FLEXIBILITY IN USING IRON ORES FOR DIRECT REDUCTION

Raul G. Morales
Comercial Manager

Hylsa Technology Division
Monterrey - Mexico

SUMMARY

In Direct Reduction (DR) processes, the characteristics and cost of available iron ores play a very important role. The selection of suitable raw materials will optimize productivity, energy consumption and the overall economy of industrial plants.

The raw material specifications for direct reduction processes should be determined primarily by the overall economics of both the direct reduction plant and the associated steelmaking plant.

Since the use of economic iron ores is the key for the feasibility of direct reduction projects, it is of prime importance the flexibility of a DR technology in processing different iron ores.

KEY WORDS

Direct reduction (DR), Direct Reduced Iron (DRI), DR grade-iron ores, DR plant, DR technology, Hot Briquetted Iron (HBI), metallization.

1. INTRODUCTION

Many commercially available DR grade-iron ores, both in pellet and lump ore form, have been extensively used in direct reduction plants. Therefore, their behavior during reduction conditions is already well known to DR plants operators.

However, there are some other iron ores, from different parts of the world, whose properties have not been evaluated for direct reduction. It is therefore necessary for the DR technologist to have accurate methods available for correlating small/medium scale test results with industrial scale performance.

HYL has been actively involved in the direct reduction field since the 1950's. Experiences gathered from industrial operations in fixed bed and moving bed reactors, together with an active research and development organization, support a very deep knowledge on the behavior of different iron ores in the direct reduction process.

The flexibility of the DR technology in using different raw materials is a key factor for cost optimization. In this regard, HYL operating plants have proven this flexibility using cheaper iron ores, either in pellet or lump ore form.

2. HYL DIRECT REDUCTION PROCESS

The HYL process concept is presented in Fig. 1. The process is designed for the direct reduction of iron ores (in pellet or in lump form) by the use of reducing gases in a solid-gas moving bed reactor. Oxygen is removed from the iron ores by chemical reactions based on hydrogen (H_2) and carbon monoxide (CO), for the production of highly metallized Direct Reduced Iron (DRI).

In the reduction reactor, iron carbide (Fe_3C) is also formed by the combination of carbon with metallic iron from the reduced product.

The operating conditions in the HYL process are based on a reducing gas composition rich in hydrogen (70%-87%), elevated pressure (> 5.5 kg/cm^2) and high reduction temperature (> 920 °C).

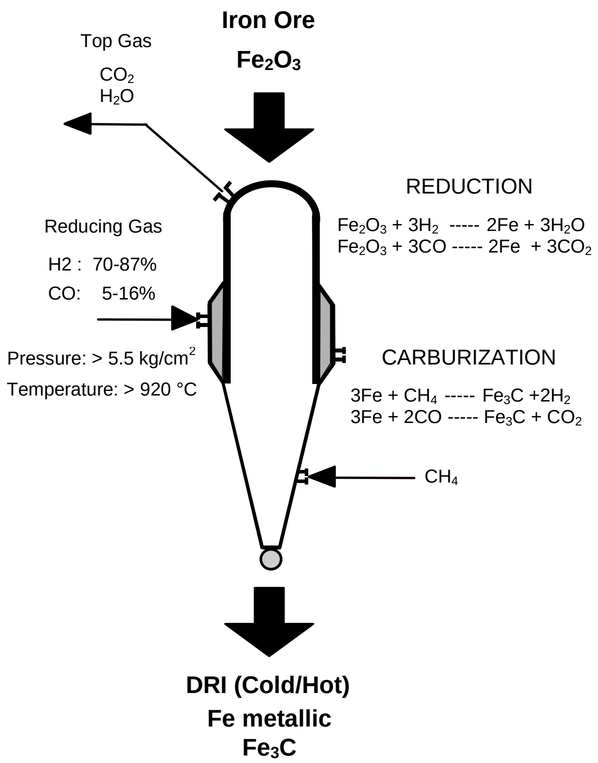

FIG. 1- HYL direct reduction process

Presented at the Metal Bulletin-2nd. Latin American Steel & Iron Ore Conference, Rio de Janeiro, Brazil, April 2000

3. TYPICAL MATERIAL BALANCE

A typical material balance for HYL plants is shown in Fig. 2. Iron ore received at the plant battery limits is normally screened to 6.3 mm. or to 3.2 mm., depending on the iron ore quality and on the specific operating practices of the DR plant.

The main chemical reactions occurring in the direct reduction process are related to oxygen removal and carbon incorporation. The chemical change is the formation of metallic iron and iron carbide.

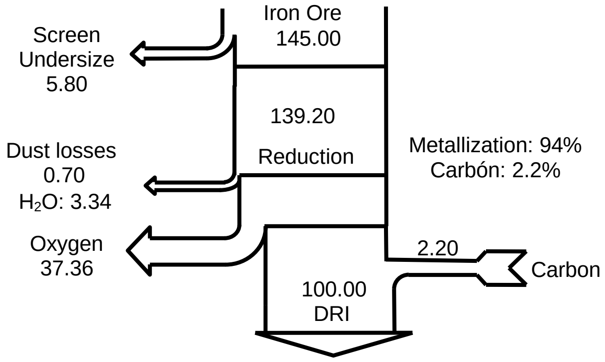

FIG. 2- Typical material balance

There is a fraction of the solid fine material that is carried with the gas stream, depending on the size distribution of the solid material and the reducing gas velocity through the reactor. This iron dust is normally removed from the gas stream in a quenching/scrubbing system, and then recovered as sludge in the clarifier of the cooling water systems.

For a typical iron ore mixture, based on 70% pellets and 30% lump ore, the estimated iron ore consumption is about 1.45 ton/ton DRI for 94% metallization and 2.2% carbon.

4. DRI/HBI PRODUCTION COSTS

The heavier component of the DRI/HBI production cost is the iron ore factor. As shown in Table 1, for a DR plant using 100% pellets at international prices, the DRI direct production cost is estimated to be about 90 US$/ton. About 66% of this production cost is related to the iron ore cost, being the rest related to natural gas, electricity, water and miscellaneous items.

It is clear from these data, that the use of economic iron ores is the key for the feasibility of direct reduction projects. Therefore, it is of prime importance the flexibility of a DR technology in processing different iron ores, with satisfactory results in productivity, product quality, operating reliability and energy consumption.

Table 1 - DRI production cost for 100% pellet

Item	Unit	Cons.	Price (US$)	Cost (US$)
Iron ore pellets	ton	1.42	42.00	59.64
Natural gas	Gcal	2.40	8.75	21.00
Electricity	kWh	70.00	0.03	2.10
Water	m^3	1.50	0.20	0.30
Miscellaneous	-----	-----	-----	7.00
Direct production cost				90.04

In moving bed DR processes, one of the natural trends for cost reduction is to increase the amount of lump ore in the iron ore feed. However, although in most of the cases lump ore is cheaper than pellet, this is not a general rule and a cost comparison should be made for each particular case. In general, DR grade-lump ores available in the international market can be used in higher percentages in HYL DR plants. An example of the impact in the direct production cost is presented in Table 2, for 70% pellet/30% lump ore.

Table 2 - DRI production cost for 70% pellet/30% lump ore

Item	Unit	Cons.	Price (US$)	Cost (US$)
Iron ore pellets	ton	1.02	42.00	42.84
Lump ore	ton	0.43	37.00	15.91
Natural gas	Gcal	2.40	8.75	21.00
Electricity	kWh	70.00	0.03	2.10
Water	m^3	1.50	0.20	0.30
Miscellaneous	-----	-----	-----	7.00
Direct production cost				89.15

There are some deposits of DR grade- lump ores, wherefrom the material can be made available at very low prices. However, although the chemical and physical properties of the ore are acceptable, the behavior during reduction should be carefully analyzed particularly regarding material disintegration. The productivity, quality and performance issues, for these raw materials, must define the complete economic equation of the DR plant.

An example of the impact of using a cheap lump ore in HYL plants in shown in Table 3. As it can be observed, some penalties have been considered in the iron ore and energy consumption and the production of briquettes (HBI) has been considered necessary due to an expected higher fines generation. Anyway, the HBI production cost can be very attractive, provided that the DR plant is properly designed to process this specific raw material.

Table 3 - HBI Production cost for 100% lump

Item	Unit	Cons.	Price (US$)	Cost (US$)
Lump ore	ton	1.50	18.00	27.00
Natural gas	Gcal	2.50	8.75	21.88
Electricity	kWh	80.00	0.03	2.40
Water	m^3	1.60	0.20	0.32
Miscellaneous	-----	-----	-----	8.00
Briquetting	-----	-----	-----	3.50
Direct production cost				63.10

Another interesting option is for those iron ore mining companies, which are in position to integrate the mine and the DR plant, with the incorporation of a pelletizing plant. The direct production cost for this case is presented in Table 4.

Table 4 - DRI production cost with pelletizing

Item	Unit	Cons.	Price (US$)	Cost (US$)
Iron ore pellets	ton	1.42	29.00	41.18
Natural gas	Gcal	2.40	8.75	21.00
Electricity	kWh	70.00	0.03	2.10
Water	m^3	1.50	0.20	0.30
Miscellaneous	-----	-----	-----	7.00
Direct production cost				71.58

5. DR GRADE IRON ORES

The raw materials most suitable for direct reduction-steelmaking are selected according to the following criteria:

- Chemical and physical characteristics.
- Reduction properties.
- Overall economics of both direct reduction and steelmaking.

The typical range of chemical analysis for DR grade-iron ores is shown in Table 5 and a comparison for different iron ore sources is presented in Table 6.

For the HYL direct reduction process, there are not practical limitations regarding the chemical composition of the iron ore. Common impurities such as sulphur and phosphorous, which can be present in some particular ores in relatively high concentration, can be used without any technical limitation in HYL plants.

Particularly, regarding the sulphur content in iron ores, the HYL process is very flexible for using high-sulphur feedstocks, since reducing gas is not recycled through a reformer, and thus the possibility of poisoning the reformer catalyst by sulphur does not exist. Moreover, most of the sulphur from the iron ore, converted to H_2S in the reduction reactor, is eliminated from the process in subsequent separation steps, i.e. quench towers and CO_2 removal unit. Therefore, DRI produced in HYL plants has typically low sulphur levels.

Table 5 - DR grade-iron ore composition

	(% weight)
Fe Total	65.00-69.00
Gangue	1.40-7.00
Phosphorous	0.01-0.10
Sulphur	0.001-0.05
$SiO_2 + Al_2O_3$	1.10-4.00
CaO + MgO	0.10-3.00
$Na_2O + K_2O$	0.05-0.20
CaO/SiO_2	0.02-1.50

Table 6 - Examples of iron ore sources

	Pellet A	Pellet B	Lump A	Lump B
Fe Total	68.00	67.80	68.10	67.50
FeO	0.10	0.60	1.61	1.15
CaO	0.70	0.52	0.44	0.50
MgO	0.30	0.57	0.10	0.50
SiO_2	1.08	1.56	0.47	1.00
Al_2O_3	0.60	0.34	1.24	1.00
S	0.003	0.005	0.002	0.007
P	0.018	0.023	0.030	0.030
Others	0.09	0.12	0.03	0.09
L.O.I.	-----	-----	0.50	0.50
Gangue	2.79	3.13	2.82	3.62

It should be stressed that a proper selection of iron ores is related to the overall economics of the direct reduction, steelmaking and downstream processes. Although a low chemical quality of the iron ore will not affect adversely the reduction process, the energy needed for melting DRI in the electric arc furnace is influenced by the DRI metallization, carbon content, gangue content and basicity.

6. DRI/HBI QUALITY

The economy of the overall steelmaking process (DR-EAF) is the key condition for the specification of the iron ore chemical composition.

DRI and HBI are raw materials used by their iron content but which, due to their composition and characteristics (Table 7), have a number of differences which lead to a different behavior than scrap in the meltshop. The three main chemical factors used to characterize a particular DRI/HBI are the metallization level, the content and form of carbon, and the content and type of gangue.
The typical metallization levels in modern DR processes vary in a range from 92% to 95%. In the HYL process, the DRI carbon content can be controlled up to 5.0%, in order to reach an optimum level for melting in the EAF. For this total carbon content, about 90% is in the form of iron carbide (Fe_3C).

Table 7 - DRI/HBI Quality

Metallization (%)	92.0-95.0
Carbon (%)	1.10-5.00
Total Fe (%)	84.0-95.5
Metallic Fe (%)	80.0-90.0
Gangue (%)	1.90-9.10
P (%)	0.013-0.14
S (%)	0.001-0.07

Another important factor, influencing the electrical energy consumption during DRI/HBI melting in the EAF, is the gangue quantity and composition. In order to be melted, the gangue oxides require additional energy consumption.

The phosphorous and sulphur content in DRI/HBI depends primarily on the composition of the pellet or lump ore used in the process. A high content of these elements in DRI/HBI could affect adversely the liquid steel quality.

The content of residual elements such as copper, nickel, chromium, molybdenum and tin is very low in most of the commercially available iron ores. Lead, zinc and antimony are normally absent.

7. IRON ORE BEHAVIOR IN DR PLANTS

In direct reduction plants, the iron ore behavior at reduction conditions is the most important factor to determine the design conditions for processing a particular iron ore.

7.1. Reducibility

It indicates the velocity at which the iron ore can be reduced. The reducing gas flow is set according to the ore reducibility. Most of the commercially available iron ores have shown adequate reducibility for being processed in HYL direct reduction plants.

7.2. Sticking Tendency

The sticking tendency of an iron ore represents its tendency to form bonds between molecules of different particles, and as a consequence clusters, which could lead to solids flow problems. Since this phenomenon is promoted by heat, the reduction conditions, i.e. reducing gas flow and temperature, are adjusted according to the sticking tendency of the iron ore to be processed.
To minimize the sticking tendency of iron ores during reduction, HYL plants incorporate a coating unit, which is utilized for spraying small amounts of a cement-water slurry or an alternative material to the iron ore feed. The cement consumption (dry basis) is about 4-6 kg per ton of iron ore charged to the reactor.

7.3. Disintegration Tendency

Besides the disintegration associated to the mechanical strength of the ore, thermal fragmentation will occur during the reduction process, first as the ore heats, followed by reduction fragmentation as the ore starts to reduce to magnetite.

The disintegration tendency of the iron ore at reduction conditions must be properly evaluated for any direct reduction process.

8. IRON ORE EVALUATION

The quality specification of iron ores, to be used in Direct Reduction (DR) plants, includes the chemical, physical and reduction properties.

Historically, the first specifications were taken from models similar to those already developed for the blast furnace. Once DR processes accumulated enough experience, the tests conditions and evaluations were adjusted in order to better represent what actually takes place in a DR process.

HYL maintains an active research and development organization, which has developed extensive knowledge on the evaluation and behavior of iron ores for the direct reduction process. This evaluation can be performed at different levels, depending on the specific information requirements for each particular ore.

- Laboratory tests.
- Pilot plant tests.
- Basket tests.
- Industrial plant tests (slices).
- Industrial plant tests (full scale).

9. PROCESS PARAMETERS

9.1. Reduction temperature

The operation at high temperature in DR plants leads to better plant productivity (Fig. 3).

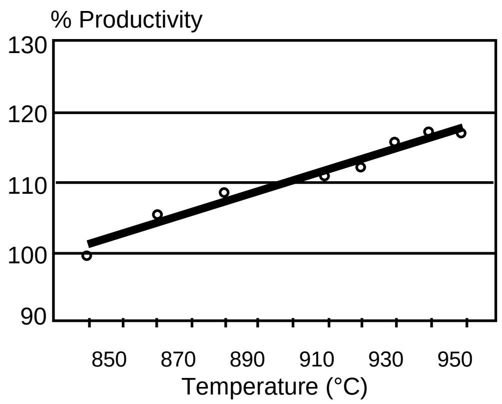

FIG. 3 - Effect of temperature on productivity

However, in a DR process the maximum operating temperature could be limited by the sticking tendency of the iron ore feed.

Most HYL plants operate at reduction temperatures up to 980 °C, increasing the reducing gas temperature from 920 °C (heater outlet) to 980 °C (reactor inlet) by means of oxygen injection at the transfer line between the heater and reactor. In the HYL self-reforming scheme (maximum O_2 injection), the reducing gas temperature at the reactor inlet is about 1,020 °C.

9.2. Operating pressure

The operation at high pressure in the reduction reactor has the main advantage of feeding larger mass flowrates for a given volume flowrate. Under these conditions, it is possible to increase the reactor productivity and to keep the gas velocity through the reactor below the point at which the burden could be fluidized. At lower gas velocities, the pressure drop through the reactor is also smaller.

Therefore, the processing of friable ores can be carried out in better conditions. As some of these ores generate an important amount of fines, the operation at high pressure assures that the amount of solid material carried by the gas stream is kept to a minimum. On the other hand, operating with an adequate fluidization factor when processing these materials, the solids flow pattern and the gas distribution are properly controlled.

Due to the high operating pressure, the amount of metallic units lost in HYL plants is between 5 to 10 times lower than the losses for DR plants operating at atmospheric pressure.

9.3. Reducing gas composition

In moving bed reactors, the direct reduction process is more efficient when hydrogen is used as the reducing agent. Main reasons of this are the following:

Reaction kinetics is faster, leading to lower residence time in the reduction reactor.

Since the sticking tendency in DR shafts is directly associated to the evolution of heat during reduction, the possibility of clustering is minimized by using hydrogen as reducing gas, basically due to the endothermic nature of the reduction reactions with hydrogen.

According to several experimental evaluations made by HYL, the generation of fines during reduction is decreased when the hydrogen content is increased in the reducing gas stream. This is due to the use of a reducing gas with lower molecular weight, as well as to a faster transition through the hematite-magnetite region, where the material strength is minimized and it disintegrates easily.

The reducing gas used in the HYL process is rich in hydrogen, with a high H_2/CO ratio of up to 9.5/1. This gives the process an important flexibility for the use of different iron ore qualities.

10. IRON ORES USED IN HYL PLANTS

The HYL process has demonstrated a wide flexibility to operate at high temperature with oxide pellets, lump ore, or mixtures of both. A list of the iron ores used in industrial HYL moving bed plants is presented in Tables 8 and 9.

Table 8 - Iron oxide pellets used in HYL plants

GIIC	Bahrain	IMEXSA	Mexico
CVRD	Brazil	P. Colorada	Mexico
Samarco	Brazil	Sicartsa	Mexico
CMP	Chile	Hierro Peru	Peru
Essar	India	LebGok	Russia
KIOCL	India	LKAB	Sweden
Mandovi	India	SIDOR	Venezuela
Alzada	Mexico		

Table 9 - Lump Ores Used in HYL Plants

Corrego	Brazil	G.G. Brothers	India
Esperanca	Brazil	Mineral Sales	India
Feijao	Brazil	NMDC	India
Ferteco	Brazil	P. Parties	India
MBR-LORD	Brazil	Belitung	Indonesia
MCR-Corumba	Brazil	Aquila	Mexico
Mutuca	Brazil	Sishen	S. Africa
SARD-SAMITRI	Brazil	El Pao	Venezuela
Bailadila	India		

11. PRACTICAL CASES

The flexibility of the HYL process for the production of different product types and combinations of them, using different raw materials as pellets or lump ores, can be illustrated by the following examples of industrial HYL plants in operation:

11.1. Usiba and IMEXSA

Producing cold DRI only, with the operation of a cooling gas circuit made up with natural gas. The product is discharged at less than 40 °C. The configuration of these plants is shown in Fig. 4.

The Usiba plant, in Salvador Bahia, Brazil, started operations with the HYL moving bed process in December, 1994. The nominal capacity of this plant is 310,000 ton/year of DRI.

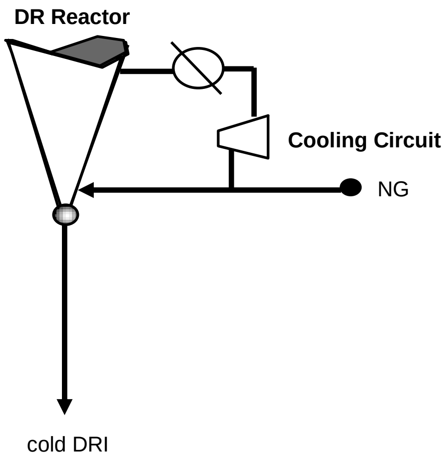

FIG. 4- Usiba and IMEXSA plants

Since start up, the Usiba plant has had a very smooth performance, with excellent results in production and quality. Since last year, the percentage of lump ore in the iron ore feed has been increased, reaching a monthly average of 75% (Fig. 5). For the period shown in the diagram, June 1998 to May 1999, the plant productivity has averaged 114%.

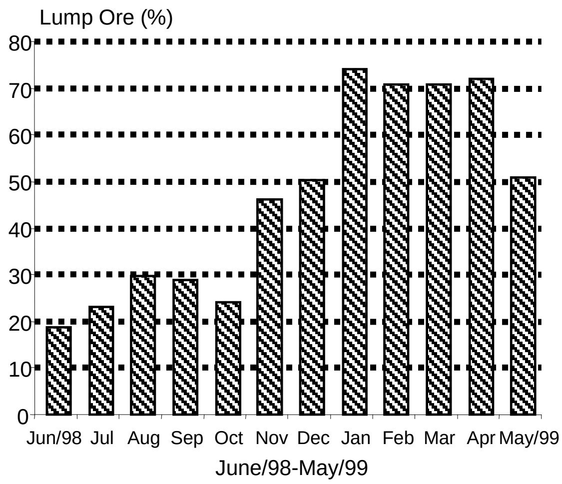

FIG 5- Lump ore utilization in Usiba

The IMEXSA HYL plant, located in Lazaro Cardenas, Mexico, has a nominal production capacity of 2.0 Million ton/year of DRI, operating with four moving bed reduction reactors and two reformers (two modules). The first module was started up in 1988, whereas module II initiated operations in 1991.

The IMEXSA HYL plant has operated with a wide variety of raw materials, including 10 pellets and 4 lump ores. However, since the start up of their own pelletizing plant in 1997 (using Brazilian pellet feed), the HYL modules have been basically operating with a mixture of local raw materials, Peña Colorada and IMEXSA pellets.

Using different raw materials, the IMEXSA HYL plant has been consistently producing above the nominal capacity of 2.0 Million ton/year of DRI (Fig. 6).

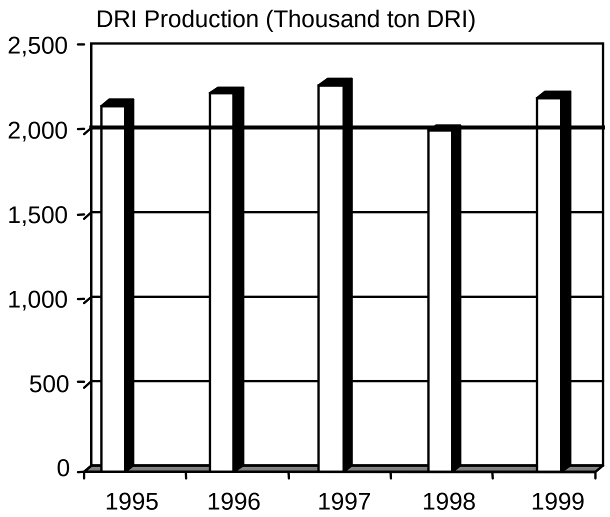

FIG. 6 - Production of the IMEXSA HYL plant

11.2. Vikram Ispat (Grasim)

In some cases, it could be convenient to produce a mix of HBI and cold DRI to serve the export market and local market respectively. The Vikram Ispat (Grasim) plant in India is operating since June 1998 under this concept. The average HBI/DRI ratio in 1999 has been about 50/50. The plant configuration is presented in Fig. 7.

The Vikram Ispat (Grasim) plant started up in October, 1993, with a nominal capacity of 750,000 ton/year of HBI. Since June, 1998, an external DRI cooler was incorporated to provide flexibility for the simultaneous production of both DRI and HBI, depending on the local and export market demand.

The Grasim plant has operated with a wide variety of raw materials. To date, 6 pellets and 8 lump ores have been successfully processed in this plant.

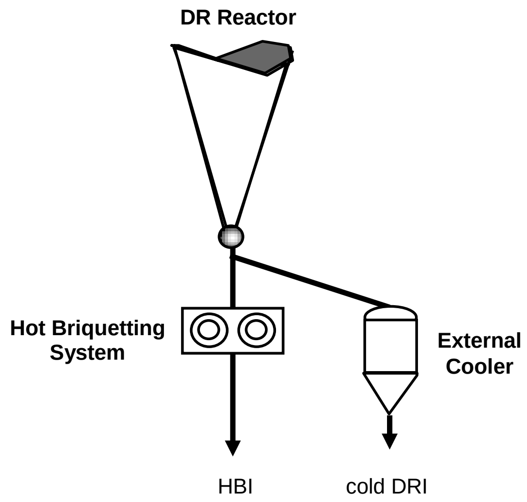

FIG. 7- Vikram Ispat (Grasim) plant

In the last 12 months, the plant has operated with 30%-45% lump ore. In March, 1999, when the plant reached a monthly productivity of 121%, the percentage of lump ore used was 33%. HBI production was 37,515 ton and DRI production reached 37,970 ton (Fig. 8).

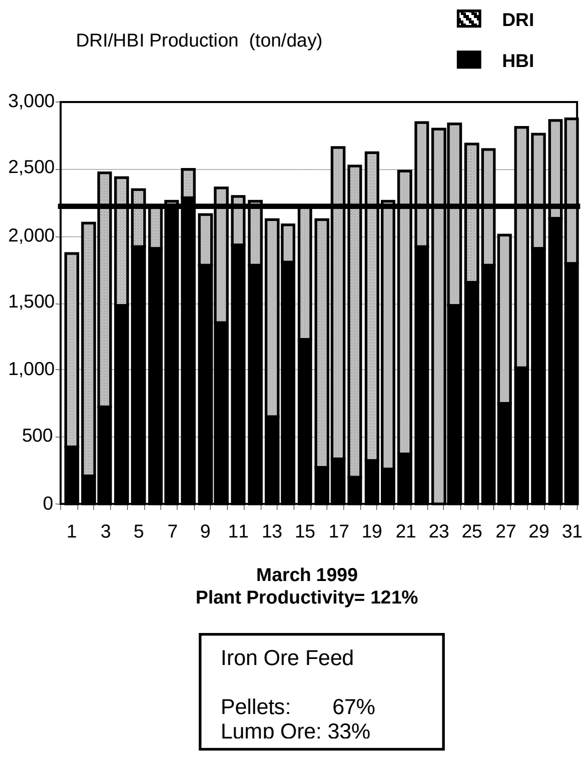

FIG. 8- Production of Vikram Ispat (Grasim)

The product quality in March, 1999, averaged 93.75% metallization and 1.17% carbon (Fig. 9).

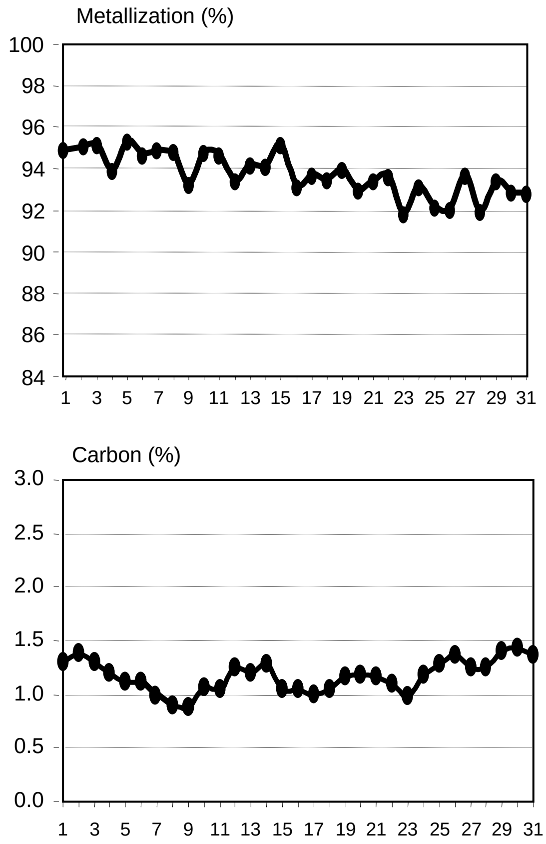

FIG 9- DRI/HBI metallization and carbon

12. Conclusions

The economic production of DRI/HBI is mostly influenced by the cost of iron ore, as pellet, lump ore, or fines, depending on the capabilities of each direct reduction process. Indeed, the flexibility offered by a particular DR technology in the use of cheaper iron ores, is a key factor in the feasibility of DR projects worldwide.

The HYL DR technology has been optimized through more than 43 years of industrial operations, with both the fixed bed and the moving bed processes. All the know-how obtained through the process evolution has given maturity and reliability to the plant design, while keeping an important flexibility in the use of different raw materials.