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DIRECT REDUCTION FOR THE DEVELOPING NATION[1]

by

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SUMMARY

The author describes the basic criteria he believes should be observed by those who may be called upon to evaluate direct reduction for the developing nations, and some of the "gray areas" he feels need to be better understood and judiciously appraised.

Some of the fundamentals applicable to all processes are covered, such as sponge iron reoxidation and the quality, selection, and testing of ore, and the differing parameters which apply to sponge iron production for the local market and for export.

Under the heading "Process Selection" he debates the relative merits of the "moving bed" and "static bed" concepts, and whether or not gas consumption is the essential comparative criterion rather than total energy cost and process efficiency.

INTRODUCTION

There is a burgeoning demand for industrial independence in the developing nations of the world and steelmaking facilities are looked upon as an essential first step. Direct reduction will play a principal role in this internal development and growth, a role to which it is uniquely applicable. It is hoped that the presentation here of some of the conclusions drawn from the author's 15 years of close association with the subject will help toward a better understanding of the present day problems of applying direct reduction to the needs of the developing countries.

Prior to 1958 the subject of direct reduction held little more than academic interest for the major steelmakers. There was almost emotional opposition by the established steel fraternity to the term "sponge iron." Much of this resistance was generated by the promoters of direct reduction making extravagant claims for the magic qualities of sponge iron and predicting that direct reduction would put the blast furnace "out of business." Sophisticated steelmakers argued validly that the economics of direct reduction could not be properly evaluated without reliable commercial-scale cost data for the entire steelmaking sequence from ore to ingot. They also criticized published plant investment cost estimates limited to the boundaries of the reduction unit only without including all the necessary ancillary processing and offsite facilities.

An essential ingredient also lacking at that time was reliable information and operating experience on the cost and technique of converting sponge iron to steel. This, of course, has undergone significant change in the past 15 years and reliable electric furnace operating data are now available based on the conversion of millions of tons of sponge iron to steel. In fact, reduced iron, as sponge iron, metallized pellets or briquettes, is now widely accepted by the metallurgist and steelmaker alike as a desirable source of high-grade metallics. Almost without exception the major steel producers around the world have tested sponge iron in most of the conventional steelmaking processes with good results and have also found it superior to scrap as the coolant in oxygen converters. However, there is definite need for the development of new efficient methods for melting sponge iron to produce large quantities of hot metal other than the electric furnace.

Unfortunately, it is not a simple matter to evaluate the application of direct reduction to the developing nations. There are distinct differences between steelmaking with pig iron, scrap, and sponge iron, and generalizations about operating cost, plant investment cost, optimum plant size, profitability, etc., should not be made without full knowledge of the present state of technical development and the applicability of each of the direct reduction processes to the individual case.

In some localities the economic factors are not nearly as restrictive as one might assume and costs are sometimes found to be acceptable at surprisingly high levels, particularly where political, monetary and industrial independence are a vital part of the evaluation. This would not be true in highly industrialized environments such as the U.S.A., the European Continent, and Japan, or where the product is to be sold in the world market, but it is undeniably true in many countries where direct reduction is being studied as a means for producing steel for local consumption to replace imported semi-finished or finished steel products, or raw materials to produce steel.

There is little doubt that the advent of direct reduction has arrived, but it must be intelligently applied in the proper environment.

BLAST FURNACE VS. DIRECT REDUCTION

Attempts to compare the relative viability for the developing nation of a multi-million ton blast furnace-coke oven complex and a 200,000 to 500,000 ton direct-reduction plant are clearly fruitless and responsible for much of the confusion surrounding a proper evaluation of direct reduction in its own right. Before the advent of direct reduction there was no alternative procedure readily available. Now that there is, it is still not simply a matter of choosing one or the other.

There are many developing countries where small- or intermediate-scale steelworks of 150,000 to 350,000 tons per year is the optimum size. The conventional multi-million ton blast-furnace steelworks is not the optimum size for most of these locations and is impracticable for other equally cogent reasons. In most developing countries there is insufficient population, local demand, and purchasing power to justify initially such large-scale installations. The perpetuation of foreign exchange expenditures for the importation of coking coal and the serious question of its future availability must also be considered. Product distribution problems are also too acute in some localities to permit centralized large-scale production, and decentralized area development would probably be desirable.

The steelworks for developing countries should also be moderate in size because of the financing problem the integrated blast furnace-coke oven steel mill complex presents. Its so-called minimum economic size has undergone some radical upward revisions over the past 15 years. In 1958 a leading authority considered the optimum economic size integrated steelworks was one million annual tons. One year later he was convinced that the ideal capacity was two million tons. It is now contended that the minimum economic size is not less than three to four million tons.

In converting this to money, the problem of financing is immediately apparent. The investment cost per ton of crude ingot steel for a grass-roots integrated blast furnace-coke oven complex in the one to two million ton range is given in a United Nations European steel industry publication as ranging from

$257 U.S. per annual ton in the Far East to $350 in North America, with $300 being considered the Western European average. This means that one is faced with an investment of $300 to $600 million if one accepts one to two million tons as the minimum economic size. It is hard to envision how such projects could be undertaken financially by many of the developing nations; hence the current emphasis on direct reduction at substantially lower capital cost for plants of modest size which can be progressively enlarged in reasonable increments as demand warrants.

One all too often hears the statement, "If the local demand is insufficient to justify the minimum economic size blast furnace complex, we will sell the surplus tonnage in the export market." It is the author's firm opinion that with rare exception this philosophy is doomed to failure. The project in the developing country should first be feasible on the basis of local demand.

Japan is frequently cited as an example which could be emulated by others as a country able to sell steel competitively in the world market even though they must import all the necessary raw materials. Japan is not an exception to the rule; the Japanese steel industry is firmly based on the local demand of 75 million people in a highly industrialized country with a highly skilled and productive work force with relatively high per capita income and purchasing power. The 15% of their steel production which is exported only serves to improve the level of productivity of the home industry. The first concern of the Japanese steel industry and government is any slackening of local demand; it could not survive on steel exports alone. Japan is able to sell competitively in the export market because of the assured and higher priced home market, a unified steel policy, and the firm support of the government.

SOME FUNDAMENTALS

Perhaps it would be helpful to re-emphasize at this point certain fundamental and almost axiomatic factors governing the economics of direct reduction and its application to steelmaking.

The nature and extent of extraneous elements, compounds, and impurities associated with iron ore and the manner in which they are combined, both chemically and physically, are some of the critical processing and economic variables with which direct reduction has to contend. From the steelmaker's standpoint, it is the iron content in which he is primarily interested; this, and the degree to which the reduced ore or metallized pellet is free of contaminants, directly affect the economics of his operation and the quality of his product. The problem of producing high-grade metallic iron units from ores containing impurities of wide variety and state can range from the relatively simple to the extremely complex.

With the exception of certain normal absorption and chemical side reactions which occur when passing a reducing gas at elevated temperature through an iron ore, such as partial sulphur removal or ignition loss, direct reduction performs no important function other than the removal of oxygen. It may seem redundant to mention this obvious fact, but it is surprising that direct reduction is still regarded by some as a magical means to beneficiate low-grade iron ore. In other words, silica, alumina, phosphorus, copper, nickel, etc., will remain in the sponge iron if they are present in the ore, and whether or not the resulting sponge iron from a given raw material can be profitably processed to steel is the crux of the entire matter. After all, it is possible to produce steel from almost any ore by any process if one chooses to ignore the technical complications and expense, but no process can utilize low-grade raw materials without experiencing correspondingly poor economics. At some point in the transformation it is necessary to remove the gangue constituents. The economic advantages of using high-grade ores or pelletized concentrates in the blast furnace also hold true for direct reduction.

When one considers that the true capacity of a direct reduction plant is measured in terms of Fe throughput, it follows that, if possible, extraneous gangue in a low-grade ore should be removed as the first step in the process sequence where the iron losses associated with the upgrading of the raw material have the lowest unit cost value. Such procedure also reduces the processing cost and installed cost of the reduction plant per ton of iron, or, conversely, permits the processing of the maximum weight of iron units for a given plant size.

There is an economic limit and in some instances an absolute limit beyond which an iron ore or sponge iron cannot be beneficiated and, therefore, 100% reduced sponge iron free of residuals cannot be manufactured at a price low enough for use in normal carbon-steel production. The basic problem, therefore, is the economic evaluation of the debit which one must apply against sponge iron for these factors and the establishment of debits and credits for variations in residual oxygen, carbon content, and insolubles. Where the economic balance lies between melting cost and beneficiation cost is a factor which must be determined for each ore, location, and steelmaking process.

TWO BASIC PROJECT TYPES

There are two broad areas of application for direct reduction: (1) the conversion of iron ore or iron oxide pellets to semi-finished or finished products in a fully integrated steelworks and (2) the manufacture of a highly metallized product in pellet or briquetted form for export sale. This material is referred to by many names among which are sponge iron, metallized pellets, pre-reduced iron, melting stock, and a number of trade names for the reduced product in briquetted form.

The first category is on firm ground; for example, the Grupo Acero HYLSA in Mexico has, to date, manufactured over five million tons of finished steel products utilizing three and one-half million tons of sponge iron in 130,000 electric furnace heats. They produce hot and cold rolled sheet and strip, tin-plate, wire rod, rebar, light structurals, and welded pipe. This commercial experience has made it possible to obtain the firm operating data necessary to determine the investment and operating cost factors applicable to other localities. The HyL direct reduction process is recognized today as a mature and absolutely reliable system applicable to a wide variety of ores, localities, and conditions.

The majority of prospective users in the developing countries have been smaller producers, and their requirements have fallen within the range of 200 to 600 tons per day. A mini-steelworks is most often desired by prospective users in these areas either as a new integrated direct-reduction installation or by the "backward" integration of an existing re-rolling or scrap-melting operation.

The second category and, ultimately, perhaps the most attractive is the production of high-grade melting stock or semi-finished or finished products for export, which will involve much larger plant sizes, 2000-4000 tons per day. There is a large potential market for pre-reduced iron in many locations. For profitable production of such material, the selection of plant site, the availability of fuel, and the grade of ore or pellets, are of the utmost importance. Production cost must be at an absolute minimum, necessitating large-scale production, cheap fuel, and an ore which, in its native state, is either extremely low in gangue, silica, and other undesirable residual elements, or which is amenable to beneficiation and pelletizing.

If the sponge iron is to be transported or shipped as a non-briquetted end product, oxide pellets should be used as the basic raw material rather than lump ore. Sponge iron produced from lump ore is usually too friable for transport and the penalty for excessive fines could be prohibitive.

Minimum quality requirements have been given as 85-92% metallization, 3-5% insolubles, and 1-3% carbon. Since the delivered cost of such metallics generally includes a sizable increment for transportation and must be sold competitively with scrap in the open market, the logistics of such programs must be carefully evaluated.

Of almost equal importance to the development of sponge-iron melting stock for global distribution is the need of a commodity market price for the material. The established steelmaker cannot evaluate sponge iron without reliable conversion cost data derived from adequate scale tests. He frequently wishes to perform these tests in his own plant on substantial tonnages of representative material before defining an acceptable specification and price.

In several geographical areas direct-reduction plants to produce high-grade metallics for export using natural gas and oxide pellets appear economically attractive. Iran, Venezuela, and Australia are particularly fortunate in this regard. The further integrated conversion of sponge iron to billets or finished products in such locations, not only for local consumption but also for export, is receiving careful scrutiny and appears to be on firm economic ground.

ORE SELECTION

The textbook definition of ore as being "one that can be mined and processed at a profit" applies with equal validity to direct reduction, and the meaning of the word "profit" is subject to all the corollary considerations that might apply to widely divergent local circumstances, and not necessarily confined to money. Some important factors relative to ore quality should be emphasized at this point:

a. The fact that an iron ore is low in residuals and has a high Fe content does not assure that it is either reducible or acceptable. Swelling and decrepitation tendencies at high temperature in a reducing atmosphere may necessitate pelletizing.

b. It should be predominantly hematite if it is to be used in lump form. If it is magnetite, it can be pelletized to fully oxidize the magnetite to hematite during induration. This also eliminates sulphur.

c. The porosity or permeability of the ore or pellet is very significant.

d. The reducibility and quantity of reductant required to reduce lump ore is far more unpredictable than when pellets are used and subject to much wider variation; in specific instances as much as 50% or more.

Many ores, even when ground to absolute minimum fineness, cannot be upgraded or beneficiated by even the most sophisticated modern procedures because of their interstitial bonded structure or composition, and can only be utilized by melting and slagging-off the impurities. The melting of large percentages of gangue obviously requires increased consumption of fuel or electrical energy, but in certain circumstances this may prove to be the most tenable alternative.

For example, for many years steelmakers in Great Britain processed iron ores which produced two tons of slag per ton of metal. Originally, Hojalata y Lamina, S. A., in Mexico profitably produced steel in electric furnaces from lump sponge iron containing 8-12% silica. One would, however, not propose to translate these exact practices blindly to other locations.

If avoidable, low-grade, high-gangue sponge iron should not be charged directly into an electric furnace or other steelmaking process unless the ore cannot be upgraded by mechanical, flotation, or magnetic means. The operating difficulties using low-grade materials can be as forbidding as the cost. In the development of the HyL process a high-grade hematite ore with an iron content ranging from 60-65% was utilized by economic preference, not technical necessity.

It is also true that pellets have proved generally superior to lump ore due to their uniform size, which is conducive to better gas distribution in the reduction vessel and yields a more stable and physically stronger product.

THE SCRAP AND FUEL QUESTION

Scrap and fuel availability and cost are having and will continue to have a decided influence on the future growth of direct reduction. One will effect it adversely in some locations, the other, favorably. In most of the industrialized centers of the world, such as central Europe and the North American Continent, natural gas and the lighter hydrocarbons are becoming difficult to obtain on a long-term contract basis. This will unquestionably shift the center of gravity for the development of direct reduction to those areas in which natural gas and the lighter hydrocarbons are in plentiful supply.

For example, it appears likely that the future application of direct reduction in the United States of America using gas or liquid fuel processes is extremely doubtful. Solid fuels are in much more plentiful supply than either natural gas or the lighter hydrocarbons, particularly in the U.S.A.

To date the success of the direct-reduction processes using solid fuels has, unfortunately, been limited and it appears likely that the future use of coal or other solid fuels will be through the medium of total gasification. Thus far, the gasification processes have not been technically developed to a high degree and the resulting reducing gas or effluent gas is prohibitively expensive. Many outstanding research and technical organizations in the world are working strenuously to find a solution to this problem, particularly one which will produce a gas similar to natural gas, or a gas which can be used directly as a reductant without reforming.

The occurrence which has recently revitalized interest in direct reduction is, of course, the escalating price of scrap in the world market. As a rough approximation of the economic parameters involved, if natural gas or lighter hydrocarbons are available at a price of 35-40¢ U.S. per million Btu's, sponge iron can be produced from high-grade oxide pellets competitively with scrap at $40-45 per ton. Gas or naphtha available at 50-55¢ per million Btu's can produce sponge iron competitively with scrap at $50-55 per ton. If the cost of scrap is $65 or higher, gaseous fuel at 75-85¢ per million Btu's is distinctly viable, and as of this writing scrap prices higher than $65 prevail in many places.

REOXIDATION

The tendency of reduced iron oxide to lose metallization by slow reoxidation when exposed to the elements, or with such rapidity that the material is pyrophoric, i.e., burns spontaneously, has become a matter of major significance to the potential users of the product and the shipper. The writer's first experience with this subject was in 1960. Allegheny Ludlum Steel Corporation in Pittsburgh, Pennsylvania, U.S.A., advised that they were experiencing a loss of 15-30% metallization by the reoxidation in an exposed pile of HyL briquettes which they were testing as a scrap substitute in alloy steelmaking. Although the briquettes were produced in powerful ram presses and were presumably less porous than non-compacted sponge iron, they were not sufficiently impervious to inhibit absorption of significant amounts of excessive moisture when exposed to the elements.

A joint research program was immediately undertaken by HYLSA de Mexico and The M. W. Kellogg Company, a Division of Pullman Incorporated, to study the problem, using briquetted and non-briquetted sponge iron. A variety of anti-oxidation treatments, additives, inhibitors, sprays, and coatings were tested under a wide range of conditions. It was concluded that, although some were effective, the cost associated with their application or their undesirability in steelmaking was prohibitive.

However, the most significant finding was that HyL sponge iron did not reoxidize to any deleterious extent over extended periods of time if protected from wetting, i.e., rain or surface water drainage, and that compacting or briquetting was not necessary. Covered storage was found to be the least costly and effective method of preventing reoxidation.

The fact that HyL sponge iron can be transported in pellet form without further compacting is significant, since it has been found that briquetting can entail operating and maintenance problems as well as high cost. Compacting retards the rate of reoxidation but does not prevent it under all conditions; it only appears justified for the purpose of agglomerating the product of the fluid-bed direct-reduction processes.

A "passivating" procedure has been developed by Midrex to partially reoxidize their reduced product and form a "patina" of rust to inhibit reoxidation of their pellets, which otherwise are pyrophoric and must be stored in silos under an inert-gas blanket. This treatment, of course, entails additional cost and a loss of 2% metallization.

The design of systems and the handling techniques required to prevent wetting of the material from the time of its manufacture through the various steps of loading, transportation, unloading, and use is not difficult. A specification for such an operation was developed jointly by Corporacion Venezolana de Guayana and Hojalata y Lamina, S. A., and was successfully employed in handling a 1000 ton shipment of lump sponge iron manufactured in Monterrey, Mexico, and returned by ship to Venezuela for open-hearth steelmaking tests.

86,000 metric tons of reduced pellets have been shipped from Puebla to Monterrey, Mexico, in open gondola railroad cars - a distance of 600 miles, with negligible loss of metallization.

The matter of ocean transport has been discussed with some of the major ore carriers who foresee no serious problems in maintaining the reduced material in dry condition during transportation, particularly in cargo vessels, in which the hatches can be sealed. Significant progress has been made in resolving the problems of transporting sponge iron.

PROCESS SELECTION

In evaluating direct reduction for domestic consumption in the developing country, maximum use of indigenous raw materials should be carefully considered even if of lower grade. One should not be overly concerned about adopting only the most modern techniques or external competitive pricing. It is the internal welfare of the nation that counts not the academics of the solution. For example, technical purists have criticized projects such as the Altos Hornos Zapla works in Argentina which uses low-grade iron ore and a reductant made from eucalyptus tree charcoal, specifically cultivated for the purpose, in low-shaft furnaces. Nevertheless, steel from this plant could have proved vitally important to the welfare of the nation if imports were cut off in times of emergency. Today, with direct reduction available, Argentina can be completely independent of foreign supply. It has both natural gas and iron ore with which to fortify its steel capability, and is actively moving in this direction.

Selecting the process which is best suited to satisfy the local criteria and conditions is a complex and sometimes frustrating problem because some of the logical process alternatives have yet to be commercially demonstrated to the point where annual production can be predicted with complete reliability. The success or failure of the venture and the validity of the conclusions reached with respect to economic viability and profitability rest solely on the confidence with which annual production can be predicted. Cash flow, profitability, and labor, utility, and maintenance costs are all contingent on achieving and sustaining consistently the anticipated tonnage.

No one direct reduction process will find universal application; the type of ore, end use of the reduced product, availability and type of fuel or energy, and the problems of raw material and product logistics will dictate one process over another, at least in theory.

There are four basic types of direct reduction processes currently in vogue under eight names:

1. Static-bed - HyL
2. Moving-bed - Midrex, Purofer, Armco
3. Fluid-bed - Esso-Fior, U. S. Steel's Nu-Iron
4. Rotary kiln - SL/RN, Krupp

To this list could be added a new travelling-grate process by Allis-Chalmers. Of these eight only four, namely, HyL, Midrex, SL/RN and Krupp have been tested in commercial operation. U.S. Steel's Nu-Iron has not yet achieved satisfactory commercial performance in Venezuela and is having serious briquetting difficulties. Armco is still starting up its first installation in Texas, U.S.A. Esso-Fior, Purofer, and Allis-Chalmers have no commercial installations in operation or under construction. Midrex has four plants in operation, one in Portland, Oregon, U.S.A., one in Georgetown, South Carolina, U.S.A.; one in Hamburg, Germany; and the most recent one, which started-up in mid-April of this year, for Sidbec in Canada. A number of SL/RN and Krupp solid-fuel type plants have been built and operated.

The four HyL commercial installations are operating at 115% of their combined rated capacity. The SL/RN plants have had serious problems reaching and sustaining production at prescribed levels and two plants have been abandoned, one for Inchon Iron & Steel in South Korea and the other for Falconbridge Nickel in Canada. Overall performance could be rated at less than 50% of rated capacity. The first three Midrex plants have not achieved their rated production of 400,000 metric tons of pellets per annum for a sustained period of one calendar year. The combined overall output to date has been less than 60% of rated capacity. The latest Midrex installation has not been in operation long enough to permit an evaluation of the long-term prospects.

As one would expect, there is a wide difference of opinion as to the relative merits of the so-called moving-bed, fluid-bed, and static-bed processes. It is frequently asserted that a moving-bed or fluid-bed concept is continuous whereas a static-bed is a batch operation and, ergo, continuous must be better. Those who have the unenviable responsibility of making a selection and accepting or rejecting the validity of this contention should examine this statement with a goodly measure of skepticism.

One can evaluate direct reduction either from the standpoint of the theoretician or from the standpoint of the responsible executive whose primary concern is capital cost, production cost, assured tonnage, and consistent and uninterrupted plant performance.

The policy of UNIDO to recommend only those processes with at least two years of sustained commercial operation from which to evaluate performance is absolutely sound. This period of time is required to develop realistic efficiency factors, annual consumption data, and maintenance and operating costs. Many of the international banking institutions also require verified proof of successful performance. The Export-Import Bank of the United States is very firm on this point.

It is the author's contention that the theoretician's concept and the responsible executive's concept are compatible if both understand the basic assets and liabilities of the several processes and then stubbornly insist upon firsthand confirmation of the results in actual performance.

These are the fundamental engineering principles which have been incorporated in the design of the modern HyL direct reduction plant:

a. No moving parts in the reactor system, and no moving parts whatever subjected to high temperatures.

b. Long refractory life. (No full reactor lining replacement in 12 years.)

c. No physical degradation of reduced material.

d. No catalyst sulphur poisoning. (Five-year life.)

e. Plant shutdown not required for repairs.

f. A cool and non-pyrophoric product.

g. Direct operator control of metallization, carbon content, retention time, and temperature.

h. Lowest maintenance cost.

i. Highest on-stream efficiency (90-95%).

j. Lowest operating cost.

k. Lowest capital cost per annual ton.

l. Can handle lump ore, if desired.

m. No bridging, accretions or cluster formation in the reactor.

n. No channeling or "rat-hol'ng" of gas through the reactor bed.

It is these attributes which account for the demonstrated reliability of the HyL process.

The HyL process employs a fixed static-bed reactor in which the lump iron ore or pellet to be reduced remains at rest throughout the entire sequence of chemical changes until it is discharged. This occurs in each reactor every twelve hours in the standard cycle. In the four-reactor plant sponge iron is discharged every three hours.

The HyL process operates at the highest temperature the ore or pellet can tolerate without fusing. The Mexican pellets are reduced at a temperature of approximately 950°C. When discharged, the product is cold and non-pyrophoric.

Reducing gas temperature is under the operator's control and can be altered at will. The reducing gas is produced from natural gas in M. W. Kellogg steam-methane catalytic reformers for which Pullman Incorporated owns the patents.

Process cycle time and, therefore, the degree of reduction is under the operator's direct control and can be adjusted to manufacture a partially reduced or a highly reduced product.

The HyL reactor system can be shut down and started up in a matter of hours without removing the material in the reactor vessels. Each reactor can be inspected and maintenance performed without plant shutdown.

The HyL process is not discontinuous to any greater extent than a blast furnace operation could be termed discontinuous. One reactor is being unloaded and recharged while the other three are in primary, secondary, or cooling position. There is no interruption to the process; the reduction operation is continuous; the flow of reducing gas is continuous.

The fluid-bed processes were originally developed by oil companies with years of experience in fluid-bed catalytic cracking. It was postulated that, using this technique, powdered iron ore could be reduced at very high rates, under absolutely uniform process conditions, thereby achieving the lowest possible capital and operating cost per ton. As it developed, the fluid-bed proved an erratic performer with iron ore and frequently lost its fluidity and "slumped" without warning. It is also necessary to perform the reduction in a multiple-bed reactor in which the fluidized material is transferred at regular intervals of time from one level to the next. The reduced fines product has then to be briquetted for use and to prevent reoxidation.

The slumping tendencies have been cured, but the low capital-cost objective apparently has not materialized and briquetting still remains a major problem. This system would appear to have good potential if preceded by a beneficiation plant which could provide a high-grade concentrate or where high-grade ore fines are available, as in Venezuela.

Let us examine objectively the question most often raised in comparing the relative merits of the several processes; namely, gas consumption. The proponents of the continuous processes do not present their data on an actual annual basis, but report fuel consumption on the basis of their best sustained run, whether it be a matter of hours or days, and do not take into account delays in down time for repairs, maintenance, or other interruptions during which there is a non-productive use of gas. There is a significant difference when reporting gas consumption on an annual basis versus consumption for a period of maximum production in which no interruptions or delays occur.

For example, at the HyL plants in Mexico the gas reformers operate continuously and the aggregate of the meter readings for the entire year constitutes the true total gas consumption for the plant. The average consumption per ton is derived by dividing this total by the actual tonnage produced, which takes into account all variations in production level due to delays from any and all causes. The published figures for HyL gas consumption do not represent the performance of the HyL process when operating at maximum efficiency.

At the Puebla works the actual average annual gas consumption is approximately 17.05 x 10^6 Btu's per metric ton of reduced pellets. Comparing the annual average Puebla reduced pellet production rate of 830 metric tons per day versus the maximum or best day of 920 metric tons results in the following:

$\frac{830}{920}$ x 17.05 x 10^6 = 15.4 x 10^6 Btu per metric ton of reduced pellets. (The published theoretical consumption for Midrex is 15.0 x 10^6 per metric ton of pellets.

Therefore, 15.4 x 10^6 Btu represents what might be called the optimum gas consumption for the HyL process and corresponds to the type of theoretical value published by others.

Swindell-Dressler and HYLSA have never used this number or this method of analysis because it is their firm conviction that the economics and profitability of a project must be based on annual consumption values, which is the only true basis for appraising process performance.

The electric power requirement for the HyL process is 7.5 kilowatt-hours per metric ton of sponge iron; for Midrex at Hamburg, it is 185 kilowatt hours.

With gas at \$.30 U.S. per MM Btu and electric power at \$.01 U.S. per kilowatt hour, a direct energy cost comparison of HyL "actual" versus Midrex "theoretical" would be:

	HyL	Midrex
17.05 MM Btu @ \$.30	5.12	
7.5 KWH @ \$.01	.07	
15.0 MM Btu @ \$.30		4.50
185 KWH @ \$.01		1.85
Total \$(U.S.)/Metric Ton	5.19	6.35

On an equal theoretical consumption basis, i.e., HyL at 15.4 x 10^6 Btu, Midrex at 15.0 x 10^6, the cost differential favoring HyL would be \$1.66 per ton.

Of much greater significance than gas consumption is the effect the process efficiency factor has on manufacturing cost.

Let us assume that the reduction plants for process "X" and process "Y" are rated at the same annual production capacity and plant "X" actually produces 100% of its rated annual tonnage (efficiency factor 1.0), whereas plant "Y" produces only 60% (efficiency factor 0.6).

If one further assumes that the capital charges for depreciation, insurance, taxes, interest, etc., total, say, 15% of the plant cost per annual ton, which, for argument's sake, we establish at $45 U.S. for both processes, the capital charge component of manufacturing cost for process "X" is $6.75 per ton and $11.25 for process "Y."

This differential of $4.50 per ton, due solely to a difference in process reliability, is the equivalent of a 15.0 MM Btu energy debit against process "Y" with gas at $.30 per MM Btu.

In the process comparisons given in the literature on the subject of direct reduction, no attempt is made to incorporate this all-essential variant.

The converse to expressing the impact of the efficiency factor in terms of an energy debit would be either to evaluate the plant cost per annual ton for process "X" at $45 and assign to process "Y" an "effective" capital cost of $75 per annual ton or, more precisely, establish a realistic and factual lower production rating for process "Y." After all, adjusting the production cost or plant cost discrepancy after the fact does not compensate for the missing tonnage the purchaser expected.

AFTER SELECTION

Experience has shown that certain basic requirements of the financing institutions must be met after the process selection has been made before implementation of the project can materialize. Among these are:

a. A comprehensive feasibility study by an independent consultant.

b. A thorough market survey.

c. A complete financial analysis.

d. Provision for operator training.

e. Availability of operating personnel for a limited period.

f. Initial management of the facility.

g. Technical or advisory participation of a recognized operating company.

h. Definitive project estimate.

FUEL SOURCES

The preferred source of reductant is reformed natural gas followed in order of increasing plant and operating cost by liquefied petroleum gases (propane, butane), virgin naphtha (350°F. endpoint), and fuel oil. In order to utilize fuel oil, the reducing gas must be generated by partial oxidation of the oil requiring the addition of an oxygen plant. The process for the production of this gas, as well as the manufacture of the reducing gas from the lighter fuels given above, is identical to that employed for the manufacture of synthesis gas for the production of ammonia. However, the composition of the gas produced by the partial oxidation of fuel oil is different from the others and has not been tried on a commercial scale in the HyL process. The use of fuel oil can be designated, therefore, as technically feasible but unsupported by adequate test data.

Broadly speaking, almost any mixture of carbon monoxide and hydrogen can be used, but it should be noted that refinery off-gas, coke-oven gas, etc., are usually subject to wide variations in composition, may have to be compressed, and generally are not available in sufficient quantity for meaningful exploitation.

The solid fuel processes are extremely sensitive to variations in fuel composition and characteristics, and no conclusions should be drawn on their applicability without tests on a substantial scale by competent authorities with adequate facilities.

TESTING FACILITIES AND PROCEDURES

Before any assumptions can be made or conclusions drawn as to the acceptability of an iron ore for direct reduction, it must be tested on an adequate scale. There is no way to avoid this, nor the expense, and it is absolutely essential to the preparation of a definitive project feasibility and profitability study without which financing will be difficult, if not impossible to arrange. It is impossible for the prospective client or the engineer to correlate technical and economic feasibility without taking the necessary steps to develop essential data. The proper development of these data requires the performance of appropriate tests against which local cost factors can be applied.

Complete facilities for ore testing are available both at the works of Hojalata y Lamina in Mexico and at the research facilities of Swindell-Dressler Company in the United States. These range from bench-scale facilities for the testing of cubed ore samples and individual pellets to full-scale production runs in the Mexican plants, and can include, if desired, the conversion in the electric furnaces to sample ingots or billets and further processing to finished products.

A pilot plant is available at Monterrey, Mexico, and calibrated against the commercial units so that it is possible to obtain process data necessary to design and guarantee HyL plants to accommodate the variety of iron ores or pellets the prospective client submits for evaluation.

The pilot plant has all the basic process cycle features of the commercial units and is designed with a depth of bed identical to the large reactors. The pilot reactor holds a charge of six tons for each test run. The pilot plant is fully instrumented and can establish any desired process simulation. Test results are computerized for efficient and accurate computation.

The following are excerpts from the official sales policy manual on "Testing Procedure" issued by Swindell-Dressler Company, the world-wide sales and licensing agency for the HyL process and applies to either lump ore or pellets.

> "The test program procedures designated Phase I and Phase II are outlined below:
>
> "<u>Phase I</u>
>
> a. The client must furnish, for preliminary testing, 50 kilos of a representative sample of the ore he proposes to use. The ore should be shipped in sealed drums.
>
> b. After receipt of the ore, appropriate tests will be made to develop preliminary data in three important areas:
>
>   (1) The reducibility of the ore relative to the Mexican ore standard.
>
>   (2) The probable processing steps required to convert the ore to the desired end product.
>
>   (3) The schedule of tests required for Phase II.
>
> c. A report will be prepared for the client setting forth the results of the tests and further recommendations.
>
> "<u>Phase II</u>
>
> Predicated on the findings in Phase I, any or all of the following tests might be indicated for Phase II:
>
> a. Crushing and grinding
>
> b. Beneficiation
>
> c. Pelletizing
>
> d. Reduction
>
> e. Melting and finishing in the electric furnace."

The Phase I reducibility test is performed at Monterrey and is termed a "bag test." Two or more small representative samples of the client's ore are placed in metallic wire bags and inserted at different levels and locations in the commercial reactors immediately adjacent to similar bag samples of the main charge of Mexican ore. After subjecting the samples to the full normal operating cycle, the samples are removed when the reactors are unloaded, placed in sealed containers appropriately identified, and removed to the laboratory. The client's sample and the Mexican control sample are then analyzed for comparative results.

If the Phase I results show that the degree of reduction and physical character of the sponge iron are qualitatively equal to or better than the Mexican control sample, the conditions of time, temperature, gas consumption, etc., established for the commercial unit appear applicable to the client's ore and preliminary projected plant economics can be given.

If the Phase I results are not comparable, pilot-plant testing may have to be undertaken to establish a preliminary evaluation of the ore-processing characteristics to establish quantitative differences.

A favorable prognosis in Phase I does not necessarily assure the technical success of the larger scale Phase II program and no firm position can be established until the work in Phase II has been completed and evaluated.

On the basis of successful Phase II tests, processing information and data will be established, a definitive estimate of plant and operating costs prepared, and a performance guarantee given. The quantity of ore needed for Phase II depends upon the number and complexity of the tests; the normal requirement is 50 tons of a truly representative sample for test d. "reduction" only. If tests a., b., c., and e. are necessary or desired, correspondingly larger tonnages of ore will be necessary. Only test d. is required if oxide pellets are furnished.

HYL PLANTS

The first 75,000 metric ton per year commercial HyL plant was installed in the steelworks of Hojalata y Lamina, S. A. in Monterrey, Mexico, and began operation in 1957 and has been in operation ever since. It is currently producing 92,500 metric tons per year. The second plant for Hojalata y Lamina, S. A., initially rated at 187,500 metric tons per year, commenced operation in 1960 and has also been on stream since that time. It is currently producing 238,000 metric tons of reduced pellets per year.

The third plant, identical to the second plant built for HYLSA, was installed for Tubos de Acero de Mexico S. A. (TAMSA), the largest seamless pipe and tubing manufacturer in Mexico, located in Veracruz, Mexico. This plant started up in 1967 and is currently operating at 127,000 metric tons per year.

The fourth HyL plant was built for HYLSAMEX at Puebla, Mexico, and started up in 1969. Originally designed to produce 225,000 tons of reduced product annually, it is currently producing 284,000 metric tons per year.

A fifth HyL plant erected in Bahia, Brazil, for Usina Siderurgica da Bahia, S. A. (USIBA), identical to the plant at Puebla described above, and commenced operations this year.

The sixth HyL plant for HYLSA is under construction in Monterrey, Mexico, and will commence operations in December of this year. It will have a capacity of 175,000 metric tons of reduced pellets.

A contract for a seventh plant was signed in June of this year with Sider Hellas S. A. of Athens, Greece, with a design capacity of 280,000 metric tons per year.

With the addition of these three new installations, the total production of all HyL plants will reach 1,695,000 metric tons per year.

CONCLUSION

In recent months articles have appeared in the technical media expressing serious doubts as to whether the advent of direct reduction has truly arrived. They wonder about the protracted start-up periods some of the newer processes are experiencing after earlier widely-publicized prognosis of imminent success, and plant shutdowns after serious financial losses caused by failure to reach predicted production.

This is creating a distinct direct-reduction "creditability gap." This "creditability gap" is not without foundation in fact. With the single exception of the HyL process, there is still a glaring lack of substantive plant operating data which can be used by the analyst as representing truly comparable statistics.

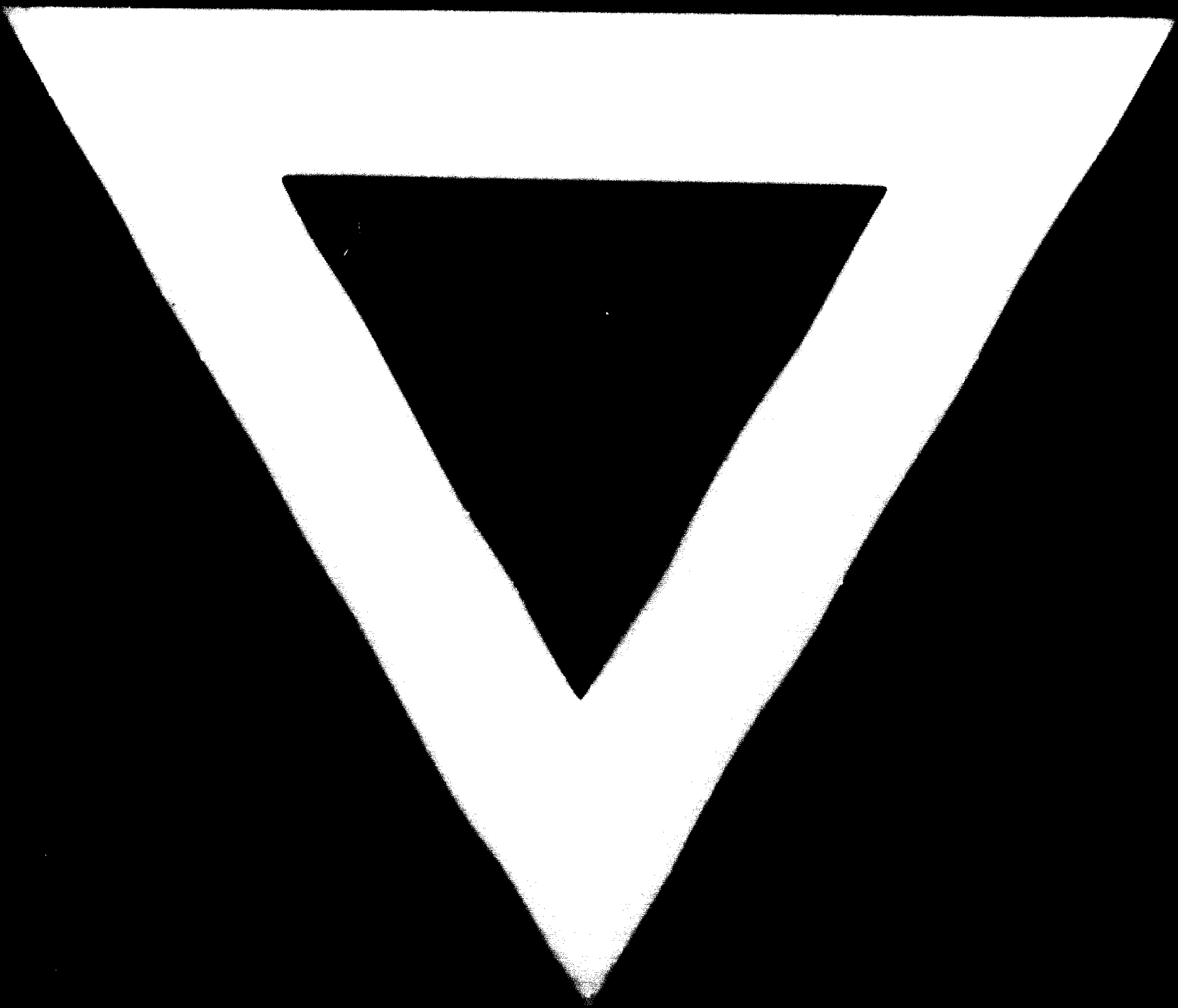
Missing from the literature and meetings such as this one is information on why plants failed, and actual operating data and production costs.

The limited success achieved to date by some of the leading contenders and the understandable reluctance of their sponsors to disclose clarifying information makes it impossible for the analyst to evaluate with confidence the full gamut of process alternatives theoretically applicable to the individual need of the developing nation.

It is up to the investigator and the prospective client to rectify this situation by demanding firsthand verification and detailed information and data on the results and operating experience for all processes, including a complete record of down-time and operating upsets and their causes, and the cost of maintenance and repairs, for a period of not less than 18 consecutive months.

With this information an efficiency factor can be established for each process and applied impartially in the comparative evaluation.

If a full and comprehensive response is not forthcoming, the process should be removed from contention in the comparison, regardless of the stature and antecedents of the sponsor--CAVEAT EMPTOR!



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