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05284

United Nations Industrial Development Organization

Distr.
LIMITED

ID/WG.146/118
13 September 1973

ORIGINAL: ENGLISH

Third Interregional Symposium
on the Iron and Steel Industry

Brasilia, Brazil, 14 - 21 October 1973

Agenda item 5

AN APPRAISAL OF SOME OF THE DIRECT REDUCTION PROCESSES FOR THE PRODUCTION OF SPONGE IRON

prepared by

the secretariat of UNIDO

id.73-6493

LIST OF CONTENTS

I. INTRODUCTION

1. The purpose of this short review is not to add still one more paper to many well prepared papers, documents and treatises on the subject of direct reduction processes for the production of sponge iron, that are already readily available and others that are additionally to be discussed at the current UNIDO's Third Interregional Symposium on the Iron and Steel Industry. The object merely is to make a short appraisal of the current status of some of the direct reduction processes based on solid reductants for the production of sponge iron. It will not be possible in this paper to extend the appraisal to cover gaseous direct reduction processes for sponge iron production; most of the gaseous direct reduction processes were fully discussed through a series of comprehensive papers presented at the E.C.E. Seminar on Direct Reduction of Iron Ore, held at Bucharest in Romania in September 1972. 1/

2. What simply is attempted in this paper is not to make any possible predictions for one process or the other, or forecast the world's sponge production over the next decade or two; these aspects of sponge production and technology have well received ample study and exposition at several international technical meetings and symposia including the earlier Iron and Steel Symposia organized by UNIDO and other UN agencies and notably amongst them the Economic Commission for Europe (UN) which provided possibly a most fruitful week last year (September 1972) to debate and share the experiences, pit-falls and fruits of sponge production technology in different parts of the world. Developing countries are in general greatly excited and concerned about the possibilities of sponge production endowed as some of them are with abundant and rich natural resources and raw materials but lacking as most of them do the means to do so - chiefly financial and technological. UNIDO wholly dedicated as it is to the industrial development of the developing countries has therefore considered it necessary to sound and advise care and caution in reviewing the current status of sponge iron production processes based on the use of solid reductants.

1/ "Direct Reduction of Iron Ore: Technical and Economic Aspects" Seminar organised by the United Nations Economic Commission for Europe and held at Bucharest, Romania, 18 - 23 September 1972.

3. One is, of course, aware fully that none can claim to have said the last words on these subjects, "famous last words" as if it were. What we advocate is to outline to the developing countries the current status of solid reductants' based sponge production processes rationally, realistically, unemotionally and pragmatically so that the developing countries can draw their own conclusions judiciously and objectively on what undoubtedly is a difficult and complex technology of direct reduction of iron ores using solid reductants.

4. The metallurgical chemistry of direct reduction itself, however, is relatively not so complex; it is based simply on stripping of the iron oxide of its oxygen contents at comparatively low temperatures, for solid state reduction at 1,000°C and below. The problems involved of doing so and difficulties encountered on industrial scales are not only metallurgical but also relate inter alia to engineering design and development. Much success can follow if such fundamental problems are fully recognized and tackled and not lost sight of in the maze of arguments for and against on the "if it were so" and "I told you so" basis. The correct approach would be to identify the sources and causes of severe difficulties, shortcomings and deficiencies met with on industrial scale, and recognize the industrial limitations to up-scale a process and accept the success or failure of a process realistically and in the latter case, endeavour by all means to rectify the serious shortcomings, however, not at any or all costs and certainly not at the developing countries' cost. The ambivalence in such a situation may well be recognized.

5. We are aware that one is treading on a most difficult and controversial ground and liable to be misunderstood and labelled as pessimists in the advance of direct reduction technology based on solid reductants. We do not accept such a charge even if it is so levelled. On the other hand, we are firmly of the opinion that a realistic and unbiassed appraisal of the current status of direct reduction sponge technology based on solid reductants is necessary in order to make effective and satisfactory future progress in these fields. We do not intend glossing over the serious difficulties met with as merely teething troubles nor magnifying or multiplying them out of all proportions. What we intend is to outline factually and realistically the current reported status of the direct

reduction sponge processes using non-metallurgical coals/anthracite/ lignite, based as far as possible on the operations of the industrial plants set up in different parts of the world. One must, of course, be conscious of the limitations of such an appraisal/review since it has to be, of necessity, based on reported and/or published papers and documents compiled from multiple sources. With this somewhat apologetic preface and introduction we now come to the main issues which the short paper seeks to highlight. However, before coming to the subject proper, it is advisable to clearly demarcate and understand the differences between a highly metallized product (sponge) for direct steel-making in the electric arc steel melting furnace and partly metallized product for iron making in an electric sub-merged arc iron smelting furnace; the two products are different from one another chiefly in respect of the degree of metallization and the end-products they directly produce, viz. steel and pig iron respectively. This distinction is to be clearly understood in view of the anomalous claims made in respect of their successes and failures vis-a-vis the metallization technology. Direct reduction represents almost the complete solid state reduction of the oxides of iron in the ore; the directly reduced sponge iron is suitable for charging to a steel making furnace for melting and refining to steel. The pre-reduction is the partial reduction of iron ore in the solid state; the pre-reduced sponge is suitable inter alia for ironmaking. Although pre-reduction has received less publicity than the direct reduction processes, steady progress has been made and industrial pre-reduction plants have well been operating successfully on a commercial scale for years now. In the ferro-alloy industry for example, pre-reduction in rotary kilns prior to electric smelting of the ferro-alloy in the sub-merged arc electric furnace, has been successfully employed for both manganese and chrome ores primarily in Japan. Pre-reduction of lateritic nickeliferous ores in rotary kilns has been carried out in New Caledonia and also in Greece for years now. Pre-reduction of the same ores is currently being done in shaft furnaces in the Dominican Republic.

6. Jurden 1/ made an interesting analysis of pre-reduction prior to blast furnace and prior to electric smelting of pig iron. In the case of the blast furnace, considerable pre-reduction takes place in the shaft of the

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1/ "Direct or Indirect Iron" - D.H. Jurden - Paper presented at the ECE Seminar on Direct Reduction of Iron Ore, Bucharest, September 1972 blast furnace itself and so the advantages of a pre-reduced charge are not so marked as in the case of electric sub-merged arc furnace for iron smelting where the shaft height and effects are minor. The charge of a fully and directly reduced sponge to the blast furnace is another question which needs a separate techno-economic study and appraisal.

7. Additionally another metallized product, notably HIB - Briquettes has recently made its appearance which can be charged into an iron blast furnace for iron smelting with a view to increase iron productivity, lower coke rates and production costs. The discussion of the HIB gaseous direct reduction process is, however, outside the scope of this short paper.

8. In the case of iron smelting in a sub-merged arc electric smelting furnace, which is employed in the process flow-sheet to produce ferro-vanadium via the vanadium enriched slag or ferro-nickel, the intermediate product pig iron can be used for steel-making such as by the LD oxygen steelmaking process. In all these cases, the degree of metallisation of the metallised product/sponge could differ either by design or attainability, depending upon different process variables; in both cases, sometimes a virtue is made of a necessity and vice-versa. It also needs due emphasis that since contaminants are not physically removed in the direct reduction processes, it is important that a high grade, uncontaminated, low gangue raw material (lumpy high grade iron ore and/or pellets) is used for direct reduction.

9. For relevant particulars and details of the direct reduction processes inter alia discussed in this short paper, the reader can refer to many publications, reports and standard reference books 1/ 2/ 3/, etc., on the vast subject of direct reduction of iron ores. Both past and recent tech-

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1/ The Reduction of Iron Ores - 1972; L. Von Bogdandy and H.J. Engell Springer Verlag

2/ Alternative Routes to Steel Making ; Iron and Steel Institute, London 1971

3/ Iron Ore Reduction - Proceedings of the Symposium sponsired by Electro-Chemical Society - Pergamon Press nical literature is full of comprehensive reviews, papers, reports, forecasts and achievements concerning the direct reduction processes for which claims have been made over the last decade or two; surprisingly comparatively very little has been published about the failures of some of the direct reduction processes on industrial scales or even on pilot plant scale. Literally hundreds if not thousands of patents have so far been taken on direct reduction processes the world over. The reader is often left much confused and confounded, if not bewildered as a result; these then are some of the lacunae which this paper seeks to outline. The well-known dictum "Failures pave the way to success" is the underlying theme of this short review paper.

II. DIRECT REDUCTION SPONGE IRON AND PRE-REDUCTION PROCESSES BASED ON SOLID REDUCTANTS

10. As stated earlier, the reader is referred to comprehensive papers, documents and publications on direct reduction sponge iron processes based on solid reductants for obtaining requisite details. So without going into their details, their reported performances of some of the listed processes would be outlined in the following pages. The attached tabulation is self-explanatory. It is possible that some of the plants and their equipment may have been recently updated and/or expanded. What is attempted herewith is to outline their reported performances to the best of one's knowledge. It is, of course, possible that despite the best efforts and intentions to outline the most up-to-date information on the reported industrial performance of these direct reduction plants and processes, there is still some leeway to be made, some more updating to accomplish and some more conclusions to be drawn; such a process is, of course, unceasing and continuous.

11. We shall not refer in this short review to one of the most controversial and vulnerable aspect of the direct reduction processes based on solid reductants and that is the "works production costs" and the "comprehensive production costs" for sponge production; the latter including all overheads, depreciation, interest, amortization and administrative charges, etc. Such data in some cases are often merely based purely on theoretical work, hypothetical projections and desired calculations. It is exceedingly difficult to obtain, review and critically analyse actual plant figures and production cost data. It is well established that the performance characteristics are directly related to the production costs apart from any physical, technical and operational success or failure of a plant and a process. Sponge production costs and prices are important parameters in relation to steel scrap prices adjudged on F.O.B. and C.I.F. basis. After all sponge iron seeks to supplement and/or replace steel scrap and the price structure of the former should be proportionally balanced and attractive in comparison with the latter. Another factor would indeed be the physical availability of the steel scrap in the world markets in times of war and peace and at an acceptable price structure.

PRE-REDUCTION ROTARY KILN PLANTS FOR ELECTRIC SMELTING FURNACES TO PRODUCE PIG IRON

Pre-reduction process, plant and location	Larima Nickel Co. (LARCO) Salonki Highway, Greece	Yawata Ariake Iron and Steel Co. Japan	Strategic-Udy Orino Steel Plant Matanzas Venezuela	Elkem Rudnici-i-Zelezarnica Skopje Yugoslavia	Highveld/Elkem Highveld Steel and Vanadium Corp., Witbank South Africa (LURGI kilns made to ELKEM designs)	SL/RN Inchon Iron and Steel Co. Seoul South Korea	S.L.N. New Calendonia Noumea Plant of Société de Nickel
Plant capacity, t/year: Hot metal	Pre-reduced charge	40,000	1[illegible]0,000	540,000	4[illegible]0,000	1[illegible]5,000	200,000 tons of ferro-nickel/year to contain [illegible],000 tons of nickel (1971) Further expansion planned to produce [illegible],000 t/y of nickel contained in ferro nickel
Production equipment: Rotary kiln - Nos.	Pre-reduction of lateritic ore 2 operating and 1 more to start in 1973	One	One	Six	Five	One	
- Size.	90 m x 4.2 m dia. 90 m x [illegible].2 m dia.	3.50 m dia. x 75 m	3.35 m dia. x 107 m	4.15 m dia. x 95 m	4 m dia. x 60 m	4 m dia. x 60 m with preheating grate	[illegible] old rotary kilns [illegible] new rotary kilns [illegible] m x 4 m dia. for preheating, drying and some prereduction at 800°C - below the range at which sintered ore rings form
Smelting - Nos.	4 electric smelting furnaces	One	One	3 and 2	Four	One	
- Capacity:	25 mVA to produce ferro-nickel (15% Ni) and slag(38% Fe) which is discarded 2 oxygen converters (15 t cap. each) to produce FeNi (26-32% Ni) and slag containing 68% Fe currently discarded but planned to yield iron in future.	14 mVA	33 mVA	33 mVA and 43 mVA	33 mVA	28 mVA	Hot blend is sent to [illegible] old (11mV) and [illegible] New ([illegible] mV each) electric smelting furnaces
Raw materials: Iron ore - Quality	Lateritic nickeliferous iron ore Larima(%)/Euboia(%) Fe 33.0 34.0 Ni 1.45 1.20 Cr_2O_3 2.50 3.20 CO 0.07 0.06	Beneficiated iron sand Fe - 57% TiO_2-12%	Fines concentrate Fe - 50-59%	Lumpupgraded ore (chamosite) Fe - 40-42% SiO_2 - 16-17% Al_2O_3 - 8-9%	Lump ore Fe - 55% V_2O_5 - 1.6% TiO_2 - 13%	Lump ore and pellets Fe - 49-56%	Garnierite ore containing iron and nickel oxides Total consumption is 2.5 million t/y
-Size range:	N.A.	N.A.	-10 mm	10 - 40 mm	N.A.	8 - 20 mm	- 20 mm
Reductant: - Quality	-Coke reportedly - plans to use lignite from Ptolemais	Natural coke F.C. - 71% VM - 5% Ash - 21%	Low grade coal F.C. -40% VM - 44% Ash - 1%	Dry lignite and coke F.C. - 35%/ Ash 10 % VM - 45% Ash - 20%	Bituminous coal F.C. 55% VM - 32% Ash - 12%	Anthracite F.C. - 62% VM - 5% Ash - 33%	coke with oil-firing (for heating)
- Size range:		- 15 mm	Fines	20-60 mm	-	Fines	
Product and usage	- Pre-reduced hot charge (900°C) FeNi and Fe-enriched slag - steel billets	Pre-reduced cold charged	Pre-reduced hot charged	Upto 35% reduction, hot charged	35% pre-reduction, hot charged	70% pre-reduction, cold charged	Predried, preheated and somewhat prereduced charge
Start up	1967	1961	1963 permanently closed down since last 7 years	1968 pre-reduction kilns shut down since 1971 permanently	1968	1969-70 pre-reduction and steel-making shut down since 1971 permanently as reported	In the sixties, the plant started and in 1968 major expansion took place

SPONGE IRON PLANTS BASED ON SOLID REDUCTANTS/ROTARY KILN OPERATIONS

	KILN PROCESSES				BATCH PROCESSES		
PROCESS	SL/RN	SL/RN	KRUPP	SL/RN	HOEGANAEVES	ECHEVERRIA	NUEVE PROCESS
Plant and location	New Zealand Steel Ltd, Glenbrook, New Zealand	Falconbridge Nickel Mines Ltd., Sudbury Canada	Dunswart Iron and Steel Works Beneni, South Africa	Aces Fines Piratini S.A. Charqueadas, Brazil	Hoeganaes, Sweden, Oxelosund, Sweden Riverton, USA	Patricio Echeverria S.A. Legazpia Spain	Siderurgica Monfalcone (SIMO), Italy
Capacity t/y of sponge	150,000	300,000	150,000	65,000	130,000 (total)	20,000	30,000
Production equipment	One kiln 4 m ø 75 m	One kiln 5 m ø 50 m with pre-heating grate	One kiln 4.6 m ø 74 m	One kiln 3.6 m ø 50 m	Silicon carbide saggers	40 Nos of alloy steel retorts	8 Nos of silicon carbide lined vessels
Raw materials Iron ore - quality	Iron sand green pellets/concentrate Fe - 61% SiO_2 - 1.1% Al_2O_3 - 2.8% TiO_2 - 8.3%	Pyrrhotite pellets Fe - 65-67% Ni - 0.5-1%	Lump ore Fe - 65-67%	Itabira lump ore Fe - 67%	High grade concentrate	Lumpy hematite ore Fe - 54-60% SiO_2 - 8-12%	N.A.
size range	4 - 8 mm	10 - 12 mm	5 - 25 mm	5 - 30 mm	- 30 mesh	10 - 50 mm	N.A.
Reductant	Brown coal(dry) F.C. - 52% VM - 43.3% Ash - 4.7% - 10 mm size	Bituminous coal F.C. - 55% VM - 39% Ash 3.7%	Anthracite F.C. - 79% Ash - 11-12% Duff coal F.C. - 57% VM - 26.5% Ash - 16.5%	Bituminous coal F.C. - 38.5% VM - 26.5% Ash - 35% 1-25 mm size	Coke breeze Producer gas	Anthracite coal V.M. - 8.2% Ash - 27.3% F.C. - 62.5% S - 1.1% Producer gas	Low grade coal Propane
Start-up	1970 operating far below rated capacity as reported	1971 <u>now closed down</u>	Early 1973	Mid 1973	1911	1958 reportedly <u>closed since</u> 1965	1972

12. Having listed herewith the pre-reduction and direct reduction processes/plants [1] currently operating or closed down since, let us now outline and discuss the performance of some of them. Before doing so, reference is made to the following note of caution sounded recently by the Battelle Memorial Institute [2] in an outstanding exposition of the subject of direct reduction.

"The published literature on direct reduction is biased. Most publications deal with a limited range of subjects. These subjects include descriptions of processes, the results of chemical and metallurgical experimental work (including pilot plants), economic forecasts for new plants, and predictions about the future. Missing from the literature are reports on how and why certain plants failed and the actual costs being experienced in operating plants. Until we reach a situation where both sides of the story are equally well known, and the deficiencies of the direct reduction are balanced against the advantages, much caution must be exercised to avoid being carried away by the vocal optimist. It may be significant that some of the organizations and individuals who have operating experience with direct reduction plants (some now defunct) make a point of avoiding open presentation such as the present Symposium. The main problem is that in some cases the estimated cost of production tends to be high enough to discourage rapid acceptance on a large scale. The number of uncertainities is high. The conclusion of the present authors is that by the time that direct reduction reaches maturity as a high tonnage commercialized series of undertakings, the form of the processes and the means by which we select between them and select their raw materials will be different from the way that we know them to-day. Direct reduction processes as now visualised by no means represent the highest rate of potential for their utilisation."

13. We shall now outline to the reported experiences and observations pertaining to different direct reduction plants set up in various countries and which are based on rotary kiln operations and the use of solid reductants.

1/ The tabulated list is not claimed to be complete in itself or in all aspects.

2/ "Techniques and economics for the direct reduction of iron ore" by Messrs. H.W. Lownie Jr. and T.M. Barnes - Battelle's Columbus Laboratories, Columbus, Ohio, USA

Skopje Iron and Steel Works, Yugoslavia

14. Some relevant details[1] of the pre-reduction facilities are furnished below although it is pointed out that the pre-reduction rotary kilns' operations have now been totally stopped since the last 2½ years or more. It is at this stage pointed out that ELKEM (Norway) pre-reduction technology was followed at the Skopje Iron and Steel Works after prior investigations thereon with Yugoslav raw materials comprising the use of dried lignite for pre-reduction:

Lignite 10 - 20 mm or 10 - 20 mm and 20 - 40 mm

Fixed Carbon	- 35 %	Averages
Ash	- 22 %	
V.M.	- 44 %	
S	- 1.2 %	
H_2O	- 20 %	

Iron Ore

Tajmiste deposits of chamosite ore

Fe total	- 43 %	Averages
SiO_2	- 15 %	
Al_2O_3	- 7 %	
P	- 1.0 %	
S	- 0.07 %	
Loss on ignition	- 10 %	

15. Rotary kilns were supplied by F.L. Smith, Denmark (95 m x 4.35 dia.) with a rated capacity of 63 t/hour.

16. Electric pig iron smelting furnaces were supplied by ELKEM, three of 34.5 mVA each and the rest of 43 mVA each.

17. Serious decrepitation and degradation of the lignite took place in the rotary kilns. The hot pre-reduced charge contained excessive lignite fines which led to explosions in the ELKEM electric pig iron smelting furnaces due to extremely poor permeability of the burden in the electric arc furnace and build up therein. The use of coke along with lignite for pre-reduction could not effect technological process improvements. All the six rotary kilns have been closed down since 1971.

1/ Based on the Mission Report of Mr. Christo Popov, Metallurgical Industries Section, UNIDO

18. Salient points of current operations are:

(a) Electric smelting without any pre-reduction of iron ores is currently being practised. All the rotary kilns are idle and out of operation.

(b) Sized ore with nut coke and pearl coke is used in electric submerged arc iron smelting furnaces. Lignite is not used.

(c) The power consumption is about 3,000 kwh/ton of iron.

(d) The problems at the commercial plant are:

i) Most of the char comes out in fine form

ii) Gas blowing through roof damaging conductors and cooling members and

iii) Disturbed furnace condition

(e) Skopje is now considering installation of a blast furnace to meet hot metal requirement.

(f) With the present shortage of hot metal - steel production is low. An electric arc furnace is being installed (expected to go into production by early 1973).

(g) The iron and steel complex at Skopje in Yugoslavia as indicated earlier has eliminated the pre-reduction of iron ores in rotary kilns and six giant kilns (F.L. Smith, Denmark, suppliers) are now totally idle and out of operation for the last 2 - 2½ years.

19. The following particulars would be of interest based on the reported results of SL/RN direct reduction plants in New Zealand, South Korea and Canada.

<u>New Zealand Steel Co. Ltd., Glenbrook</u>

20. It was reported that the project had so far not proved its viability while it was still in the scale-up stage after 2 - 3 years of operation. Frequent stoppage due to breakdown and accretion in the kiln occurred on an average after 8 weeks of operation. In a 2 years' initial period only 50,000 tonnes of acceptable sponge have been supplied to the melting shop. About 20,000 tonnes of partly reduced sponge have been stockpiled for re-processing. Steel scrap has had to be purchased for the melting shop meanwhile at the C.I.F. price of about $60 per tonne.

It has been reported that both the New Zealand Steel Ltd. and the Falconbridge Plant of International Nickel Co. having similar SL/RN direct reduction plants, are of the opinion that the process has to undergo considerable and significant modifications in the scale-up stage before it is acceptable for commercial operation. The hold-up in the implementation of the project in New Zealand through scale-up has caused substantial losses in the investment programme; the loss for 1970 was of the order of 6 million NZ dollars.

21. One of the major problems experienced at the New Zealand Steel Ltd. is associated with maintaining a stable temperature zone of about 1100 - 1200°C in the kiln to control metallization. Lignite with its high volatile matter causes partial build-up and accretion in the furnace with excessive refractory wear. The build-up forms an annular ring reducing the effective internal diameter and working volume of the kiln and the flow of the feed material. Attempt is being made to reduce the carbon input at the sponge discharge end and add lignite char at the charging end for the reductant. Additional shell burners are also distributed along the length of the kiln with heat-resistant tubes projected into the centre of the kiln to spread the temperature zone to about 25 m.

22. The second major problem which causes the accretion inside the kiln was stated to be caused by disintegration of the green pellets as they were charged into the kiln. The green pellets bonded with about two per cent bentonite contained about ten per cent moisture and it was highly probable that these disintegrated to some extent on meeting the hot gases on entry into the kiln.

23. The operations of the New Zealand Steel Co. Ltd. have in the recent past been quoted in the technical journals as follows: 1/

"New Zealand Steel Ltd. failed to reach its 1970 production targets and the company's losses in the current fiscal year are expected to approach 6 million dollars (NZ). Major difficulties centre on the iron making plant which is still under guarantee from the manufacturers as to its output capacity and raw materials' consumption. The problems

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1/ Metal Bulletin, 8 April 1971, page 31 related to the pelletizing plant, the direct reduction (SL-RN) kiln and ancillary equipment. In an effort to offset its raw materials' shortfall, New Zealand Steel Co. has been forced to import Australian oxide pellets and steel scrap."

24. It is pointed out here that in the paper by the New Zealand Steel Co. itself presented during the meeting 1/ "Alternative Routes to Steel" organized by the Iron and Steel Institute (UK) in May 1971, it has been stated that:

"The most severe operating problem has been the formation of accretions which result from inaccurate control of temperature profiles within the kiln. This, in turn, has led to a series of blockages in the kiln to cooler transfer chute. "....." On shut down of the rotary kiln, accretion was discovered. It was, therefore, decided to carry out extensive research into the factors affecting pellet strength viz. its degradation within the rotary kiln".

25. The report of the New Zealand Steel's operation during mid-1971 established the following draw-backs:

(a) The major problem the SL/RN kiln unit has related to the build up of accretions in the kiln and because of this the continuous operation of the kiln is restricted to 8 to 12 weeks at a stretch. For each shut down, a period of about 2 weeks is required for the removal of the accretion and putting back the kiln into operation.

(b) With the use of green pellets, directly fed into the kiln, the loss of concentrate in the dust is quite high and because of this, the waste gas cleaning and the dust disposal system puts a limitation on the operation.

(c) Even when heat hardened pellets from Whyalla were used for the production of sponge iron in the kiln, though the dust losses were less, the accretion formation was about the same as met with in the case of using green pellets.

(d) The lignite used is very reactive and therefore results in increased carbon consumption.

1/ "Alternative Routes to Steel" Code No. P. 137
The Iron and Steel Institute, London

(e) With the use of only one type of coal it becomes difficult to balance carbon requirement and heat requirement.

(f) The thermo-couples installed in the kiln indicate the correct temperatures during the start-up period and for some time after start-up. Thereafter, because of coating of dustry raw materials on the thermocouple tips, the temperature indications become unreliable resulting in difficulties with controlling the kiln operation.

(g) Because of lower metallization and high gangue content of the sponge, the power consumption at the electric steel making furnace is 835 kWh per ton when using 75 per cent sponge in the charge. The tap to tap time of the heat generally varied between 190 to 210 minutes.

(h) If there is a 10 per cent drop in the metallisation of the product, that is from 90 per cent to 80 per cent, the power requirement increases by 100 kWh per ton at the electric arc furnace.

26. In view of the above reported draw-backs, the then sponge iron production was less than one third of the sponge plant's rated capacity which has necessitated the use and import of steel scrap to the electric furnace melting stock on a scale far greater than the project had stipulated.

27. Referring to the SL/RN based steel plant in South Korea at Inchon, the following extract 1/ speaks for itself:

"Demag and LURGI supplied this plant. The explosion in October 1970 in the electric smelting pig iron furnace which was fed with the directly reduced sponge from SL/RN rotary kiln, killed 10 workers and injured more than 30. As the explosion occurred during the guarantee period, the German firm is prepared to pay damages to the families of the dead workers - the repairs to the furnace will cost 0.8 million US dollars. Payment by Inchon has been deferred until March 1975".

28. The production of pre-reduced sponge on industrial scale in rotary kilns based on the ELKEM technology has been completely stopped in the Skopje steel plant in Yugoslavia; this plant has a rated capacity of one million tons of crude steel a year.

1/ Metal Bulletin, 5 October 1971, page 29

29. Recent tests done by ELKEM in Norway on some of the high grade iron ores from Orissa State (India) for direct reduction in rotary kiln using solid fuels have established the almost total failure and inapplicability of the rotary kiln direct reduction process for the production of sponge iron from some of the high grade Orissa iron ores/pellets owing to their adverse physical characteristics met with during rotary kiln direct reduction trials.

30. It has been reportedly concluded that considerable amount of further development study of the SL/RN process has to be undertaken before the process can be regarded as being industrially applicable. It is claimed that the view is shared by the Falconbridge study group in Canada. It is currently reported that extensive development work is underway to overcome the operational difficulties and we look forward to some of the current operational results. In this context, some of the results 1/ reported during 1972/73 are outlined below:

Annual rated target output of sponge - 150,000 tons
Total sponge output 1970/71 - about 26,000 tons
Total sponge output 1971/72 - about 50,000 tons

It has also been reported that output during 1972 - 73 is at a higher rate and further that the operational problems are under serious investigation and nearing solutions.

31. The rotary kiln's operations in the initial years could hardly extend 2/ beyond 5 - 6 weeks at a time after which the kiln had to be shut down cooled due to heavy internal accretions and ring formations; these at places along with the deposits of metallic reduced iron reportedly exceeded over 100 tons and had to be blasted for cleaning up, with consequential damage to the refractory lining of the kilns which entailed unbudgetted costly relining and down-time periods.

32. It is now gathered 3/ that the charge to the rotary kiln is currently of the green concentrate (unpelletized) which has given better operational performances. However, no results of such operations have so far been reported or published.

33. Nevertheless, we do feel that the operational results of the New Zealand SL/RN plant will be watched with great technical interest and it is possible that some of the difficulties and possibly all of them would be partially or fully overcome in the future. It is recently learnt that the

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1/, 2/, 3/ Discussions during the ECE Seminar on "Direct Reduction of Iron Ore - Technical and Economic Aspects" Bucharest, September 1972 and the International Symposium organized by the National Metallurgical Laboratory, Jamshedpur, India in February 1973 on "Science and Technology of Sponge Iron and its Conversion to Steel".

New Zealand SL/RN plant is now working for several months close to design capacity. We will be greatly interested to study the relevant data. We have dealt with its past performance in some detail with the hope that its future results would be useful to the developing countries; this we are unable to do at this stage unless we have the recent operational data and plant results at our disposal. We can, however, well appreciate the stand of the New Zealand plant authorities in not permitting the visit of a high level technical mission from a fast developing country in the recent past which UNIDO had sponsored.

34. It was reported at the E.C.E. Seminar on Direct Reduction in September 1972 that the Hammersley-HIMET direct reduction plant in Australia has now abandoned its projected SL/RN rotary kiln based direct reduction process for the production of HIMET briquettes; they are now considering the use of a gaseous direct reduction plant at Hammersley.

Falconbridge SL/RN plant - Canada

35. "Falconbridge 1/ nickel mines is closing its SL/RN metallurgical plant for nickel-iron pellet refining at Falconbridge, Ont. It failed to be an economic operation after two years of intense effort. It's been losing about a million dollars a month in 1972. The company says the roasting and sulphur plants were brought to satisfactory operation. But the key SL/RN process equipment failed to produce continuously at rated capacity. 300,000 tons of pellets in which 95 per cent of the feed would be metallised. Feed was pyrrhotite (iron sulphide) formerly dumped as tailings.

Direction of the operation was turned over to the licensors LURGI Gesellschaft of Germany in November 1972 for a performance test but no significant improvement was achieved.

Costs of the plant were $63.5 million and loss in the first three quarters of that year was $8.5 million. Falconbridge has also had to acquire the associated sulphur-recovery plant from Allied Chemical Canada Ltd. for $12.4 million in terms of its contract."

36. A further extract 2/ is reproduced from the technical press concerning the Falconbridge plant.

1/ Iron Age - 11 January 1973, page 51

2/ The Northern Miner, 28 December 1972, page 3

"Falconbridge Nickel Mines is closing its nickel-iron pellet refinery at Falconbridge, Ontario, which began production of pellets in late 1970, as it has failed as an economic operation despite two years of extensive effort. As a result the pellet refinery and adjacent sulphur plant will be shut down early in January 1973.

Falconbridge announced that it will acquire the sulphur recovery plant of Allied Chemical Canada Ltd. which adjoins the Falconbridge nickel-iron pellet refinery. The purchase of the plant will be effected on 2 January 1973 upon payment by Falconbridge to Allied Chemical of a transfer price of $12,400,000.

Allied gave notice. Under the terms of an agreement between the two companies dated 26 January 1968, provision was made for termination of the agreement and Falconbridge was obligated to purchase the sulphur recovery plant on one year's notice if the total cost to Allied Chemical for producing sulphur for a period of 12 consecutive months, exceeded 90 per cent of the total market price of the sulphur produced. Twelve months after the start-up of the sulphur recovery plant, Allied Chemical gave notice to Falconbridge of its intention to terminate the agreement. The plant's satisfactory performance has been demonstrated.

Under the agreement, Falconbridge undertook to build the nickel-iron pellet refinery and to deliver the sulphur-bearing gases from the pellet refinery's roasters to Allied Chemical, which would then recover the material as elemental sulphur. Allied Chemical has stated that the major decline in the market price of sulphur has resulted in its total costs for a period of more than 12 months exceeding over 90 per cent of the value of sulphur at the producing point.

In announcing its decision, Falconbridge stated that approximately 300 jobs will disappear; however, some 215 of the employees affected will remain with the company in other positions at its Sudbury operations. Some of these will fill vacancies which now exist; and while approximately 100 will be placed on temporary layoff, all are expected to be recalled within a 13-week period as job openings occur through attrition. About 85 employees are expected to be laid off permanently, but will be eligible for recall should additional vacancies occur.

Process guaranteed. Under a 1968 agreement, Falconbridge obtained a licence from Lurgi Gesellschaft für Chemie und Hüttenwesen mbH to use the SL/RN metallurgical process for its nickel-iron pellet refinery. Lurgi designed and supervised installation of the key equipment for this process and instructed Falconbridge in its operation. Lurgi also provided certain guarantees - based on its pilot plant testing in Germany - that the commercial plant would be capable of producing annually 300,000 tons of iron-nickel pellets in which 95 per cent of the iron would be metallized. The feed material for this plant was pyrrhotite (iron sulphide) formerly discharged to tailings as waste.

The company said that part of the pellet refinery complex comprising the roasting and adjacent sulphur plant were brought to satisfactory operation. The principal deficiency was failure of the key SL/RN process equipment to produce at rated capacity or achieve continuous operations in accordance with the Lurgi performance guarantees.

Direction of the operation of the SL/RN process was turned over to Lurgi as provided in the contract for a "performance test" in late November 1972 but no significant improvement was achieved.

In addition to operational deficiencies, certain other factors adversely affected economics of the pellet refinery operation. Chief among these were a 65 per cent increase in labour rates (including fringe benefits) and a 70 per cent increase in the price of coal since 1967 when Falconbridge decided to proceed with the project.

Sizable write-off. Falconbridge has no immediate plan for future use of the pellet refinery and sulphur plant, the total costs of which are approximately $63,500,000 excluding a loss on operation of the nickel-iron pellet refinery of $8,500,000 for the first three quarters of the current year. Investigations are being undertaken to determine whether any alternative use can be made of the facilities. It is likely that a substantial portion of the remaining carrying value of these assets will have to be written off as an extraordinary item at 31 December 1972.

The company is also reviewing a number of its other projects and investments to determine whether any additional extraordinary items should be written off. At this time it appears that additional write-offs totalling a maximum of $10,500,000 might be required.

As a partial reduction to such write-offs would be a tax offset which might amount to $22,000,000."

Highveld Steel and Vanadium Corporation

36. Reference has been made to this plant earlier in this paper. The Highveld Steel and Vanadium Corporation in South Africa does not operate on SL/RN process but on ELKEM (Norway) process; only the rotary kilns have been supplied by LURGI of West Germany but the process followed is not the SL/RN. Furthermore, the Highveld Steel and Vanadium Corporation attempts pre-reduction up to 45 per cent of metallization (Fe) and does not take the metallization up to 80 - 90 per cent Fe - which is required for sponge iron production and its refining into steel.

37. In view of the great interest this plant has created in the pre-reduction technology, some relevant details thereof are reproduced below for ready reference: 1/

"The new integrated steel plant of the Highveld Steel and Vanadium Corporation Limited at Witbank, uses the vanadium-bearing titaniferous magnetite from the Bushveld igneous complex. The magnetite outcrops at Mapoohs mine, near Roossenekal, about 90 miles (145 km) north east of Witbank, where a new mine has been opened to provide the one million tons of ore per year required by the Witbank plant, when in full operation.

At Mapoohs, the ore is mined by open cast methods, crushed, washed and screened to -1½ in (-38 mm) size and taken to Witbank by rail.

The magnetite contains approximately 56 per cent iron, and between 1.2 and 1.9 per cent V_2O_5, together with 12 - 15 per cent TiO_2, and small amounts of CaO, MgO, SiO_2, Al_2O_3, and Cr_2O_3. The presence of TiO_2 precludes the use of the traditional blast furnace for smelting the iron, and therefore an electric smelting process with pre-reduction has been adopted. The sized ore is mixed with high-grade coal and fluxes, from local sources, on a belt conveyor and charged into one of four rotating pre-reduction kilns. These are 200 ft (61 m) long, 13 ft (4 m) diameter, and are lined with high-duty firebrick. They are heated by pulverised coal from burners at the charging end, the charge and hot gases flowing co-currently; secondary air is supplied by fans along the length. The kilns discharge into

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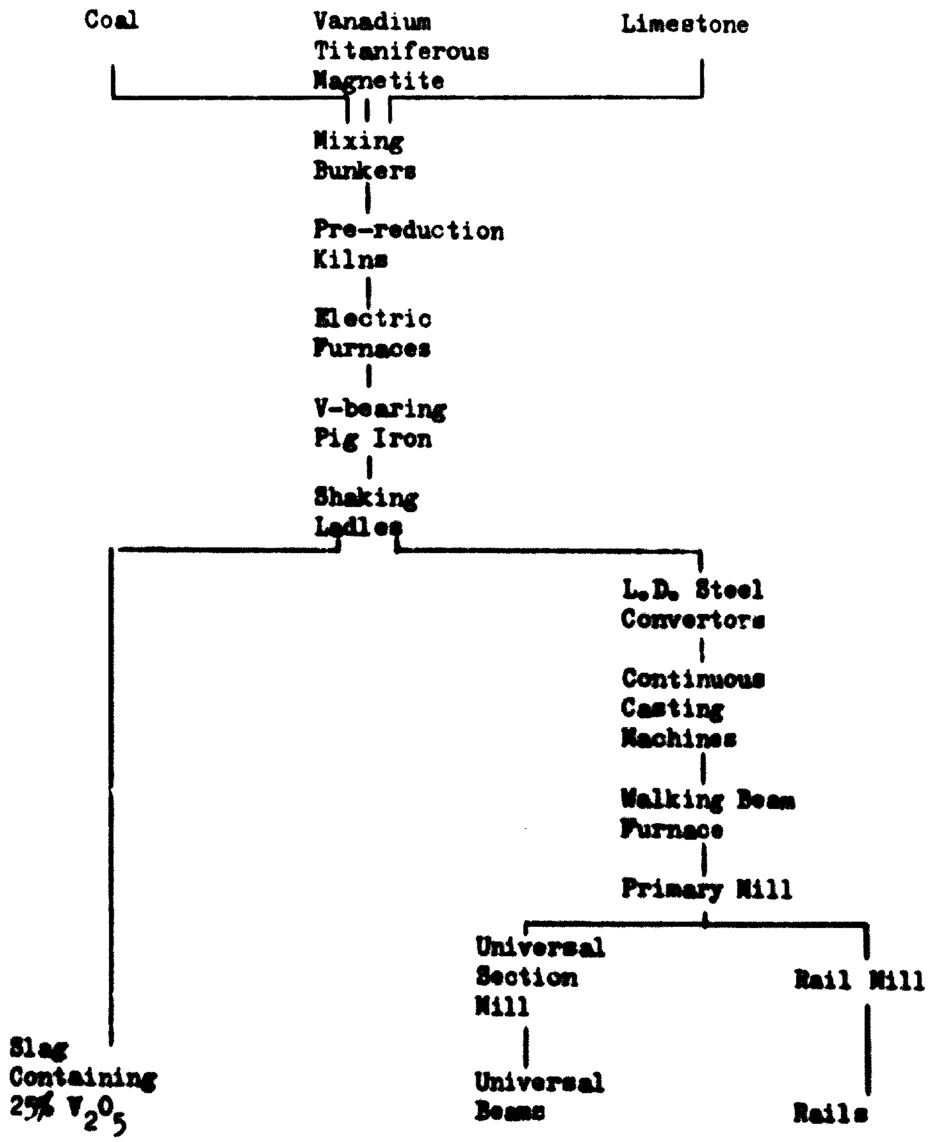
1/ Highveld Vanadium News No. 1, 1969, page 5 refractory-lined buckets which carry the hot, partially reduced ore to the stage of the submerged arc furnaces.

There is one furnace per kiln, each powered by a transformer with a rating of 33 MW. The three continuous self-vaking electrodes are hydraulically controlled, and each furnace is provided with two separate tap holes. Gas generated during the smelting has a high calorific value and is cleaned in wet scrubbers, one to each furnace, and stored in a gas holder for subsequent use as fuel in the works.

When the reduction has been completed, liquid iron containing approximately 1.4 per cent vanadium is tapped from the furnaces, the titanium being removed in the slag, which is dumped.

The hot metal containing the vanadium and about 4 per cent carbon is transferred to a separate shop where the vanadium is removed by oxidation in specially designed shaking ladles. Oxygen is blown into the ladle through a water-cooled lance, adequate mixing being achieved by oscillating the ladle at approximately 35 revolutions per minute. Additions of ore keep the temperature down and prevent the oxidation of carbon. During this operation, the vanadium is recovered as slag which, at the completion, contains approximately 25 per cent V_2O_5. The ladle has a tea pot spout through which the iron is poured into one of the two 60-ton basic oxygen converters leaving the vanadium slag behind. This slag is then tipped out in a special dump. When cold it is crushed and shipped to manufacturers of ferro-vanadium in the USA and Europe."

37. The flow-sheet of the process is given below:



38. During the E.C.E. Seminar held at Bucharest in September 1972 on Direct Reduction of Iron Ore, it was pointed out during the discussions that an additional rotary kiln had recently been put up to <u>increase</u> the total output of pre-reduced charge whilst it was also contended that it had been put up to meet the <u>deficit</u> of pre-reduced feed to satisfy the rated steel capacity of the Highveld plant. It was also indicated then at the E.C.E. Seminar that the above pre-reduced charge varied in the degree of its metallisation perceptibly and that such wide variations

could be tolerated although not welcome for subsequent iron smelting but can in no case be accepted for a sponge which is to be used directly for steelmaking.

First Interregional Symposium on "Applications of Modern Technical Practices in the Iron and Steel Industry to Developing Countries"

39. En'passant reference is made to the important conclusions on "direct reduction" arrived at almost exactly ten years back at Prague/Geneva at the First Interregional Symposium on the "Applications of Modern Technical Practices in the Iron and Steel Industry to Developing Countries" which was organized by the UN Centre for Industrial Development (now UNIDO since 1 January 1967) and which was attended by a large majority of the same participants who are attending the present Symposium at Brasilia. An extract thereof (page 143, paragraph 2 of the Report of the Symposium) is reproduced herewith for ready reference:

"The technological development and industrial experience of many of the so-called "direct reduction" processes were, in the judgment of the majority of the Symposium members, not yet satisfactory and their economic feasibility was still to be demonstrated. The utmost caution was urged in the selection of such special processes, which should be thoroughly studied in the light of the specific applicable conditions for any given case. It was agreed that certain special reduction processes which had been proved under specific circumstances might be recommended for comparable conditions of raw materials, fuel and energy supply, and market."

40. We feel that the above pertinent conclusion of the First Interregional Symposium arrived at ten years ago is still of importance, if not more so adjudged in the light of the industrial experience gained during the last decade. We feel that the above lessons have not so far been fully or effectively learnt. Let us recapitulate the cautions then sounded, which are techno-economically equally valid to-day concerning direct reduction processes in general.

41. Any direct reduction method is limited in its industrial scale application, adaptation and success to the type of ore feed and possibly its beneficiation and agglomeration to a high grade feed (over 65% Fe content with low insoluble contaminants), the type of reductants available

and the capacity of the plant. The scale up of a direct reduction plant cannot follow the analogy of a modern iron and steel plant with blast furnaces of a daily rated capacity reaching 10 - 12,000 tons. It is most important to stress that the applications of any specific direct reduction process and its success cannot be claimed to be universal or generalized to cater to any type or all types of raw materials (as has reportedly been claimed by some processes so far); its industrial success will have to be adjudged (a) technologically in its physical ability to yield the requisite sponge output corresponding to the rated capacity of the industrial sponge plant over continuous periods and not over sporadic intervals or periods with downtimes exceeding the operating times; (b) produce sponge of requisite quality and metallization again over satisfactory continuous periods and (c) its ability to prove and maintain its techno-economic viability and profitability; the basis or the yardsticks to adjudge the latter could vary viz. (i) on the sponge iron plant itself and/or (ii) on the basis of the integrated steel plant's economic results as a whole including the steel melting shop and the rolling mills. Thus each of the direct reduction processes (at times claimed to be universal and a cure of all raw materials' ills) must be techno-economically examined on its own merits and for specific raw materials, local market conditions and price structure. In doing so, several factors are important such as the reducibility characteristics of the iron ore/pellets and their relationship with time and temperature for effecting optimum reduction and metallization and thereby the total energy input for direct or pre-reduction. The physical characteristics of the ore are equally important particularly its decrepitation characteristics at room and reduction temperatures. The physical, chemical and mineralogical nature of the gangue content of the iron ore are equally important and more so if the sponge is to be used for direct steelmaking in the electric arc furnaces. The use of super-concentrates (extremely low in gangue) has now come to be recognized both from technical and economic angles. The tendency for the sponge to reoxidize and if required to withstand prolonged sea transport and handling at the two ends are other dominant factors to reckon with as also the degradation characteristics of the sponge during these transports.

Echevarria process

42. This process reduces the iron ore with a low volatile solid carbonaceous reductant such as charcoal, coke breeze or anthracite in externally

heated vertical retorts of stainless steel. The ore is reduced in about 48 hours and is discharged from the retort by a spiral discharge system through a water-cooled box. A plant of 20,000 tons annual capacity using this process was established in Legazpia, Spain, but is reported to have proved uneconomical and to have been closed down since 1965. More recently, a variant of this process known as the "NP" (Nuevo Proceso), developed by Swedish and Spanish scientists, has been investigated on a pilot plant scale in Italy by Siderurgica Monfalcone (SIMO) as a means of providing the sponge iron component for charging the arc furnaces supplying steel for their 120,000 tpa continuous casting billet plant. Sponge iron is produced in modular units of 4,000 tpa capacity each. Basically, each unit comprises a chamber heated by oil, gas (natural or propane), or possibly even coal, though the use of coal would impose restrictions on the modular lay-out due to handling problems. Within the chamber is a vertical vessel lined with silicon carbide, into which iron ore (which can be run-off-mine), low-grade coal and limestone are charged. In the case of SIMO the fuel used is propane and the reductant Yugoslav low-grade coal. The NP pilot plant was due to start operations in August 1972. The operational results, however, are not known. The supplier of these units was Danieli and Co., Buttrio, Udine.

Inchon Iron and Steel Company, South Korea

43. Extracts 1/ from the Report of the UNIDO Regional Adviser (Metallurgical Industries) in ECAFE countries are reproduced below in view of their intrinsic and technical interest concerning the pre-reduction plant (SL/RN) set up by the Inchon Iron and Steel Co. at Inchon and which has had a rather disastous start and operational history resulting in loss of men and materials and has now been closed down since.

"Inchon Iron and Steel Company's SL direct reduction plant, commissioned in February 1969, was practically the first commercial installation of its type in the world. The object was to produce 175,000 tons per year of partially reduced material for conversion to 125,000 tons liquid iron in a 28,000 kVA Demag electric smelting furnace. The hazards of an emerging

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1/ Advisory Services Report on Sponge Iron Production and Expansion Plans of Inchon Iron and Steel Co. by Mr. R.D. Lalkaka, Regional Adviser on Metallurgical Industries, December 1972. (Restricted Report).

technology were compounded by the use of inferior raw materials in the kiln - high ash Korean anthracite fines together with magnetite concentrate pellets and lump ore.

The operations experienced many difficulties of a mechanical and metallurgical nature, requiring various modifications to process flow-sheet and equipment.

Some of the problems encountered can be considered as normal "teething troubles" when running-in a plant of this type. Others were more fundamental, caused by inadequate development of process technology, lack of proper attention to problems of raw materials preparation, and absence of independent scrutiny of the original project design and economic viability.

The plant was closed down in March 1971, and an investment of about $15 million in kiln and smelter is now lying idle for the last 2½ years.

Plant Operations

After initial tests in March 1969, five campaigns were run until September 1969, when the kiln had to be taken down for complete re-lining. From July 1970, four campaigns were run until October, when kiln operation had to be stopped due to a break-out in the electric smelting furnace. The pre-reduction plant was started in December 1970 and three campaigns were operated, until serious refractory wear again forced the plant to shut down on 8 March 1971.

During campaigns the plant experienced considerable operational difficulties such as:

- rapid ring-formation in the kiln (longest run was about one month)
- inadequate control of temperature profile in the kiln
- failure of thermo-couple and melting-down of shell burner holders
- rapid erosion of kiln lining in certain areas
- inadequate strength and variations in size of pellets
- wide variations in sizes and analyses of incoming materials."

44. During the last 2½ years since the shut down of the almost new plant and following its disastrous failure, it is understood that some technical teams have visited Inchon to investigate into the plant's operations;

their reports have naturally led to detailed arguments. However, on one and the most important aspect there is no argument, namely that, that in the developing country a brand new metallurgical plant has come to a stop entailing thereby heavy loss of men, money and materials. There is no point in denying that it does put the clock back in these fields particularly for developing countries with their scanty resources of foreign exchange and capital investment.

Piratini SL/RN Steel Complex, Brazil

45. We hope that with the full knowledge of the difficulties likely to be encountered on an industrial scale operation of the SL/RN plant, the Piratini plant could be a full fledged success apart from any "teething troubles" which any industrial plant has to face in many cases. We look forward to such a positive likelihood which, considering the high standards and international status of Brazilian metallurgists and engineers and the singlemindedness of their technological applications, becomes more certain. It has been reported that the National Steel Plan of Brazil aims to raise the steel production in the country to over eleven million tons of crude steel by 1976 and to over tweny million tons/year by 1980. There is no doubt that the dynamio plans, efforts and outlook of the Brazilian steel industry will lead to a massive break-through and economic growth over the next few years. We also do hope that the Piratini SL/RN iron and steel complex will share this boom in Brasil.

National Metallurgical Laboratory, Jamshedpur, India

56. In the recent international Symposium on "Science and Technology of Sponge Iron and its Conversion to Steel" organized by the National Metallurgical Laboratory, Jamshedpur, held in February 1973, some of the relevant aspects were discussed, and we look forward to the study of the proceedings of this Symposium before long. The National Metallurgical Laboratory, Jamshedpur, had set up a well integrated mineral beneficiation/pelletizing pilot plant including a rotary kiln and sponge production facilities several years back and currently a much larger integrated rotary kiln pilot plant for research and development work on sponge production has now been planned. These are steps undoubtedly in the right direction.

III. UNIDO'S TECHNICAL ASSISTANCE PROJECTS IN THE FIELD OF DIRECT REDUCTION USING SOLID REDUCTANTS

47. UNIDO has fully realized the importance of research and development work in the field of pre-reduction and direct reduction sponge technology. UNIDO is at present engaged in the study and possible establishment of a Demonstration Plant in India for the direct reduction of high grade Indian iron ores and non-coking ocals based inter alia on rotary kiln operations with a capacity of about 30,000 tons of sponge output annually on the basis of the following, for Andhra Pradesh Industrial Development Corporation (APIDC):

(a) A pre-reduction kiln that would be erected for the production of 100 tons per day of pre-reduced iron ore. The facility could be used to demonstrate the economic feasibility of operating at that relatively low output under local conditions in the State of Andhra Pradesh in India.

(b) Simultaneously with the development of the rotary kiln plant designs, tests would be carried out at the pilot plant facilities of the National Metallurgical Laboratory at Jamshedpur in India, to determine the parameters involved in the production of low gangue (under 2 per cent) superconcentrates from local iron ores; the use of Singareni non-coking coals as reductants for pre-reduction of those concentrates; and the production of mild and light alloy steels from those pre-reduced materials in electric steel making furnaces.

(c) APIDC should undertake to ensure the erection of an electric steel-melting furnace as part of the project, and also to locate the billet continuous-casting unit, now on order, with that facility.

(d) APIDC should undertake to obtain preferential raw materials and electric power price schedules for the project to ensure its economic viability once the technical feasibility is established

48. The total UN input would be of the order of 1.5 million US dollars besides matching contributions of the Indian Government in local currency.

49. It is to be hoped that arising out of these technical deliberations, research and development work, the progress in direct reduction fields should be speedier, particularly for countries possessing abundant resources of high grade iron ores and non-coking coals but lacking reserves of high grade metallurgical coking coals.

50. In this context, it is pointed out that formed coke made basically out of non-coking coals could pose a challenge to direct and pre-reduction technology based on solid reductants if the formed coke could be made economically for use in normal iron blast furnaces. The progress in these directions would be worth watching.

51. In compiling and analysing the technical data and information from multiple sources, it is possible that some of the particulars given herewith may not be fully up-to-date in every way or may have been since modified. What is therefore attempted is to provide general trends of the operations and their results concerning pre-reduction and direct reduction to produce sponge iron based on solid reductants.

52. In conclusion it is emphasised that the approach of UNIDO to these new metallurgical processes and technologies is one of enlightened technical and practical interests particularly in relation to their possible applications and processing in developing countries and regions. We realise that we may be misunderstood but it is to be appreciated that the developing countries with their meagre resources, financial and technical, do have a valid case when they feel and do so strongly too, that they should not be used as the base for commercialising technically and industrially unproven metallurgical processes and technologies. UNIDO in its total dedication to the developing world and sincere efforts to promote and build up technical linkages between advanced and the developing countries, endeavours to do so and bridge the gap between the two on solid, firm and lasting foundations.

SUMMARY

In this short paper, an attempt has been made to outline the current status of pre-reduction and direct reduction sponge iron plants based on solid reductants. Gaseous direct reduction processes are not included in this review.

The difficulties met with in the industrial scale operations of sponge plants using solid reductants have been outlined in relation to some of the individual plants and how these are sought to be overcome. Whilst it is indicated that there are numerous papers, documents and treatises on direct reduction processes and plants, there is a singular lack of papers outlining their industrial experiences, difficulties and failures and additionally how effectively are these being overcome. It is concluded that technical information and up-to-date data on these aspects of sponge production technology are of vital interest to the developing countries and regions, and further that such data need continuous updating.

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