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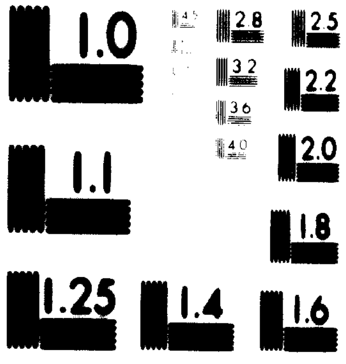

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

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September 1967

Report on

H.Y.L. Direct Reduction Process

for

The Production of Sponge Iron

United Nations Industrial Development Organization
United Nations
Vienna

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CONTENTS

INTRODUCTION

The development of direct reduction processes gained effective impetus during the late 1950's in the wake of heavily mounting consumption of high grade metallurgical coking coals and their increasing depletion and consequent shortages in certain countries but primarily with the objective of developing iron-making processes alternative to iron smelting in the blast furnace. Considerable painstaking researches, development work and pilot plant trials have been undertaken to develop direct reduction processes for the production of sponge iron from iron ores based on the use of gaseous, liquid and solid fossil fuels including non-metallurgical, poorly coking or non-coking coals and anthracite. Around the 60's, the interest in direct reduction processes somewhat receded into the background owing to remarkable changes and improvements in blast furnace technology for iron production pari-passu with lowered coke rates attained during iron smelting in the blast furnace by the injection of steam, liquid and gaseous fuels and in some cases of pulverised coal/oil slurries through the blast furnace tuyeres following the attainment of high air blast temperatures and in some cases, concurrently with oxygen enrichment of the air blast. Additionally, multitude of direct reduction processes flooded the technical literature making still more multitude claims. In the maze of all pervading claims made by a vast array of direct reduction processes, the metallurgical world needed a breather to sort out and scrutinise the rival claims and more so, the developing countries of the world. In the later years, however, the interest in direct reduction processes significantly rose following the successful commercial scale operations of a few of the direct reduction processes including the HYL direct reduction process based on the use of natural gas. Nevertheless, the choice of direct reduction processes became rigidly selective in their technology and industrial scale applications, particularly in the background of a country's raw materials' resources, e.g. cheap and abundant natural gas and oil, their ready availability and shortage of classic technology and industrial practices and particularly so after the myriad of numerous fast-sprung direct reduction processes had fallen by the wayside in the industrial race and only those that had withstood the economic parameters and technical up-scaling by the metallurgical industry, were advocated. One of the most successful, if not the most successful direct reduction process, is what has come to be known as the HYL direct reduction process based on the use of natural gas for effecting direct reduction of the oxides of iron and supplying the thermal needs of the process. This then is the general background of the UNIDO mission which recently visited Mexico to study the HYL direct reduction process not only from the point of view of its inherent metallurgical and industrial scale success but also more specifically for examining its potential applications in various developing countries in different regions of the world such as Iran, Gabon, Algeria, Taiwan, Iraq, Kuwait, besides others in Latin America, etc. that have been endowed by nature with abundant resources of cheap natural gas and in some cases, supplemented by equally rich and high quality reserves of iron ores. Many countries and regions are today partly utilising their natural resources and in some cases none at all. The aim of the UNIDO mission therefore was to critically study the HYL direct reduction process for the production of sponge iron as followed in Mexico, examine its metallurgical and economic potentialities on full commercial and industrial scale with a view to define areas and scope for its industrial scale implementation, should its utilisation overences in developing countries be considered metallurgically feasible and economically acceptable - such an objective indeed requires a combined study of many specific and interlinked parameters including inter-alia the following:

1. Metallurgical feasibility of the HYL direct reduction process based on high quality iron ores employing cheap and abundant natural gas for the economic production of sponge iron and conversion of the latter to different grades of steels.

2. Availability of steel scrap in general and that of classified, pedigree steel scrap in particular in various regions.

3. The quality and availability in reserves of iron ores. Their physical, chemical and metallurgical characteristics including their reducibility data.

4. The price structure of the natural gas, its availability, distribution and delivery system. The availability and price structure of solid, metallurgical grade fuels in the country.

5. The regional and inter-regional trade and market survey and requirements of plain carbon, mild and structural steels besides alloy, tool, special and stainless steels in the region vis-a-vis home consumption and export potential.

6. The status of iron and steel industry and that of light, medium and heavy engineering industries in the region covering home requirements and possible export potential.

7. Availability and price structure of electric power in the region, particularly for electric steel-making and steel-rolling purposes.

8. The status of heavy plant equipment and machinery manufacturing industries in the country; the ratio of indigenous to imported equipment and machinery required.

9. The resources of capital finance including requisite foreign exchange of the region for heavy plants establishment.

10. The status of trained manpower in mechanical, metallurgical, chemical and electrical industries including supervision and managerial personnel.

HYL DIRECT REDUCTION PROCESS FOR SPONGE IRON PRODUCTION

Two HYL plants are in full successful production at the Monterrey works of the Hojalata y Lamina S.A. - the first known as FE-1 is a 200 metric tons/day plant of total iron in the form of sponge iron with 85 per cent of metallisation. The second plant also at Monterrey, known as FE-11 is also currently in full production with nominal production cap city of 500 metric tons of total iron per day. The 200 tons per day HYL unit at Monterrey originally produced hot sponge iron in lump form, which was transported a short distance in metal charging hoppers to the melt shop and converted to steel in the electric furnaces. The carbon content of the sponge was approximately .5 per cent and required the addition of graphite during the melting and finishing operations. The operation of the 200 ton plant was revised after the successful performance of the 500 ton plant to produce cold sponge iron by the addition of the cooling cycle.

The product from the 200 ton plant now contains combined carbon averaging 1 per cent to 1 1/2 per cent and is transported and charged to the electric furnaces as initially designed. The 500 ton per day plant produces cold sponge iron which averages 1 1/2 - 2 per cent combined carbon and is handled by conveyors, stored in hoppers, and charged to the electric furnaces in lump form without screening or compacting.

In the 200 ton unit, the reactors are built in two flanged sections, After optimum reduction is complete, the lower section is lowered and rolled out to a discharge point and the reduced product dumped into a portable hopper. In the 500 ton unit, the reactors remain fixed and the reduced ore is removed by means of a boring device through a discharge port in the bottom directly on to a conveying system.

The 200 ton unit utilises five reactors, each capable of holding 13 tons of ore. The 500 ton unit uses four reactors, each capable of holding 125 tons of ore.

Work has started on a third plant of 500 tons/day for Hojalata y Lamina near Mexico City (Puebla) as a spearhead of a completely new integrated steel works. Another plant of 500 tons/day capacity of Tubos de Acero de Mexico SA (Tamsa), at Vera Cruz in Mexico has successfully completed its production trials and is now in commercial scale operations. The establishment of an HYL plant for a 500 tons/day output is now in blue print stages for Usina Siderurgica de Bahia SA (Usiba). Table I gives the latest production figures of the Monterrey plant FB-11. Metallisation represents the percentage of total iron which has been converted to the metallic Fe - the unmetallised iron is assumed to be in the form of FeO which represents partial reduction by the natural gas. 85 per cent metallisation is a pre-determined objective and it is not that higher degree of metallisation cannot be achieved in the HYL process. Some iron oxide is purposely retained in the sponge iron to provide the oxygen needed for oxidation of the metalloids during subsequent steel-making in order to make up the slag eliminating thereby the need of adding high grade iron ore to the melt.

TABLE I

Plant FB-11 Monterrey, N.L.

August 1966 - January 1967

Production Statistics

Month	Monthly Production in metric tons of total Fe	Percent Metallisation	Natural Gas NM^3/Ton Fe
1966			
August	14,688	82.5	721
Sept.	14,157	84.1	701
Oct.	16,112	81.5	660
Nov.	16,106	82.8	687
Dec.	14,879	82.1	731
1967			
January	15,250	84.1	706
Average	15,190	82.9	701

Average daily production - 510 metric tons

The operational data for a typical HYL plant including the general guarantee figures projected by the supplier before the customer's take-over are given below:

HYL ORE PRODUCTION PLANT

Fuel		24,400,000 Btu/Metric Ton Fe
Water Makeup		2,400 Gallons/Metric Ton Fe
Electric Power		12 kWh/Metric Ton Fe
Labour		54,000 Man-hours/Year
Supervision		9,000 Man-hours/Year
Catalyst and Chemicals	US$	20,000/Year
Miscellaneous Supplies	US$	30,000/Year
Maintenance, Material and Labour	US$	280,000/Year

ELECTRIC FURNACE MELT SHOP

Sponge Iron	50% Wt.	85% Wt.
Scrap	50	15
Total Charge	100	100
Steel Yield % Wt.	88-95	82-90
Electric Power kWh/Ton	660-710	800-840
Carbon Electrodes Kg/Ton	7.6-8.2	9.0-10.1
Lime, Kg/Ton	72-90	90-110
Dolomite Kg/Ton	9-11	11-13
Lining Material Kg/Ton	5-7	8-12
Ferro-Alloys Kg/Ton	5.7	5.7
Flourite Kg/Ton	5.8	6.5
Refractories Kg/Ton	8-10	9-11
Miscellaneous Supplies US$/Year	50,000	
Maintenance US$/Year	300,000	
Labour and Supervision MH/Ton	2.0	2.5

HYL ORE REDUCTION PLANT

GENERAL GUARANTEE

Natural Gas	780 NM^3/Metric Ton Fe
Water	2,900 Gallons/Metric Ton Fe
Electric Power	15 kWh/Ton
Production	500 Metric Tons/Day/Fe Total
Product Quality	85% Wt. Non-Oxide Fe
Carbon Content	2.5 to 1.5% Wt.

The above is based on iron ore containing at least 60% Fe with reducibility and another physical and chemical characteristics comparable to the Durango ore used in Monterrey, as established by suitable pilot plant tests.

DESCRIPTION OF THE HYL PROCESS

1/ The HYL direct reduction process for the production of sponge iron is one of the most successful processes of its kind. Extensive technical literature and data have been published thereon from time to time in the world's technical press; It is therefore not considered necessary to reproduce the above except to summarise a review thereof as a general technical background. In the background of the above presentation, an attempt will be made to define the capital cost structure and operational cost analysis based on the technical data currently available. For fuller details of the HYL process itself, Appendix "A" may be studied.

The HYL process converts iron ore into sponge iron through the action of a mixture of carbon monoxide and hydrogen gas. The reaction occurs in a fixed-bed chamber where the gas flows downward through lumps or agglomerates of ores. The reducing gas mixture is prepared by the steam-reforming of natural gas or other hydrocarbons. The sponge iron is formed in the reaction chambers; is cooled therein by contact with fresh, cold reducing gas; and is removed for subsequent conversion to steel.

The steam-reforming process for the production of hydrogen-carbon monoxide mixtures is operated in many places and has been extensively described in the literature. In the plants at Monterrey,

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1/ "The effect of iron ore characteristics on the operation of the HYL process" by Joseph F.S. Kelly, Manager of Development, Swindell Dressler Company, a devision of Pullman Inc., Pittsburgh, Pa., USA.

there are several reforming furnaces which supply gas to the reaction chambers. At the new plant in Vera Crus a single, large gas-reforming furnace prepares the reducing agent for all of the reaction chambers in the plant. This modification in the equipment for the production of reducing gas has made a considerable saving in the capital requirement for the process. The development made possible by the pioneering work of the M.W.Kellog Division of Pullman Incorporated in connection with the resulting economies in the production of sponge iron are a striking illustration of the benefits to be derived from the exchange of technological innovations between industries when there exists an organisational network suitable for the communication of information about engineering progress in specialised areas.

The fixed-bed reactors, which contain the ore agglomerates or lumps, normally pass through a four-step cycle. These steps are:

(1) Removal of finished sponge iron and load with fresh ore;

(2) Secondary reduction in which the ore is heated and partially reduced by hot gases coming from another reactor;

(3) Primary reduction in which partially reduced ore (from the secondary stage) is further reduced by strong reducing gas;

(4) Cooling, in which the hot sponge iron (from the primary stage) is cooled by contact with fresh reducing gas. This also removes the final portion of the reducible oxygen and causes the deposition of some carbon on the finished sponge.

In the usual plant design, four reactors are employed, each spending three hours in each stage, for a total cycle time of 12 hours. At any instant, one of the four reactors is in each of the four stages of the cycle, producing the balanced array shown in Figure 1.below:

FIGURE 1.

Operating Cycle HYL Process

Hours

0	3	6	9	12

Secondary	Primary	Cooling	Cleanout
Cleanout	Secondary	Primary	Cooling
Cooling	Cleanout	Secondary	Primary
Primary	Cooling	Cleanout	Secondary

The general outlines of the plant which has been constructed at Vera Cruz for Tubos de Acero Mexico, S.A. (TANSA) is shown in Figure 2.

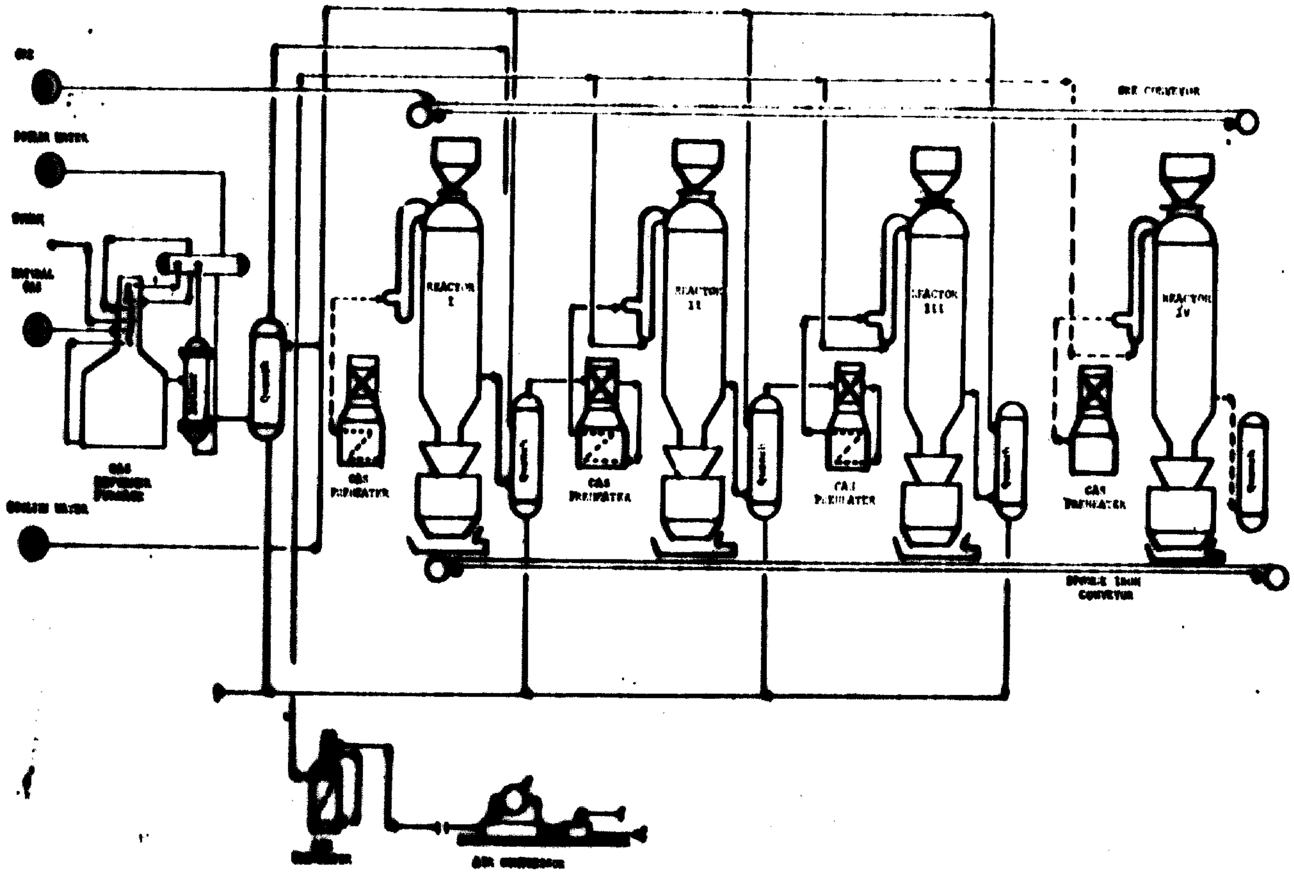

Fig. 2. — Process Flow Diagram.

There it will be noted that a single reforming furnace makes the reducing gas which is then utilised in four identical reactors. The reducing gas is prepared by the catalytic conversion of methane with steam to produce mixture of carbon monoxide and hydrogen. After leaving the reforming furnace, the gases are cooled to remove excess water vapour and are then ready for transfer to the iron ore reduction section of the plant. At this point, the cooled gas contains about four volumes of hydrogen for each volume of carbon monoxide.

This gas flows directly to a reactor which contains sponge iron that has just passed through the primary reduction stage. In passing through the reactor, the gas is heated to an elevated temperature while the sponge iron, as previously stated, is cooled to atmospheric temperature. This cooling stage also completes the reduction, thereby adding to the gas a certain content of water vapour and carbon dioxide. To remove these gases, which would be harmful in later reduction stages, the gas is cooled by direct contact with water sprays in a quench tower. Water formed during reduction is removed by condensation and the resulting gas is ready for transportation to another reactor.

The gas temperature is raised to a high level and the gas then enters a reactor containing hot, partially reduced ore which has just completed the secondary stage. In this primary stage the bulk of the ore reduction takes place and a considerable quantity of water vapour and carbon dioxide appear in the exit gases. As in the case of the gases leaving the cooling stage, the gases from the primary stage are also cooled in a quench tower to bring about the removal of water by condensation. The gas is again heated to a high temperature and flows into a reactor which has just been charged with fresh cold ore. During the ensuing secondary stage, the ore is heated and partially reduced by contact with the hot gas. The gases which emerge from the secondary stage still contain appreciable quantities of hydrogen and carbon monoxide and are used as fuel to supply heat to the various furnaces and heaters in other parts of the plant. The calorific power of this final gas is not quite sufficient to supply all of the heat needed in the process and it is therefore necessary to introduce some additional natural gas into the fuel gas system.

The reactor section of the plant has been designed to possess a high degree of operating flexibility. This was done in order to make it possible for the plant personnel to adjust the process conditions in according with variations in the mineral quality of the ore which may be supplied to the plant from time to time. The reaction temperature may be varied between about 1600°F and 1900°F depending upon ore reducibility. The particle size of the ore may vary from about 1/2" to about 2". While the normal reactor time cycle provides for three hours in each stage, it is possible to change this time programme if the mineral makes it possible to do so. The nominal production rate of the plant is 500 tons per day of total iron, in the form of sponge iron which is 85 per cent metallised, but this production rate may vary depending upon the quality of the ore. In a very strict sense, therefore, it must be clearly understood that the production capacity of the plant is a function of the quality and reducibility of the ore supply.

Reactor Heating System

Heat is introduced to the reactor through a special patented procedure which was developed by the engineering staff of Hojalata y Lamina, S.A. After the reducing gas leaves the quench tower at each reactor, as previously described, it is heated in a conventional tubular gas heating furnace to a temperature of 1300°F to 1500°F. At the same time a stream of air is also heated to approximately the same temperature in another furnace of a design similar to that used for preheating gas. A carefully controlled quantity of this preheated air is then injected into the reducing gas stream, causing the combustion of a portion of the reducing gas. The resulting heat of combustion raised the temperature of the gas mixture to 1300°F to 2250°F, and it is this hot gas which then flows downward through the bed of ore in the reactor. The temperature of the gas mixture after this limited combustion is established at a level which is sufficient for the reducibility requirements of the ore in the reactor. This control is achieved by careful regulation of the ratio of air to reducing gas. A high degree of temperature regulation and process adjustment is made possible by this patented arrangement. Reactors in both primary and secondary stages are heated in the same manner.

In providing an outline of the HYL Direct Reduction Process for the production of sponge iron, flexibility of the process needs to be stressed. Although an important criterion for the success of HYL direct reduction process is the necessity to start with high grade iron ores low in gangue, low grade iron ores could be employed provided their prior beneficiation is undertaken to upgrade their metallic values and lower their gangue contents - the latter would inevitably find its way into the reduced sponge since in the HYL direct reduction there is no slag formation. Prior beneficiation may also involve agglomeration of the upgraded ore including its pelletisation depending upon the nature of the beneficiation flow sheet required and the degree of fine grinding needed for liberation of the gangue. such treatment would, of course, raise the ultimate cost of the reduced sponge. As such, the choice of low grade iron ores and their beneficiation would depend upon the overall economics of producing the HYL reduced sponge; alternative may well be to import high grade iron ore - here again, the determining factor would relate to the cost of the imported high grade ore. In some cases, post-beneficiation of the reduced HYL sponge may be employed depending upon the ultimate economics of doing so. High sulphur bearing iron ores are first roasted to lower their sulphur content before direct reduction. Following typical data on chemical analysis of the iron ores and the resulting sponge are given below (Table II) along with the consumption of reducing gas on the basis of HYL Pilot Plant operations conducted during 1966 on the following iron ores (after S.Kelly):

Encino ore	A massive hematite-magnetite from a deposit near Colima, Mexico
Wadi Fatima ore	An oolitic hematite from Saudi Arabia
Itabira ore	A specular hematite from Brasil
Pellets	A hard fired, high grade pellet from South America

TABLE II.

Chemical Analysis of Iron Ores

Percentage	Enicino	Wadi Fatima	Itabira	Pellets
Total Fe	87.42	48.67	70.09	69.0
Ferrous Fe	11.50	0.54	8.01	1.0
SiO_2	1.98	6.93	0.94	2.0
Al_2O_3	1.9	2.82	0.77	-
S	0.013	0.040	0.013	0.02
P	0.518	0.568	0.086	0.03
Cl	—	0.25	—	—
Ignition loss	0.66	11.50	0.380	—

Chemical Analysis of the Sponge Iron

Percentage	Enicino	Wadi Fatima	Itabira	Pellets
Total Fe	87.80	65.6	92.68	90.0
Metallisation	86.20	84.4	85.4	85.0
S	0.016	0.027	0.009	0.02
P	0.551	0.900	0.236	0.04
Gangue	6.49	29.0	1.61	3.5

Note: Carbon content of the sponge can be controlled by adjustment of operating conditions. At Monterrey it is usually held between 1.5% and 2.0%.

Consumption of reducing gas. Pilot plant operation - 85% metallisation[1]

Ore Source	Natural Gas consumption
Enicino	100%
Wadi Fatima	150%
Itabira	110%
Pellets	90%

ECONOMICS OF THE HYL PROCESS

With regard to the economics of building an integrated steel-making facility based on the HYL direct reduction process, it is obvious that each plant and location will have a different set of cost factors and basic parameters.

In the latest brochure of Swindell-Dressler Company, entitled "The HYL Direct Reduction Process - Steelmaking with Gas", data have been published concerning the HYL direct reduction process as given herewith:

Plant and Operating Costs:

165,000 Metric Tons Fe/Year HYL Plant

Capital Cost : $ 6,950,000

Cost Factor	Unit Cost in US$	Days/ Year	Quantity	US$/Year
Natural gas	0.30/MCF[2]	330	4,050,000 MCF	1,215,000
Water Make-up	0.027/MGal[3]	330	176,000 MGal	4,750
Catalyst and Chemicals		330		20,000
Operating Labour	0.30/MHR[4]	365+10	49.500 MHR	39,600
Supervision	1.25/MHR	36[illegible]0	9,000 MHR	11,250
Maintenance	4% Capital Investment			273,000
General Overhead	100% Labour and Supervision			50,850
Miscell. supplies				30,000
Royalty	1.00/Ton Fe			165,000
Net Operating Cost/Year	11.00/Ton		165,000 Tons	1,814,450

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[1] Consumption of natural gas required for plant operations with Enicino is taken as 100%.
[2] MCF = Thousand Cubic Feet
[3] MGal = Thousand U.S. Gallons
[4] MHR = Manhour

Melt Shop and Casting Plant

Capital Cost: $ 8,000,000

Cost Factor	Unit Cost in US$	Days/ Year	Quantity	US$/Year
Natural Gas	0.30/MCF 1/	330	61,500 MCF	18,450
Water Make-up	0.027/MGal 2/	330	125,000 MGal	3,375
Operating Labour	0.80/MHR 3/	365+10	525,000 MHR	420,000
Supervision	1.25/MHR	365+10	9,000 MHR	11,250
Maintenance	4% Capital Investment			320,000
General Overhead	100% Labour and Supervision			431,250
Electrodes	600/Ton		2,000 Tons	1,200,000
Lime	12/Ton		20,500 Tons	246,000
Dolomite	18/Ton		2,625 Tons	47,250
Ferro Alloys	400/Ton		1,450 Tons	580,000
Fluorite	18/Ton		1,450 Tons	26,100
Refractories	145/Ton		2,500 Tons	362,500
Magnesite	46/Ton		1,300 Tons	59,800
Oxygen and Acetylene				88,000
Miscellaneous Supplies				50,000
Net Operating Cost/Year	15.46/Ton		250,000 Tons	3,863,975

1/ MCF = Thousand Cubic Feet
2/ MGal = Thousand U.S. Gallons
3/ MHR = Manhour

50,000 KW POWER PLANT

Capital Cost: $7,850,000

Cost Factor	Unit Cost US$	Days/Year	Quantity	US$/Year
Natural Gas	0.30/MCF 1/	365	2,520,000 MCF	765,000
Water	0.027/MGal 2/	365	525,000 MGal	14,175
Chemicals		365		47,000
Operating Labour	0.30/MHR 3/	365+10	75,000 MHR	60,000
Supervision	1.25/MHR	365+10	16,000 MHR	20,000
Maintenance	1% Capital Investment			78,500
General Overhead	70.0% Labor and Supervision			56,000
Net Operating Cost/ Year	US$ 0.0053/KWH		196,000,000 KWH	1,031,675

General Plant Facilities

Capital Cost: $6,711,000

Cost Factor	Unit Cost US$	Quantity	US$/year
Labour	0.80/MHR	125,000 MHR	100,000
Supervision	1.25/MHR	9,000 MHR	11,250
Miscellaneous Supplies			50,000
Maintenance	1.6% Capital Investment		107,375
General Overhead	100% Labour and Supervision		111,250
Net Operating Cost/Year			379,875

1/ MCF = Thousand Cubic Feet

2/ MGal = Thousand U.S.Gallons

3/ MHR = Manhour

Summary of Costs for

Total Steelmaking Facility

Capital Cost : $29,511,000

Cost Factor	Unit Cost US$	Quantity	US$/Year
Natural Gas	0,30/MCF 1/	6,631,500 MCF	1,989,450
Water Make-up	0,027/MGal 2/	826,000 MGal	22,300
Catalyst and Chemicals			67,000
Operating Labor	0.80/MHR 3/	774,500 MHR	619,600
Supervision	1.25/MHR	43,000 MHR	53,750
Maintenance			783,875
General Overhead			649,350
Electrodes	600/Ton	2,000 Tons	1,200,000
Lime	12/Ton	20,500 Tons	246,000
Dolomite	18/Ton	2,625 Tons	47,250
Ferro Alloys	400/Ton	1,450 Tons	580,000
Fluorite	18/Ton	1,450 Tons	26,100
Refractories	145/Ton	2,500 Tons	362,500
Magnesite	46/Ton	1,300 Tons	59,800
Oxygen and Acetylene			38,000
Miscellaneous Supplies			130,000
HYL Royalty	1.00/Ton Fe		165,000
Net Operating Cost/Year			7,089,975
Iron Ore - 60%Fe	12,00/Ton	275,000 Tons	3,300,000
Scrap	45,00/Ton	115,000 Tons	5,175,000
Direct Cost of Product/Year	62,26	250,000 Tons	15,564,975

1/ MCF = Thousand Cubic Feet
2/ MGal = Thousand U.S. Gallons
3/ MHR = Manhour

Electric Furnace Data

(Basis: 17 ft. Furnace; Low Carbon Steel Product)

	Case 1	Case 2
Furnace Charge		
Scrap - %	40	15
Sponge Iron - %	60	85
Total Charge - %	100	100
Ingot Yield - %	91,4	93 1/
Tap-to-Tap Time - Minutes	304	320
Lining Life - Heats	120	115
Roof Life - Heats	43	43
Consumption per Metric Ton of Ingot Produced		
Electric Power - Kwh	680	790
Electrodes - Kg	8,0	9,7
Lime - Kg	82	100
Dolomite - Kg	10,5	11.5
Magnesite - Kg	5,2	6,6
Refractories - Kg	10	10,4
Ferro Alloys - Kg	5,8	5,8
Labour and Supervision - MHR	1,9	2,0

1/ Ingot yield is in accordance with experience of Hojalata y Lamina, S.A. Better yield at lower scrap percentage is to certain extent due to the fact that all scrap charged is clean good quality home scrap.

Some test results have recently been reported concerning the production of sponge iron by the HYL process using ITABIRA (Brasil) ore and the manufacture of steel from such sponge iron.[1/]

CVRD "rubble" type iron ore (Itabira hematite) can be reduced in a conventional HYL plant with an efficiency comparable to the normal practice at HYLSA in Monterrey.

A 500 metric tons per day plant (nominal capacity) specifically designed to operate with Itabira iron ore would produce up to 600 metric tons of Fe per day with a consumption of natural gas of 710 Nm^3 per ton of Fe. It should achieve a 85 to 89 per cent metallisation with 92.5 per cent of total Fe and a carbon content of 2,0 to 2,5 per cent in the sponge iron.

Such a sponge iron (with 89 per cent metallisation) is an excellent material to be charged in high proportion (about 33 per cent) into electric furnaces, producing high quality steel with heat times of 118 minutes. Such times were only obtained with 97 to 98 per cent metallisation sponge iron made from iron ores other than the Brasilian as referred to in technical papers until now issued.

The Itabira ore sponge with higher metallisations (97 to 98 per cent) would allow heat times of 110 minutes (tap to tap) leading to 55 metric tons/hr tap to tap productivities in 100 metric ton furnaces with 390 kW/metric ton power supplies.

The technical feasibility of USIBA's project is completely proved by the Monterrey tests. The conclusions of the present paper would only improve this feasibility.

[1/] "Production of Sponge Iron by the HYL Process using the ITABIRA Ore - Manufacture of Steel from such Sponge Iron" by Claudio H.M. Braga, Angelo A.T. Pereira and Ralpho R. Décourt.

The economic feasibility of the project is also assured since none of the technological improvements presented were called upon for the project. As a matter of fact, the profitability of the project is based on production and productivity parameters which are even lower than the ones attained with Monterrey tests.

The improvements envisaged through the modern technology lead to capital costs lower than 360 US dollars for annual metric ton of capacity and operating costs considerably less than 58 US dollars per metric ton (slabs or billets) for plants within the range of 140,000 metric tons of finished products a year. The above figures were the ones indicated for USIBA and would certainly be also met in a project with similar favorable conditions in regard to raw materials (iron ore, natural gas).

Some valuable technical data have been presented recently on electric arc furnace steelmaking with HYL sponge iron 1/ and the following typical data are presented therefrom:

Melting Data

Iron Yield:

During the first quarter of 1967 one furnace has been continuously smelting sponge iron heats with an average metallic load of 87 metric tons composed as follows:

Sponge gross weight	58 metric tons	
Scrap gross weight	38 " "	
T o t a l	96 " "	
Sponge, Fe content	50 " "	
Scrap, Fe content	37 " "	
T o t a l	87 " "	
Sponge Fraction		58%
Steel teemed	79.5 " "	
Iron yield to ladle steel		91.4%

1/ "Electric Arc Furnace Steelmaking with HYL Sponge Iron" by Mr. J. Celada S.

Iron yield in the early days of sponge iron use was relatively low but has shown constant improvement as suitable melt shop practice has developed and at present is better than 91 per cent.

Heat Time:

The charge melt-down rate is 27 metric tons per hour with an average tap to tap heat time of 304 minutes as follows:

Melting and charging	193 minutes
Refining	51 "
Delays	25 "
Tapping	7 "
Furnace Repair	28
Total	304 minutes tap to tap
Melt-down rate	27 metric tons/hour
Ladle steel production rate	15.7 tons/hour

Power and Materials Consumption:

The power and materials consumed per metric ton of ladle steel in the same period are:

Electric Energy	680 KW
Electrodes	8 Kg.
Lime	32 Kg.
Dolomite	10.5 Kg.
Magnesite	5.2 Kg
Lining Life (13" Magnesite brick)	180 heats
Roof Life (9" 70% Alumina brick)	43 heats

Sponge Iron Variables

Analysis:

The average sponge iron analysis during the first quarter of 1967 is shown in Table III. The process conditions at the sponge iron plant are normally set to produce 84 per cent metallization but are readily adjustable to produce any desired metallization. Likewise, normally carbon content is maintained within a range of 1.8 to 1.9, but can be varied between 1.5 and 4 per cent by suitable process adjustment in the reduction cycle.

Metallization and Carbon Content:

Eighty-four percent metallization of the sponge iron may appear low, but experience at Monterrey has shown that to achieve optimum overall economics, higher metallization alone is not the sole criterion. Metallization is evaluated in relation to the carbon available in the HYL sponge iron. During melt-down the carbon content, preponderantly combined carbon as iron carbide, reduces the wustite (FeO). Enough wustite should be present to sustain this reaction and to have FeO left over to combine with the slag and to promote the oxidation of the phosphorus. FeO in the slag should be about 20 per cent in order to have the proper fluidity.

If metallization or carbon content is increased, the viscosity of the slag will increase due to insufficient FeO, delaying the melt considerably. If, on the other hand, metallization or carbon content is diminished, the slag will be too rich in FeO, diminishing yield and lining life.

It is believed worthy of re-emphasis in discussing optimum metallization that the higher oxidizing characteristics of the melt with lower metallization can effectively remove most of the phosphorus during the melt-down period. Otherwise, phosphorus elimination must be accomplished during the refining period with corresponding increase in heat time.

Conditions may be set to obtain higher metallization with the corresponding reduction in carbon content. This will reduce somewhat operating costs at the melt shop, but these savings will be offset by a corresponding decrease in the output of the sponge iron plant. Experience has shown that HYL sponge iron of the analysis given in Table III renders a balanced economic operation from ore to steel with the type of ore now being used.

Granulometry:

During the past two years the Las Encinas iron ore has shown increasing friability tendencies in crushing, screening and handling with a corresponding effect on the granulometry of the sponge iron.

It became necessary to appraise carefully the effect of an increasing percentage of fines in the electric furnace charge or alternatively face the possibility of screening the sponge iron and agglomerate or discard the fines. Extensive tests were made to determine the operational problems, and effect on yields and operating cost the use of fines would present. It has been conclusively demonstrated that sponge iron with the screen analysis shown in Table V can be successfully converted in the electric arc furnace without significantly affecting operation, yield or cost.

The data presented herein for the first quarter of 1967 are based on the exclusive use of sponge iron containing the high percentage of fines shown in the tabulation without screening or agglomeration and without modifying earlier charging and melting practice.

Future Trends:

Ten years ago sponge iron and direct reduction were viewed by many of the steel fraternity as little more than intriguing metallurgical curiosities. Today, there is growing worldwide appreciation of sponge iron as a valuable source of high grade metallics. With this growing acceptance new possibilities are foreseen for sponge iron.

Lump sponge iron or reduced pellets are considerably easier to handle than scrap; they can be handled by conveyors instead of cranes and introduced into oxygen converters with appreciable saving in time and expense. There will be new melt shop design concepts and material handling techniques employed by the steelmaker as the use of sponge iron becomes more prevalent.

Control of carbon content makes it possible to improve operating efficiency by continuously charging sponge iron to electric furnaces, a procedure which is facilitated by the ease with which it can be handled. This concept is being actively explored by Hojalata y Lámina and a number of established steelmakers.

There is much yet to be learned about the preparation and utilisation of sponge iron in steelmaking. With its growing acceptance will come new melting and refining techniques and methods other than the electric arc furnace practice described in this presentation.

The one firm conviction gained by Hojalata y Lámina from its ten years of experience is that sponge iron is here to stay and that direct reduction will play an increasingly important role in supplying metallics for the manufacture of carbon and alloy steel products for the markets of the world.

TABLE III

Average Sponge Iron Composition during First Quarter 1967

(Per cent by weight, dry basis)

Fe	47,42	
Iron in $Fe_{0,95}O$	13,88	
Iron in Fe_3C	25,09	
TOTAL IRON		86,39
C	0,09	
Carbon in Fe_3C	1,80	
TOTAL CARBON		1,89
PHOSPHOROUS		0,417
SULPHUR		0,023
SiO_2	6,6	
Al_2O_3	0,2	
CaO	0,3	
GANGUE		7,1
OXYGEN in $Fe_{0,95}O$		4,18
		100,00

Present Metallisation $\left(\frac{\text{non oxide iron}}{\text{total iron}}\right)$ 83,93 %

Table IV

Specifications for Steels Currently Produced from

Sponge Iron Ingots

Spec.	C	Mn	P	S	Cu	Ni	Si	Cr	Sn	Basic property or application
SAE 1006	.07	.25/.35	.015	.030	.08	.06	-	.06	.01	Extra deep drawing
" "	.08	.25/.40	.020	.030	.10	.03	-	-	-	Deep drawing and coating
" "	.08	.25/.40	.020	.035	.20	.08	-	-	-	Light drawing
" 1008	.10	.25/.50	.035	.045	.40	.12	-	-	-	Light drawing
" 1010	.09/.14	.35/.55	.040	.040	.20	.10	-	-	-	Pipe manufacturing Std.
" 1012	.11/.15	.30/.45	.035	.045	.35	.12	-	-	-	Light structural
" "	.11/.15	.30/.45	.035	.045	.20/.45	.12	-	-	-	Light structural
HYL 1541	.09/.14	.45/.65	.045/.075	.035/.065	.20	.10	-	-	-	Machined fittings
SAE 1020	.18/.23	.30/.60	.020	.030	.20	.10	-	-	-	Auto chasis
HYL 1530	.10/.14	.70/.90	.020	.040	.25	.10	.10	-	-	L.P.G.portable cylinders
SAE 1018	.16/.21	.65/.85	.035	.040	.30	.12	.10	-	-	Storage tanks
" 1027	.20/.25	1.20/1.60	.020	.045	.35	.12	.10	-	-	High tensile
HYL 1536	.15/.20	.85/1.15	.040	.050	.30/.60	.50/.70	.10	-	-	Heavy structural trailer and truck chassis
" 1927	.08	.25/.35	.030	.040	.12	.06	.60/.70	-	-	Motor's laminations
SAE 1045	.43/.50	.60/.90	.040	.050	.40	.15	.10/.20	-	-	Laminated springs and shovels
" 950	.06/.12	.30/.45	.090/.110	.035	.35/.50	.45/.55	.25/.35	.80/1.00	-	High tensile and atmospheric corrosion resistance

Notes: (1) The specifications listed are produced in the forms of structural plate, hot rolled sheet and strip and cold rolled sheet and /stri and include applications of extra deep draw and coating finish.

(2) Low carbon rimmed steel = 68% of steel produced
Medium carbon rimmed steel - 23% of steel produced
Killed and semi-killed steel - 9% of steel produced

Table V

Sponge Iron Screen Analysis

Made with Facino Ore

Mesh Number	Retained	Accumulated
1/2	23,39	23,39
1/4	24,59	47,98
6	14,95	62,93
12	9,59	72,52
20	6,14	78,66
40	4,69	83,35
70	5,41	88,76
140	5,36	94,12
-140	5,38	100,00

REGIONS AND SITUATIONS SUITED TO THE PROCESS

In well-developed steel centres the HYL process can be used to produce a cheap and dependable supply of iron free from copper and other harmful contaminants. Its sulphur and phosphorous content can be kept down by proper choice of ores and hydrocarbons. The process deserves serious consideration because of the contributions it can make to the move toward higher quality which now characterizes the efforts of many established steel producers.

The HYL process may be seriously considered in situations where good lump or agglomerated ore is available and where natural gas or petroleum naphta is an economical source of energy. Its special advantages are:

(a) Proven commercial operation in the world's largest sponge iron facility;

(b) Labour requirements suited to emerging economies;

(c) Variability in size since plants have been constructed for 200 and 500 tons per day of sponge;

(d) Ease of capacity expansion because additional reactors and gas reforming furnaces can be added as desired;

(e) A wide range of types of ore lumps and agglomerates can be converted into sponge;

(f) An experienced engineering and consulting service is available for design, construction and initial operation.

As more capital and experience become available, the other stages in the steelmaking process can be installed until a substantial degree of iron and steel self-sufficiency has been achieved.

A reverse course of development is often more suitable when local supplies of ore are not adequate. Then it may be better to begin with steel-forming plant and work backward to steel refining, using imported scrap, sponge or pig iron. Finally, complete integration is achieved by adding reduction and beneficiation equipment. This, indeed was the procedure followed by Hojalata y Lamina S.A. in their development. It has the great merit of quickly reducing foreign exchange demands with a minimum investment.

A third alternative arises when more capital can be invested. A complete steel works can be built and operated as a unified development project, based upon the sequence of process stages best suited to the local circumstances. The HYL process should receive careful consideration whenever the supplies of ore and hydrocarbon are as previously described.

Thus, capital investment for a sponge iron plant of the HYL type will vary according to local conditions. In general, however, such an installation will cost about one half of the capital investment required for a conventional blast furnace of the same capacity. This includes coke ovens.

To produce one metric ton (1,1 short tons) of iron in an 85 per cent reduced sponge iron in the 200-tons-per day plant, the following raw materials are required: natural gas 26,000 cubic feet; electric energy 75 kW -hours; water 282 cubic feet; ore 1.75 tons. Direct labour amounts to one man-hour, excluding maintenance, ore handling and overhead. As a by-product, 2900 lb. of steam at 150 psi. pressure is produced; it is being used in the plant's rolling mill.

Raw materials requirements per metric ton (1.1 short tons) of iron, in the sponge iron for an 85 per cent reduced ore, will be lower than for the existing unit. The following values are expected; Natural gas 18,000 cubic feet; electric energy 7 kW-hours; water 121 cubic feet; ore 1.75 tons. Labour will drop to about one-half man-hour since the whole operation will be simpler. Fuel economy will be achieved because of better heat conservation. Less electric energy will be used because steam is employed as prime mover in turbines. (Hence, very little excess steam is left to be used elsewhere). Since each turbo-machine will have its own electric motor standing by there is considerable versatility in plant operation. Electric power can be used whenever economic conditions make it worthwhile to allot steam to other uses.

Economic success of Fierro Esponja's sponge iron plant, coupled with an increase in the quality of rolled products fabricated with this sponge iron, has made this departure from conventional iron-making processes attractive.

GENERAL DISCUSSIONS OF THE PROCESS AND ITS APPLICATIONS

There is little doubt that the HYL Direct Reduction Process is technically sound in many ways and what is required is a study of its economic appraisal, both in capital and operational costs structure and the ruling price pattern of its end-product, viz., the sponge iron as made in a particular region. The main questions arising out of the production of sponge iron would be to determine its economic and useful uses and potential applications whether for the production of conventional plain carbon mild and structural steels, low alloy constructional steels or for alloy, tool, special and stainless steels. This has, therefore, to be determined in relation to the availability of internal steel scrap in the region, its quality and physical state and its price structure delivered at any central or regional point of consumption. In turn, this subject has to be evaluated in the context of the import of steel scrap and its price pattern both FOB and CIF values, considering that basically any import of the steel scrap will involve foreign exchange payments. Of course, the quality and physical state of the steel scrap, whether of home origin or imported, are of utmost importance in defining their range of economic and potential utility. Heavy structural and clean steel scrap preferably classified or, in other words, pedigree steel scrap, would be needed for steelmaking both for the electric arc steelmaking, basic open hearth steel furnaces or for the L.O.basic oxygen steel converters whereas for cupola charging (hot or cold blast) light steel scrap such as turnings and borings and merchant mill steel scrap besides general market steel scrap, will serve the purpose for iron making and subsequent refining of the iron into steel.

Sponge iron, on the other hand, is a pure product containing substantially less impurities or metalloids in relation to pig iron and somewhat higher carbon in comparison with steel, with varying contents of metalloids depending upon the quality of the iron ore initially reduced to sponge. Sponge iron may be regarded as a pedigree steel scrap which, in essence, it seeks to replace for steelmaking and has to compete with it in terms of its price structure. Naturally, therefore, sponge iron if used for alloy, tool, special and stainless steel production offers a much more valuable and high priced end-product than if it were to be used for the production of plain carbon, mild and structural steels which represent a much lower priced product-mix. At the same time, the methods of steelmaking, whether the end-products are low priced plain carbon, mild and structural steels or high priced alloy, tool, special and stainless steels, would in practice be more or less identical, except that the latter would curtail the use of requisite ferro-alloys.

Additionally, one has to study the regional and inter-regional market pattern requirements, the aim being to produce those steels that are currently in demand while not ignoring the basic dictum very often applicable that the supply creates the demand and the price structure of the former dictates the flow of the latter. Future demand pattern can be built around the high priced end-products, both for internal market needs and also for export potential, provided the price structure of the two warrants. The situation, of course, tends to get hazy in the case of developing countries which may have an abundance of cheap and high quality natural gas as also high quality iron ores but lack in internal market demands for the high priced product-mix which can ensure much better return of the capital investment, viz., the market demands for alloy, tool, special and stainless steels, whilst to compete in the international markets in respect thereof will be a shaky venture and of dubious value for developing countries. Such a situation prevails in the Latin American countries, including Mexico, where the HYL process holds an undoubtedly supreme position, both technologically as also commercially and economically.

On the other hand, the HYL process has also to compete with the latest technological developments in iron smelting in an iron blast furnace with w ich it seeks to compete viz., heavy injection of natural gas with remarkable economic results in terms of high iron productivity and lowered coke and flux rates. In Mexico, for instance, such a situation does exist where not far from the Monterrey HYL sponge iron plant, the conventional iron blast furnace holds its own ground. Nevertheless, the operational success of the HYL operations in Mexico is based on the inherent technological soundness of the process and its economic implementation.

Furthermore, it will be necessary to point out that where the regional market demands the supply of foundry grades of iron, the conventional blast furnace including the Low Shaft Blast Furnace installation apart from the electric smelting reduction furnace of Elkem or Tysland Hole types with or without pre-reduced burden will rule out the possibilities and value of HYL process provided, of course, the region has suitable metallurgical grade of coking coals or semicoking coals and cheap electric power. The sponge iron, in order to yield foundry grades of big aim, must be smelted in an electric reduction pig iron smelting furnace with the burden so adjusted as to yield different grades of foundry pig iron - high silicon (2.75% Si - 3.25% Si) to medium silicon and then to low silicon verging on to the basic irons. As such, the cost of sponge iron which will well nigh be in the range of the foundry pig iron smelted in the blast furnace, cannot permit the smelting of the sponge iron in the electric reduction smelting furnace to produce foundry grades of iron - technologically, of course, it will be possible to do so, but economically it will not be possible to compete with the conventional blast furnace or low shaft small blast furnace for the production of foundry grades of pig iron provided, of course, the resources of metallurgical coke or low temperature carbonized coke from semi-coking coals are economically available. In other words, in a country such as Mexico, where good metallurgical grades of coal are available and can yield high grade metallurgical coke to justify their use in a conventional small low shaft or a big iron blast furnace for the smelting of foundry grades of pig iron and where cheap natural gas is also abundantly available for the HYL direct reduction process and where high grade iron ores' availability is a common factor for the two, for the production of basic irons for direct steel-making the HYL process presents a more attractive proposition in comparison with the blast furnace in view of the former's much lower capital and over-head costs, etc.; but where the end-products are foundry grades of iron, the conventional blast furnace, including low shaft small blast furnace, will be much superior to the HYL process entailing, as the latter would, the addition of electric reduction submerged arc smelting furnace to the HYL sponge iron capital plant installation. In other words, the capital and operational costs of converting the HYL sponge iron in the electric reduction submerged arc furnaces to smelt foundry grades of iron would be an additional cost burden considering that the HYL sponge iron and the blast furnace smelted basic iron for steel-making or the blast furnace smelted foundry grades of pig iron could represent more or less an equivalent priced commodity.

At the same time, it should be borne in mind that to make foundry grades of iron in the electric submerged arc furnace, a good quality iron ore can today be pre-reduced and thereafter smelted, causing reportedly significant drop in the electric power consumption for ironmaking - much progress in this field, although still new, is contemplated particularly in Elkem electric furnaces in Sweden and elsewhere.

At the end of the steelmaking spectrum, HYL process can hold its own adjudged on related basic parameters and notably excels if the end-products are high priced alloy, tool, special and stainless steels.

There are other residual questions about the HYL sponge iron concerning its degradation characteristics which do not encourage its long distance land or ocean transport, unless, of course, the sponge is subjected to expensive prior-pelletising or briquetting operations. The pelletised or the briquetted sponge in fact today represents an unknown commodity for long distance, overland or ocean transport owing to its amenability to pellet fissuring and cracking and degradation during handling and loading in heavy ocean carriers. The ~~danger~~ [illegible] of re-oxidation of the sponge over any length storage, haulage and ocean transport has still not been overcome although some progress has been made in inhibiting the re-oxydation through spraying, etc., and fully covered storage facilities - however, some re-oxidation of the sponge does result causing a percentage loss of its metallic value. The solution of using sealed hatches surrounded by suitable gases to store and transport sponge appears to be somewhat impractical. As such, the HYL sponge should be used not far from the centre of its production to permit its speedy charging in the electric arc steelmaking furnaces.

CONCLUSIONS AND RECOMMENDATIONS

Whilst no universal yardstick can be formulated in applying the HYL direct reduction process to developing regions where the resources of raw materials and availability of natural gas so warrant, nevertheless, it is strongly recommended that the project should be fully examined in detail in each potential case leading to the preparation of detailed project report for the HYL process to bring out the salient features in its favour or otherwise, both metallurgical and economic in the background of specific product-mix and market demand pattern of the region. The HYL direct reduction process does represent a significant and notable metallurgical progress. As such, its potential applications and industrial scale implementation will be based solely on its overall economics - capital costs and operational cost factors; these parameters have to be studied and critically analysed for each of the developing regions listed earlier in relation to alternative modes of iron and steelmaking. Based on these desiderata, detailed project reports have to be prepared in formulating the capital cost structure and profitability of the project. In the case of Brasil, the implementation of the HYL direct reduction process is under study and detailed reports thereon have been commissioned. It will be necessary, therefore, to recommend that similar studies should be undertaken under the auspices of UNIDO followed by the preparation of detailed project reports for each of the potential country where the HYL direct reduction process could be expected to hold its own in comparison with alternative and conventional processes for iron and steelmaking. It will also be essential to conduct pilot plant trials in the HYL pilot plant of 30 tons per day sponge capacity, installed at Monterrey, on prospective iron ores. A miniature reduction reactor is located at the Swindell-Dressler Experimental Station at Pittsburgh on which various iron ores can be tested for their reducibility characteristics. The last word, it is claimed, has hardly been said on the subject. The HYL direct reduction process is also subjected to continuous improvements in technological practices aiming at lower operational costs and up-grading of quality at the end-product. That this has indeed been the main theme of those who had developed the HYL direct reduction process and are seeking to continually improve upon it, is shown by the two HYL sponge installations at Monterrey followed by the still newer and up-to-date installation at Vera Cruz. And this will be followed by the projected two million ton steel plant at Puebla, not far from Mexico City, based on the HYL process - with a design annual capacity of 250,000 metric tons of finished steel products, the new mill will add to Hojalata's steelmaking capacity by 90%. This plant is likely to cost 42 million dollars with a daily rated direct reduction capacity of 500 tons of sponge to feed three electric arc melting furnaces. The plant will be fed with iron ore from the state of Colima on the country's Pacific coast which supplies also the present Hojalata plants at Monterrey. These steps are in the right direction and are indicators of the progress that follows in the wake of advancements in metallurgical technology through ceaseless efforts in which the role of developing countries should be that of "partners in progress" - in the pursuit of which UNIDO will provide maximum assistance.

The following specific recommendations are now made:

(a) The Report on HYL Process of UNIDO should be sent to countries where raw materials' situation is favourable for the direct reduction gaseous process, such as Gabon, Algeria, Iran, Iraq, Morocco, Kuwait, Pakistan, Taiwan, South American countries, etc. - this should be followed up, wherever possible, by UNIDO mission visits to potential countries for reviewing and studying the application of HYL process to developing regions.

(b) Subsequently to (a) above, full tests on samples of representative iron ores should be arranged from different regions at the HYL pilot plant at Monterrey and the experimental station of Swindell-Dressler at Pittsburg and reports issued thereon.

(c) Feasibility reports should be commissioned in the first place for different areas on technical feasibility and overall economics of the direct reduction process in relation to conventional blast furnace smelting of pig iron besides low shaft blast furnace production of foundry pig irons in small plants in developing countries depending upon their raw materials' resources.

(d) Commissioning of detailed project reports on the plants in the light of (c) above, for each of the developing regions in various parts of the world.

(e) Linking the developing countries with potential sources of financial investment and capital equity participation for the establishment of the industrial plants. In doing so, the market needs in relation to iron and steel product-mix will be kept in mind, including the requirements of alloy, tool, special and stainless steels on a regional and interregional pattern, both for export and home use.

APPENDIX A

The HYL Process

The HYL process involves the batch reduction of iron ore by reformed natural gas. Natural gas enters the plant and passes through pre-heating coils in the stacks of the reformer furnaces. It then passes through de-sulphurising drums filled with activated charcoal and again through pre-heating coils in the reformer stacks to further recuperate heat. Steam is mixed with the pre-heated natural gas and the mixture passes into hot, catalyst-filled tubes within the reformer furnace. The reforming action takes place at 1600°F and the reformed gas averages (dry basis) 73.1% hydrogen, 16.3% carbon monoxide, 6.6% carbon dioxide and 4.0% unconverted methane. The reformed gases are partially cooled, recuperating the heat by passing them through water-quench boiler to generate steam. The gases then pass into a primary quench tower to remove excess steam fed to the original gas mixture in order to prevent carbon deposition and plugging of the catalyst-filled tubes. The gases are then pre-heated to 1600° - 1800°F in preheating furnaces. The residual carbon dioxide and water vapour in the gas prevents carbon deposition in the gas pre-heating furnaces. The pre-heated primary-reducing gases enter the ore reduction retorts, which are in the primary cycle of ore reduction (final reduction). The gases pass downward through the retort oxidising the hydrogen to water vapour - the partially spent gases are called the secondary reducing gases from which the water vapour is removed by direct quench with cold water in quench towers. The resulting gases are again pre-heated in gas pre-heat furnaces and passed through reduction retorts in secondary ore reduction cycle, vis., initial ore preparation cycle. The issuing gases pass through a quench tower to remove water and are considered as fuel gases only for heating the reformer tubes, firing the gas preheat furnaces and for generation and superheating of steam. Iron ores suitable for HYL process can be lump ore or agglomerated ore fines - the optimum range is + 1/4" and - 1 1/2" with 20 - 25 per cent of - 1/4" ore fines. The ore cycle commences with one retort emptied of the reduced sponge and filled with fresh ore - this takes one hour. The loaded retort then enters the secondary reduction cycle (initial ore pre-reduction) for two hours (no ore pre-heating is done), following which it enters the primary reduction, viz., final reduction for another two hours. Typically, the final degree of reduction varies from 96 per cent at the top to 73 per cent at the bottom of the ore bed in the retort and the average degree of reduction varies between 85 and 90 per cent. A final operation is done before the retort is emptied of the reduced sponge, i.e. the carburising of the sponge iron for its use in steelmaking. The hot sponge is carburised by passing natural gas through the retort for several minutes. The methane cracks and carbon is deposited on the iron to the required extent. The exit pipe for gases leaving the lower section uses specially designed coupling for ready disconnections. The entire sequence of operations is automatically controlled from a central station. The reactors are uncoupled and taken away from the fixed head into dumping position and then hydraulically tipped to discharge the sponge into suitable hopper cars for removal to the steelmaking plant. The ore reduction can be controlled at will by adjusting the reduction-cycle time and the flow of reducing gases through the ore bed.

Definitions:

Sponge iron is the product obtained from the oxides of iron by reduction at elevated temperature, generally with hydrogen or carbon monoxide, and without attaining the fusion point.

Metallic Iron : Non-oxide iron, i.e. $Fe\ Met = Fe + Fe \text{ in } Fe_3C$

Total Iron : For our purposes it is $Fe\ Tot = Fe + Fe \text{ in } Fe_{0.95}O + Fe_3C$

Metallisation : Is the ratio of metallic iron to total iron as defined above (expressed in per cent) $\%\ Met = \frac{Fe\ Met}{Fe\ Tot} \times 100$

% Reduction : Per cent oxygen removed from the ore, i.e.

$$\%\ R = \frac{\text{Initial Oxygen} - \text{Final Oxygen}}{\text{Initial Oxygen}} \times 100$$

Total Carbon : The sum of combined carbon in the form of Fe_3C and the deposited carbon

Gangue : All the compounds and impurities which accompany the oxides of iron, principally the compounds of Silica, Alumina, Calcium, Magnesium, Sulphur and Phosphorus

Basic Process Features

The HYL direct reduction process aims primarily at the removal of oxygen from the iron oxides by the action of a reducing gas mixture (H_2 and CO), as indicated in the following reactions:

$$Fe_2O_3 + 3H_2 = 2Fe + 3H_2O$$

$$Fe_2O_3 + 3CO = 2Fe + 3CO_2$$

to obtain sponge iron. The final product is solid and porous. Besides the oxygen removal, the HYL direct reduction process also obtains:

(1) Elimination of all water and CO_2 of the carbonates initially present in the ore;

(2) Elimination of 85 per cent of the sulphur present in the ores;

(3) Deposition of carbon on the sponge iron as indicated in the following reactions:

$$3Fe + 200 = Fe_3C + 00_2$$

$$3Fe + CH_4 = Fe_3C + 2H_2$$

The sponge iron is used as a raw material in steelmaking. In Monterrey and Vera Cruz it is charged to electric furnaces, but it could be utilized in furnaces of another type.

Raw Materials:

(1) Iron ore as oxides, mainly hematite (Fe_2O_3) and combinations of hematite and magnetite (Fe_3O_4);

(2) Natural Gas or anyone of the following can be used:

Light Hydrocarbons, L.P., Gas, Naphtha;

(3) Steam.

Typical analysis of iron ores used:

Total Fe	65,29
FeO (Analised)	11,76
Fe_2O_3 (Calculated)	80,38
Hematite	53,93
Magnetite	87,38
S	0,047
P	0,360
Calcination Loss	0,77
Gangue	6,76

Iron ores of lower grades can also be processed. The HYL reactors process raw or roasted iron ore with sizes:

+ 1/2" to 1 - 1/2"

Reducing Gases:

The reducing gases are produced from a preheated mixture of natural gas and steam, reformed in vertical pipes, containing a nickel catalyst; the reformation temperature is around 850°C (1562°F).

A sponge iron plant is devided into two well defined sections:

(1) Reforming Section

(2) Reducing Section

The reforming section is composed of:

One reformer
Two desulphurisers
Auxiliary equipment
(pumps, piping, etc.)

A reformer has the following parts:

(1) Chimney, with: a boiler, a steam superheater, a natural gas and steam preheater

(2) Reforming Tubes, which comprise: 210 vertical 4.5" O.D. tubes in parallel, located within a combustion chamber formed by 80 burners and the furnace walls.

Steam Generation:

Saturated steam is generated in the boiler located in the upper part of the chimney.

The steam is superheated in a superheater located in the zone immediately below the boiler. The feed water for the steam generation is softened and preheated. The steam generated in the boiler is mixed with natural gas in a molar steam/gas ratio of 2,1/1,0. The mixture passes through a mixture preheater where it attains a temperature of 430°C. The mixture then passes through the reforming pipes, where the actual reforming of the gas takes place to give a mixture of reducing gases with the following typical composition:

H_2	74%
CO	13%
CO_2	8%
CH_4	5%
	100% (dry basis)

The desulphurisers work with activated carbon beds. The main sulphur contaminant is the odorant compound added to the natural gas. The reforming reactions take place at temperatures round 850°C indicated below:

$$CH_4 + H_2O = 3H_2 + CO$$

$$CH_4 + 2H_2O = 4H_2 + CO_2$$

The unreacted CH_4 present in the reducing gas mixture is used for the carburisation of the sponge iron. The effluent reduction gases are cooled in a heat exchanger which acts as a waste-heat boiler with water coming down from the boiler dome. The gases leave the heat exchanger at a temperature of around 230°C (471°F). They are cooled at 30°C in fin-fan coolers.

Flow Diagrams:

Generalities

The reduction of iron ore to sponge iron takes place in a counter-current system with the reducing gases as indicated in the following chronological sequence:

Stages in the conversion of ore to cooled sponge iron:	The reducing gases work in the reduction stages in the following order:
(a) Secondary Stage	Cooling Stage
(b) Primary Stage	Primary Stage
(c) Cooling Stage	Secondary Stage

The reducing stages of ore to sponge iron are named after the quality of the reducing gases going through the retorts at a given moment.

The reducing gases are used in the following sequence:

(a) For cooling down the sponge iron that has just finished its reducing stages (cooling gases);

(b) For finishing the reduction of the ore (primary gases);

(c) For starting the ore reduction (secondary gases).

Reduction Cycle

The chronological sequence for the reduction of iron ore to sponge iron and the utilization of the reducing gases are as indicated in Figure No. 1 attached.

The reducing gases are passed in <u>series</u> through the reactors. Let us consider that we have the reactors at a given moment in the following reduction stages:

Stages	C Cooling	Primary	Secondary	Manoeuvres
Reactor	D4	D3	D2	D1

The complete cycle of each reactor lasts 12 hours with the following distribution:

Secondary	3 hours
Primary	3 hours
Cooling Down	3 hours
Manoeuvres	3 hours
	12 hours

The dry and cool gas leaving the quench cooler is passed through the D4 reactor (in its cooling stages), which has just finished its reducing stages.

The gas leaving the D4 reactor is passed to the quench cooler to eliminate the water and to the furnace to be heated to the reduction temperature. After leaving the furnace the gases are called primary gases. These primary gases are passed through the D3 reactors that is on its primary stage of reduction. The gases leaving the reactor D3 are passed to the quench cooler and the furnace where they are respectively dried and heated. After leaving the furnace, these gases are called secondary gases.

The gases leaving the reactor D2 in secondary stage are passed to the quench cooler, where the water produced during the secondary stage of reduction is eliminated. Once dried, these gases are used as fuel gas in the reformers.

Plant Capacity

Each reactor is loaded with 100 metric tons of iron ore of around 65 per cent Fe content, which means that the weight of the sponge iron produced in each reactor is 65 metric tons of sponge as total iron. The daily design capacity of the plant is eight reactors of 65 tons of iron per reactor which equals 520 tons of sponge as total iron.

Product

1. Typical analysis of sponge iron from Mexican Las Encinas ore (weight per cent);

Total iron	85,390	
Elemental Iron		47,42
Iron in $Fe_{0,95}O$		13,88
Iron in Fe_3C		25,09
		86,39
Oxygen in $Fe_{0,95}O$	4,180	
Carbon	1,890	
Free Carbon		0,09
Carbon in Fe_3C		1,80
		1,89
Phosphorus	0,417	
Sulphur	0,023	
Gangue	7,100	
	100,000	

$$\% \text{ Metallization} = \frac{(\text{Nonoxide iron})}{(\text{Total Iron})} \times 100$$

$$= \frac{47,42 + 25,09}{86,39} \times 100 = 3,93$$

2. Physical characteristics:

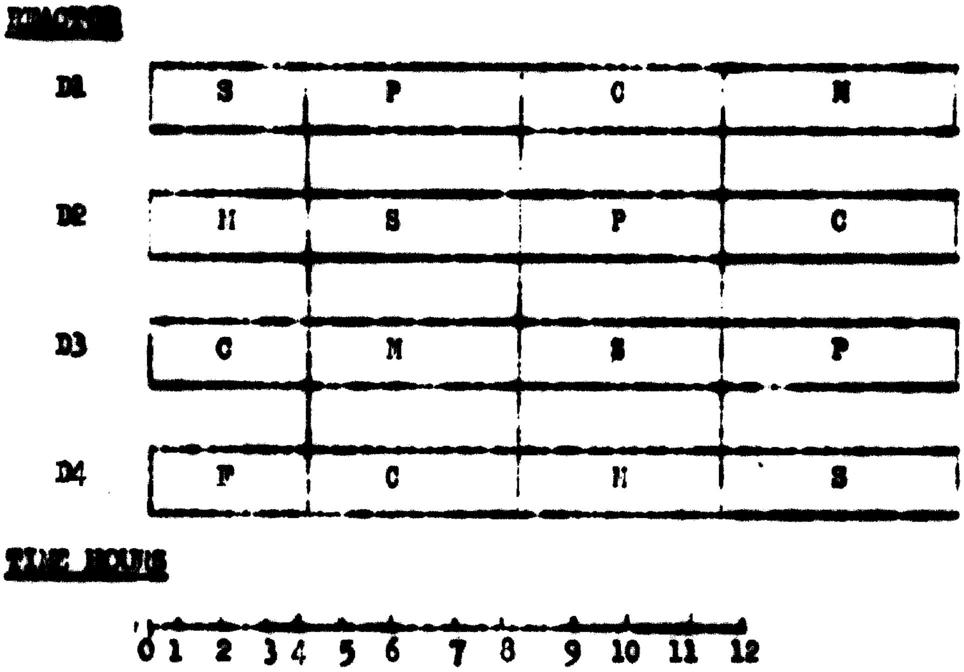
Specific weight = 5,26 gr/cm^3

Apparent density = 2,80 gr/cm^3

Volumetric weight = 1600 Kgs/m^3

Note: Volumetric weight of No.1 Scrap = 875 - 925 kg/m^3
No.2 Scrap = 750 - 780 kg/m^3

Figure No. 1



C = COOLING

P = PRIMARY

S = SECONDARY

M = MANOEUVRES

C+ M = COOLING AND MANOEUVRES

ACKNOWLEDGEMENTS

Grateful thanks are due to the management of the HYL Direct Reduction Plants at Monterrey and Vera Cruz for their full co-operation and for arranging the plant visits and supplying technical data and information, much of which has been freely reproduced in this report.

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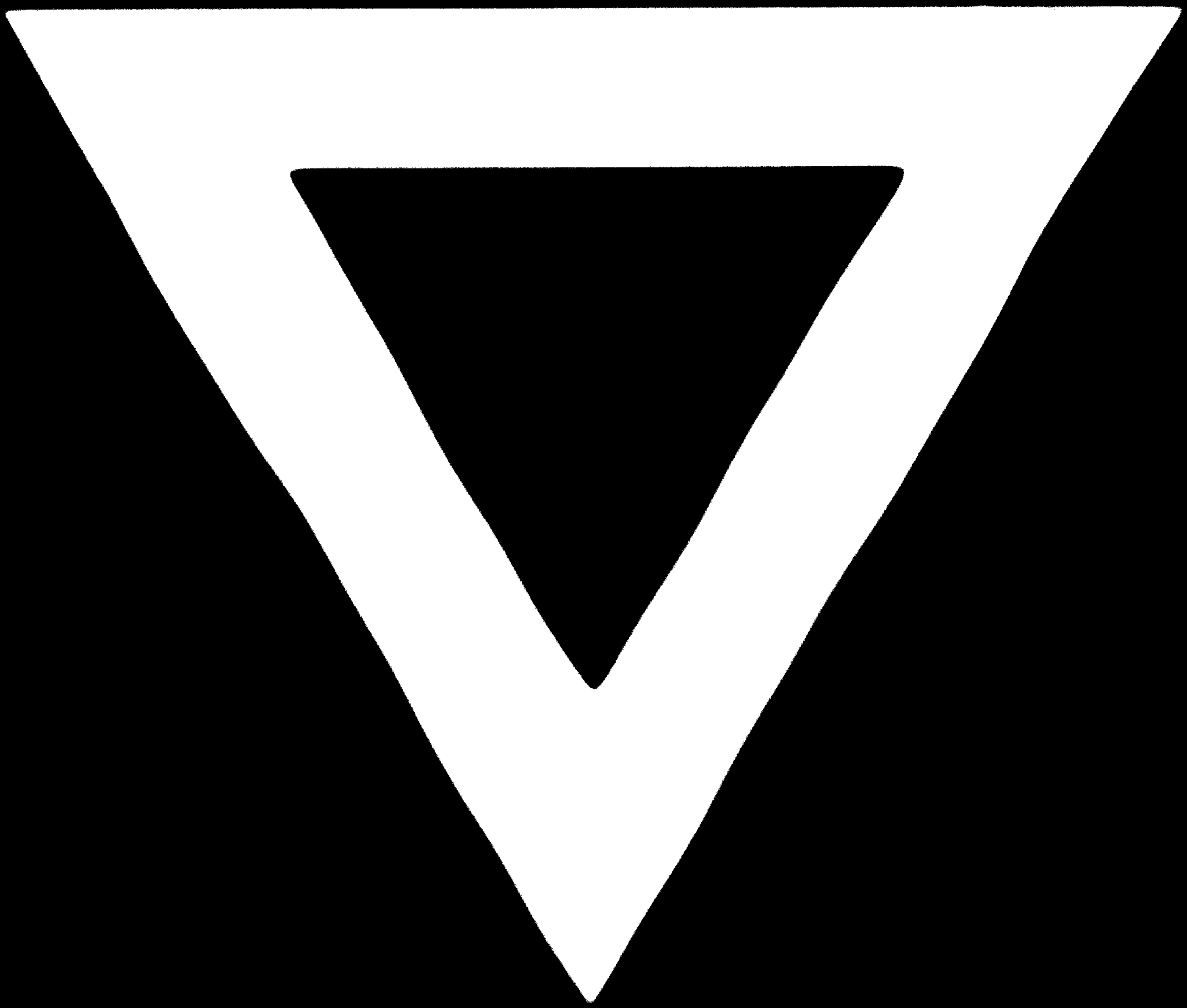

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