intense reducing conditions prevail.

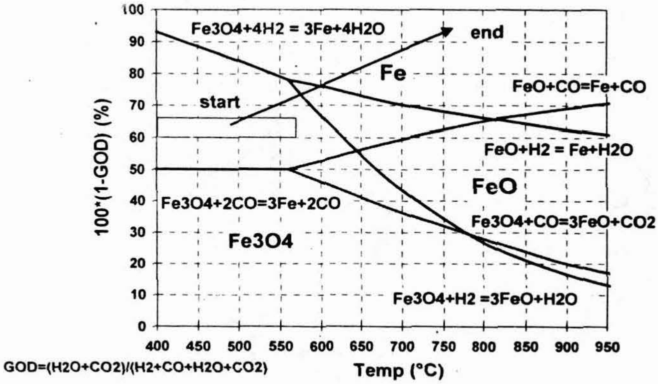

Figure 4 : Baur-Glässner Equilibrium Diagram

Additional experiments were then carried out to investigate the influence of the Reactor 4 residence time on the final product metallisation, as seen in **Figure 6**. The results showed that in average the final metallisation increased by 1% per 10 minutes reduced residence time in Reactor 4.

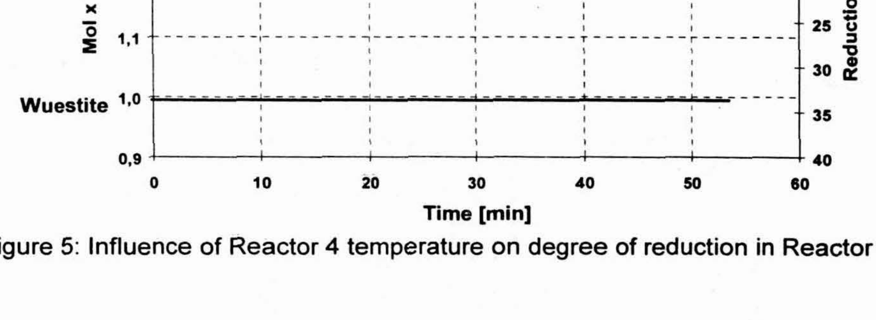

Figure 5: Influence of Reactor 4 temperature on degree of reduction in Reactor 4

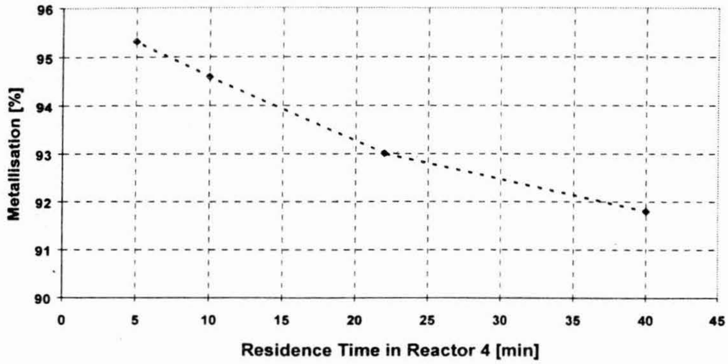

Figure 6: Final product metallisation as function of Reactor 4 residence time

Based on these findings it was decided to operate Reactor 4 of the FINMET® plant at a lower temperature in order to minimise the formation of dense, nonporous magnetite and to conduct the first reduction step in Reactor 3 at a higher process temperature. Additionally, the ore residence time in Reactor 4 was decreased.

To enable the proper adjustment of Reactor 4 temperatures a water injection system was installed in each of the four reactor trains by the end of the year 2000. Following restart of the FINMET® plant, a homogeneous reduction behaviour of the ore fines was immediately observed, which considerably decreased the sticking tendency of the material. Due to the increased porosity of the fines, the required product metallisation was continuously achieved under the foreseen process conditions. Thus the original problems of sticking and in achieving the desired degree of final product metallisation were solved.

Table 3 shows the average product quality and train production rate during a period of one week.

Table 3 : Average train production results following installation of the water-injection system

Parameter	Value
Production rate	> 75 t/h
Metallic iron	86.0%
Total iron	93.2%
Metallisation	92.3%
Carbon	1.0%
Briquette density	> 5.0 g/dm^3

In January 2001 three production trains were simultaneously in operation. The effectiveness of the implemented solution can be demonstrated by the fact that over the past several weeks new records were set with respect to daily production, campaign production and campaign lengths. **On February 13, 2001 BHP DRI's FINMET® plant produced its first millionth ton of HBI.**

Orinoco Iron, Puerto Ordaz, Venezuela

On April 12, 1997, Orinoco Iron C.A. awarded VAI a contract for a FINMET® plant to be constructed at Puerto Ordaz, Venezuela.

The plant consists of 4 trains and will also have a nominal production capacity of 2 million t/a of HBI. San Isidro iron ore fines are used as the principal feedstock and contain about 67% total iron on a dry basis.

In summer 2000 the first briquettes were produced in the first train with excellent quality. Plant commissioning is currently in progress and the plant will be gradually ramped up to its nominal design capacity in 2001.

CONCLUDING REMARKS

Based on the utilization of iron ore fines FINMET® technology offers both producers and consumers of HBI a number of decisive production, product and cost advantages. The initial "teething" problems normally encountered with the introduction of any new technology have been solved or are in the process of being rectified. VAI is confident that the FINMET® process will command the major share of future investments in new direct-reduction facilities.

CONTACT

VOEST-ALPINE Industrieanlagenbau GmbH & Co (VAI)
Reduction Technology
Mr. Wolfgang Hillisch, Product Manager for FINMET® Technology
Turmstrasse 44, P.O. Box 4
A-4031 Linz/Austria

Tel.:	+43 70 6592-8624
Fax:	+43 70 6980-6755
E-mail:	Contact.Finmet@vai.at
FINMET® Roompage:	www.aboutfinmet.com
VAI Homepage:	www.vai.at