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The HYL Process for the Production of High-Carbon DRI

HYL has developed a reformer-less method which produce highly metallised, high-carbon DRI. This simple and reliable process configuration is the basis of the new 4M industrial DR plant at Hylsa, which has been in operation since April, 1998.

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When comparing different iron unit sources for steel production, it is very important to consider adequate alternate direct reduced iron (DRI) production methods and DRI characteristics, depending on local economic structures, to obtain competitive steel production cost.

In this respect, HYL offers alternative methods for producing the most suitable DRI to any particular condition. Particularly, the reformer-less or "Self-reforming" scheme offers the flexibility to produce highly metallised, highly carburised DRI.

The HYL process.

HYL is a process designed for the direct reduction of iron ores by use of reducing -hydrogen (H_2) and carbon monoxide (CO)- gases. There are three process schemes available for producing:

DRI:

Cold DRI discharge is commonly used in an adjacent meltshop close to the direct reduction (DR) facilities. It can also be shipped and exported, provided some procedures are followed to avoid re-oxidation.

HBI:

DRI hot discharged and briquetted, most commonly used in merchant plants for overseas export.

HYTEMP® iron:

Hot discharged DRI, pneumatically transported from the DR plant to an adjacent meltshop for its direct feed in the electric arc furnace (EAF).

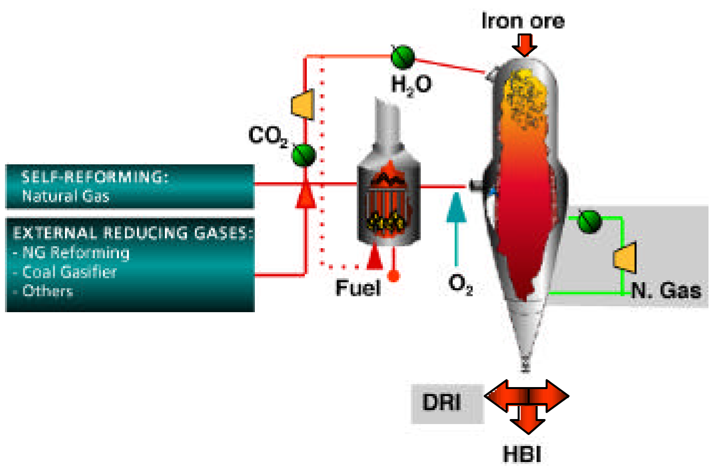
One of the main advantages of the HYL process is the configuration based on independent reducing gas generation and reduction section. As it can be observed from Figure 1 below, under these conditions the only requirement for the reduction process is a pipe supplying the required amount of H_2 and CO with no changes involved in the process scheme.

The HYL process offers great flexibility regarding the use of alternative reducing gas sources. Besides the conventional process method based on the use of H_2-rich reformed gases as a means for making up the reducing gas, HYL offers two main methods:

- Use of a Texaco-type coal gasifier as substitute of conventional natural gas-steam reformer for generation of hydrogen and carbon monoxide. This scheme is normally applicable to locations where there is no natural gas available.

- Reformer-less or "Self-reforming", which is the basis of the DR 4M plant at Hylsa facilities in Monterrey, already in operation after a successful start-up.

Figure 1
HYL General Process Scheme



HYL Self-reforming process.

This process method 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 HYL reduction reactor.

<u>Partial combustion and pre-reforming</u>

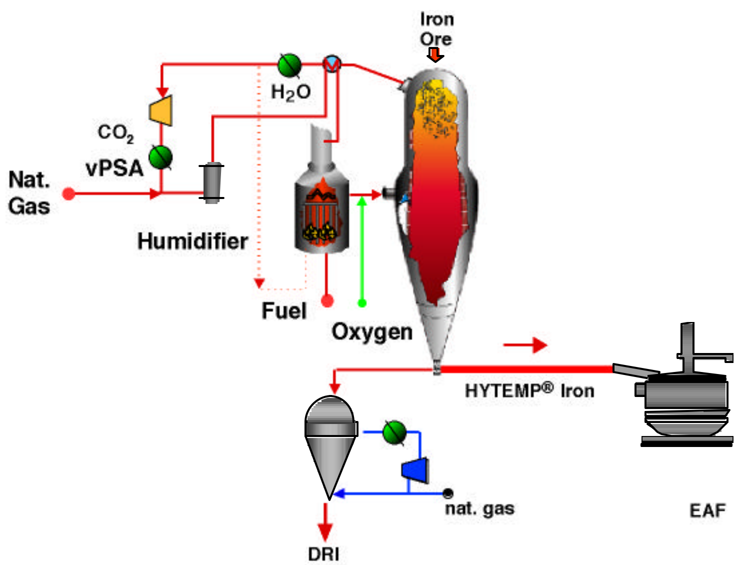
Partial combustion at the reactor inlet in HYL I (fixed bed) process-based plants have historically been utilised to boost the reducing gas temperature coming from low temperature heaters. This concept has been incorporated in the HYL process to achieve natural gas reforming in-situ, eliminating the need of a natural gas-steam reformer. A general scheme of this process, as implemented in the 4M DR plant of Hylsa, is presented in Figure 2.

Partial combustion of natural gas with oxygen provides the additional energy, which is required for natural gas reforming in-situ, and for the carburisation of the metallic iron. The simplified chemical reactions taking place in the transfer line before reactor inlet are related to partial combustion and pre-reforming of natural gas:

Combustion:	$2H_2$	+	O_2	—>	$2H_2O$		
Combustion:	$2CH_4$	+	O_2	—>	$2CO$	+	$4H_2$
Reforming:	CH_4	+	H_2O	—>	CO	+	$3H_2$
Water shift:	H_2	+	CO_2	—>	CO	+	H_2O

General path of above reactions is characterised by a dominant exothermic behavior. Net balance of the partial oxidation of natural gas provides an increase of reducing gases for reduction (as H_2 and CO) due to pre-reforming reactions.

Figure 2
Self-Reforming HYL Process Scheme



In-situ reforming

Once in contact with the solid inside the reactor, further methane reforming in-situ takes place due to the catalytic effect of the metallic iron. Under these conditions, the methane is always in contact with new catalyst (metallic iron in DRI) since DRI is continuously removed from the reactor. Therefore, in-situ reducing gas generation and reduction take place in a highly efficient environment.

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

The main reactions taking place inside the reactor can be summarized as follows:

In-situ reforming:	$CH_4 + H_2O$	—>	$CO + 3H_2$
Reduction:	$Fe_2O_3 + 3H_2$	—>	$2Fe° + 3H_2O$

Reduction:	$Fe_2O_3 + 3CO$	—>	$2Fe° + 3CO_2$
Carburisation:	$CH_4 + 3Fe°$	—>	$Fe_3C + 2H_2$

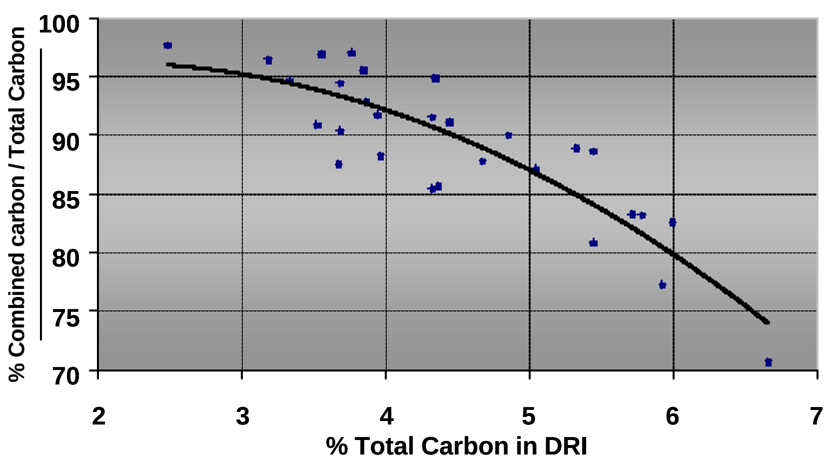
The water (H_2O) and carbon dioxide (CO_2) generated from the reduction process are eliminated through top gas scrubbing and pressure swing adsorption (PSA) systems, respectively. Most of the top gas is recycled to the DR reactor, to use unreacted H_2 and CO. The reducing gas made-up of recycled gas and fresh natural gas is preheated to 930°C in the gas heater, prior to partial combustion. All purge gas from the PSA is used as fuel in the gas heater, optimizing the overall thermal efficiency. The high operating pressure –5.5 to 8 bara- allows a high reactor productivity of about 10 tonnes/hr-m^2 and reduces dust losses through top gas carry-over. This is reflected in very low iron ore consumption, which represents significant savings in operating costs.

<u>Product characteristics</u>

Additional advantage of this process scheme is the great flexibility to obtain carbon levels between 2.0% and >5.0%, due to improved carburising conditions. Carbon in the DRI, mostly as iron carbide (Fe_3C), is derived mainly from methane (CH_4) and in less extent from CO. The level of carbon is adjusted by controlling the reducing gas composition and/or oxygen injection.

Most of the carbon in DRI, currently being produced in the 4M DR plant, is in the form of Fe_3C. Actual tests results indicate that for 4% carbon in DRI, about 93% of total carbon is in combined form. Complete results for a wide range of carbon levels are presented in Figure 3 below.

Figure 3
Combined Carbon (cementite or iron carbide-Fe_3C)
In DRI from HYL Self-reforming Process



DRI produced in this plant presents higher stability than DRI typically obtained in other DR processes. The reason of the above is the high cementite or Fe_3C content, which inhibits the reoxidation of metallic iron in contact with air. In general, one percent of cemetite is linked to 14% of iron or Fe°. The high carbon DRI with 5% Fe_3C, has more than 70% of Fe° linked to the carbon, which increases significantly the DRI stability. This product is safer to handle and storage.

The DRI obtained from the Self-reforming method presents a higher energetic value as compared to other's DR processes; much higher carbon content for same level of metallisation. Under this situation and comparing energy consumption figures of the various DR processes available in the market, the Self-reforming configuration presents the most efficient method to produced DRI.

Typical consumption figures of the various HYL process methods are presented in Table 1. Consumption figures for the Self-reforming scheme are indicated for two levels of carbon.

Table 1. Specific consumption figures of HYL DRI production methods

Item	**Unit/ t DRI**	**Conventional (NG-Reforming)**	**DR Plant + Coal gasifier**	**Self-reforming method**	
Iron ore –at battery limits	tonne	1.42	1.43	1.38	1.40
-screened and dry		1.38	1.39	1.32	1.35
Natural gas	Gj	9.83	-	9.75	9.12
Electricity	kWh	75	96	70	70
Water	m^3	1.4	1.0	0.8	0.8
Oxygen	Nm^3	-	280	47	50
Coal	kg	-	447	-	-
Labor (2)	m-h	0.18	0.2	0.16	0.16
Maintenance & supplies(3)	US$	3.75	5.0	3.55	3.55
Administrative expenses	US$	1.4	1.4	1.4	1.4
DRI metallisation		93%	93%	93%	93%
DRI carbon (as considered)		1.2%	0.4%	4.2%	2.5%
DRI temperature @ reactor discharge		650°C	650°C	650°C	650°C

1) Lump ore: 30-50%, depending on ore characteristics.
2) Manpower requirements for a 1.2-1.5 million tonnes/year plant capacity.
3) Including maintenance for HYTEMP® system.

Characteristics of the Hylsa's 4M DR plant

This process method is the basis of the 4M DR plant at Hylsa, in Monterrey, Mexico. The 4M plant incorporates the latest technological advancements. The 4M plant is characterised by both simplicity and the greatest flexibility.

There are no reformer facilities and main plant components are reactor tower, reduction gas circuit (scrubber, compressor, PSA-CO_2 removal and heater), external DRI cooler and HYTEMP® system.

Hot DRI is directly discharged from the rotary valve of the HYL reactor to the pneumatic transport system. The hot product is then transported pneumatically through HYTEMP® system and sent to an external cooler for cold DRI production and/or to the EAF of the new CSP mill of Hylsa's meltshop.

View of 4M DR plant and meltshop #2

In this regard, the 4M plant is the first industrial DR installation to produce simultaneously any proportion of both cold and hot DRI.

Start-up of operations took place last April, 1998 and operation at full capacity was achieved within the first 12 days. Actual DRI metallisation is in the order of 94% with 4% carbon. Trials have been successful in achieving 5.6% carbon.

This new plant has an initial production rate of 675,000 metric tons per year of DRI. Operating results of the 4M plant, for production and DRI quality, are presented in Figures 4 and 5 respectively.

Being the first-of-its-type industrial installation, some routine operation interruptions have taken place, mainly for equipment monitoring. Nevertheless, design production rate has been surpassed in about 6% and actual metallisation and carbon have exceeded the expected figures.

The 4M reactor itself has been designed for a maximum annual capacity of 1.5 million tonnes of hot DRI, which can be expanded later by only installing a new gas loop, when additional demand of DRI is required.

Figure 4
4M DR Plant. Production Operating Results

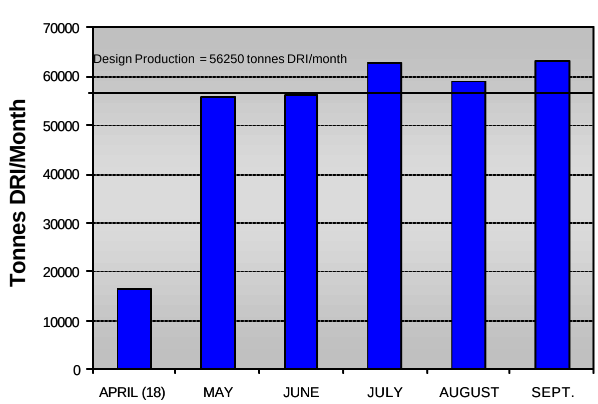
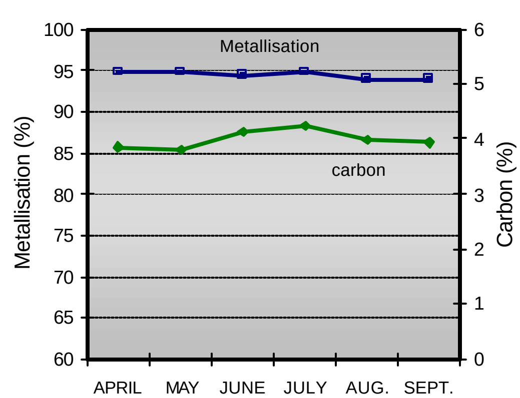


Figure 5
4M DR Plant. DRI Quality Operating Results



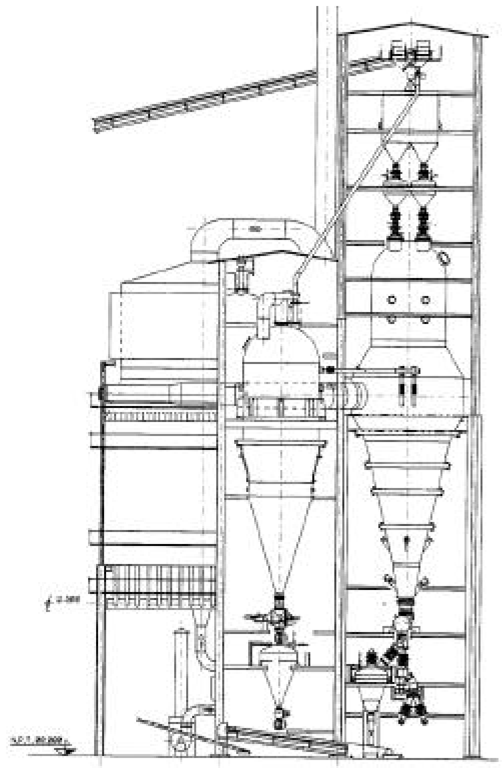


Figure 6. 4M DR Plant
Reactor & External Cooler. Elevation

The external cooler allows a great flexibility to adapt the DR plant continuous process to the EAF batch process. When the meltshop is off-operation, it is possible to keep the DR plant producing cold DRI, which is later used in the scheduled maintenance or due to unexpected interruptions.

In this regard, this plant configuration makes possible to achieve the highest meltshop productivity for integrated DR-meltshop minimills.

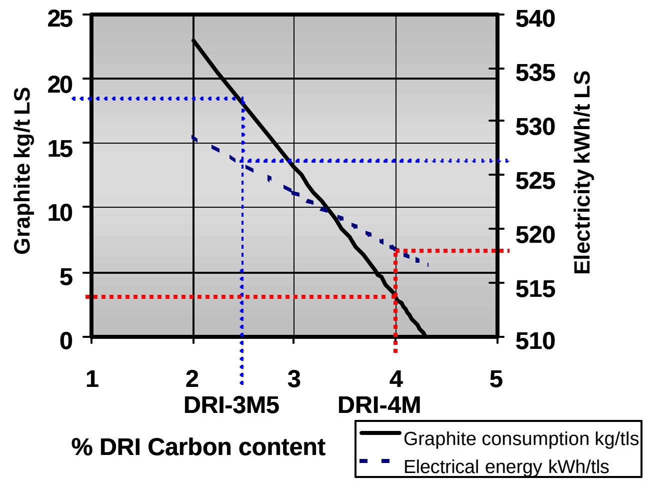
Use of high-carbon hot DRI in Hylsa's EAF.

In general, carbon in the DRI provides chemical energy input to the EAF, decreasing electric power requirements. As compared to other sources of carbon injection, cementite in DRI is characterised by a higher recovery yield in the EAF. Besides, EAF's quality carbon is normally available at higher cost than the carbon obtained from natural gas in DRI. Adequate oxygen injection is required to take advantage of this carbon. Currently, most modern EAFs are equipped with lances to inject high oxygen feed rates. Common figures are higher than 30 Nm^3/tonne of liquid steel (tls).

Benefits of high-carbon DRI in meltshop operations has been demonstrated in Hylsa's EAF. Before start-up of operations of the 4M DR plant, DRI to EAF of meltshop #2 was entirely produced in 2M5 and 3M5 DR plants. Typical DRI quality from these plants was of 93% metallisation and 2.5% carbon. After 4M start-up, DRI presented 94% metallisation and 4% carbon.

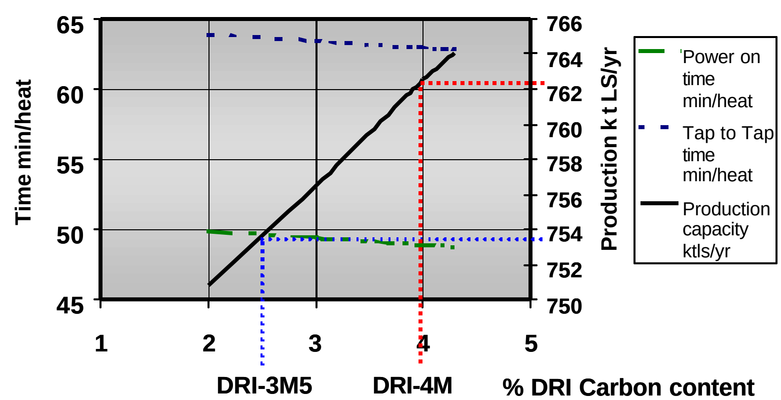
The EAF is a Fuchs-shaft DC-type with capacity of 131tls/heat. Average active power is 83.2 MW. Oxygen injection is about 30 Nm^3/tls. Maximum EAF production, related to total operating time, has been limited by the casting and continuous strip plant (CSP) facilities. This constraint will be overcome by the second caster line, which is currently staring operations. Impact of DRI carbon in the EAF is presented in Figure 7. These figures correspond to actual EAF operation for 70% of DRI in the metallic charge, keeping constant the metallisation at 93% for various levels of carbon. Oxygen injection is constant at 30 Nm^3/tls. Graphite injection is about 23 kg/tls for DRI with 2% carbon and zero for DRI with 4.3% carbon. For these operating conditions, the change from 2.5% to 4% carbon represents a decrease of 15-kg graphite and 10-kWh per tls. This power saving is a result of the replacement of graphite by cementite related to yield and heat reaction. In terms of transformation costs, incorporation of high-carbon DRI has been reflected in more than 4-$US/tls, for Hylsa's particular conditions.

Figure 7. EAF Operation
Carbon & Electricity consumption
Cold DRI-70% charge/30Nm^3 O_2/tls



Effect on power-on time, tap-to-tap time and productivity due to higher DRI carbon content is shown in Figure 8.

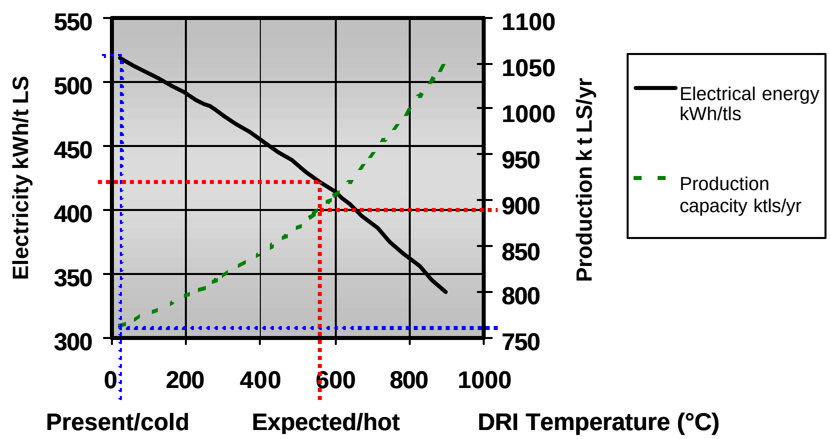
Figure 8. EAF Operation
Power on-time & Productivity
Cold DRI-70% charge/30Nm^3 O_2/tls



On the other hand, hot DRI feed provides additional sensible heat to the EAF, reducing power consumption and tap to tap time, which is reflected in productivity increase. Direct feed of hot DRI in Hylsa's meltshop, through HYTEMP® system, will start operation by the end of 1998. Expected operating conditions of the EAF are presented in Figure 9. For this case, 70% of DRI charge with 93% metallisation and 4% carbon has been considered. It is expected to feed 85% hot DRI and 15% cold DRI of total DRI charge, to compensate meltshop shutdowns and delays. Oxygen consumption has been kept in 30 Nm^3/tls. Under these conditions, expected benefits in the EAF are:

a decrease of 100-kWh/tls and about an additional potential of 130-k tls/a, which will be consumed by the caster with the second line in operation.

Figure 9. EAF Operation
Expected Power Consumption & Productivity
DRI-85% charge (85% hot DRI/15% cold DRI)



Conclusions.

The HYL Self-reforming configuration presents unique advantages for both DR installations and EAF-based meltshops.

The industrial-size technology has been successfully proven during the past 8 months of operation and has demonstrated excellent reliability, regarding simplicity of process operation and plant equipment performance. This DR plant presents a simple design with less equipment. In general, the Self-reforming method is characterised by low operating, maintenance and investment costs.

This process has demonstrated a great flexibility to adjust DRI metallisation and carburisation, suiting the particular conditions of meltshop installations. Most of the carbon in the highly metallised DRI is in combined form as Fe_3C. The cold and/or hot DRI produced presents a uniform quality, which is reflected in uniform steel qualities.

For minimills, like the case of Hylsa, oxygen is available "next door". In this way, this plant configuration takes advantage of the synergy for integrated DR-meltshop minimills.

An additional benefit is the HYTEMP® system, for the use of hot DRI in the EAF leading to important power related savings and productivity increase. The HYTEMP® hot DRI presents a unique and competitive option for liquid steel production when being compared to alternate hot liquid iron and other pre-reduced materials.

The experience of Hylsa, regarding operation practices when feeding any proportion –up to about 100% charge- of DRI, can be easily transferred to most EAF´s-based installations.