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NOTES ON FORMS OF IRON ORE PROCESSING WITH PARTICULAR REFERENCE TO WESTERN AUSTRALIA

by

R.W.L. King

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INTRODUCTION

In the Agreements between the iron ore companies and the Western Australian Government, undertakings have been given that in addition to the installations required to export iron ore the companies will, if practicable, establish secondary processing plants within approximately ten years. In the case of one company, additional upgrading of beneficiated ore is to take place by the nineteenth year, and in the case of the two major companies integrated steel works are to be established within approximately twenty five years.

Secondary processing to the extent of pelletizing is to be undertaken as the initial development by the remaining two companies.

LARGE SCALE OPERATIONS - THE BLAST FURNACE

Processing beyond pelletizing can take place through a variety of processes. In the first place, where an integrated steelworks with a capacity of 1 million tons per year or more is being considered, the blast furnace has much to recommend it. The high capital cost of the blast furnace installation can be balanced against the very low operating cost. The main disadvantage as far as Western Australia is concerned is that suitable coke or coking coal would have to be imported, presumably from Queensland or New South Wales. This need not be unduly expensive if the scale of operations is large enough. Mines and ports developed for the export of coking coal to Japan could serve also for the shipment of the requirements of a second Western Australian steel industry.

The question of when and how much capacity can be installed for the further processing of iron ore depends very much on the possibility of selling the material produced, either on the home market or overseas, or both. As pointed out above, where a substantial production (either in pig iron or steel) is undertaken, the blast furnace in its modern highly developed form would probably be the logical choice for iron ore reduction.

However, where estimates of potential markets are not sufficient to support an initial undertaking of blast furnace magnitude, there are a large number of processes, developed to a greater or lesser degree, for treating iron ore to produce a wide range of products from sheet steel to powders or pellets which are only partially reduced to metallic iron. These materials will usually be suitable either for sale as a substitute for steel scrap, or for further processing on the site to normal steel products. Some may be saleable as a "super" blast furnace feed, and small quantities may find a market for other minor metallurgical purposes.

There are two main points of difference between blast furnaces and the various direct reduction processes that are particularly relevant in the Western Australian context. Firstly, the size of the individual production units is much smaller in the case of the direct reduction processes. Economic production is possible at a much smaller rate than a single blast furnace and fluctuations in demand can be more economically met by adjusting the number of parallel units in production. Capital costs are also less than the blast furnace with its complex auxiliaries. Secondly, coking coal is not necessary, and in many processes there is no requirement for solid reducing agent at all.

CLASSIFICATION OF OTHER PROCESSES

The various direct reduction processes can be classified in many ways - by reductant, by type of product, by type of equipment used, by degree of development etc. The characteristics of some of the better known processes are set out in the attached table.

PROCESSES USING NATURAL GAS

In the Western Australian context it is worth examining more closely those processes using natural gas as both reductant and fuel. In the event of the quantity of gas available being limited the processes using some electricity or carbonaceous material (not necessarily coke) with natural gas will be of interest and are also discussed in some detail below.

The processes using natural gas alone fall into two main groups - those processing fine ore (either concentrates or fines screened from high grade lump ore) and those processing coarse material - either lumps or pelletized fine ore or concentrates.

Generally speaking, fluidized bed reactor processes are used for fines, but these processes have the major disadvantage that temperatures must be kept low to avoid sintering of particles in the bed. The resulting iron powder is pyrophoric (i.e. takes fire on exposure to the atmosphere) even at normal temperatures. Special handling methods must be used where the material is to be charged direct into steel making furnaces, and hot briquetting or some other form of processing in an inert atmosphere must be adopted where the material is to be stored and transported. The H-Iron and Esso-Little are typical processes in this group. Because none of the gangue elements are eliminated high grade ores and concentrates are favoured for these processes.

Where coarse material is handled, it is usual to pass the reducing gases through fixed beds of iron ore in shaft furnaces or reactors. The Hojalata y Lamina process has been commercial in Mexico under conditions somewhat similar to those which would prevail in Western Australia, given a good supply of natural gas. The German Purofer process, which has operated at 25 t.p.d. pilot scale, uses a shaft furnace for reduction rather than the batch reactors of the HyL process. The Finsider (I) process uses natural gas and a rotary kiln to effect reduction of pellets. The Madaras process is another which can be included in this group. Because of the higher temperatures and coarser particle sizes used, trouble with pyrophoricity of products is much less common with this group of processes than those using fines.

All the above processes using natural gas alone produce solid material, either in powder or lump form, and if it is used for steel making in an adjacent plant additional expense will be incurred in melting the material before a product comparable to blast furnace hot metal is obtained. The jet smelting process, at present developed at bench scale only, burns magnetite, oxygen and methane to produce molten iron and slag, and would be theoretically preferable in an integrated steelmaking plant.

The processes using natural gas and electricity include the Lurgi where rich ore is reduced by gas in a container heated electrically. The R-N process uses coke breeze or char for partial reduction in a rotary kiln heated by gas. Lower grade ores can be used with magnetic concentration of the kiln product to remove the gangue. There are other kiln processes using a solid reductant in which natural gas could be the principal fuel. Some of these produce molten metal in the kiln which could be used direct for steel making.

PRODUCTS OF DIRECT REDUCTION PROCESSES

Products of direct reduction processes, if solid, are suitable for use as a substitute for part or all of the steel scrap in an electric or open hearth steelmaking furnace or as a coolant in converter type steelmaking processes for which scrap is normally used. The material has two advantages over scrap in that it would be free of the substantial variations in price which occur from time to time in the scrap trade, and also of the elements such as arsenic, nickel, chromium, copper and tin which tend to accumulate as scrap is recycled, eventually reaching such proportions as to limit the proportion of certain types of scrap (particularly of motor vehicle origin) used in steelmaking furnace charges.

It is possible to feed partially reduced iron ore pellets or partially reduced sponge or powder (after briquetting) into the blast furnace as a substitute for part of the iron ore in the burden. This has advantages where the partially reduced feed is produced without the consumption of coking coal, and the output of hot metal from the furnace is increased with respect to the overall quantity of metallurgical coke used. Products of direct reduction processes in Western Australia might find a readier market in this form than as more highly reduced material suitable for use as a substitute for steel scrap.

As pointed out above, in some of the direct reduction processes molten metal is produced direct from a rotary kiln. However, in most cases where the end product of a direct reduction process is molten metal, the process used is basically one of pre-reduction in a rotary kiln, usually with solid reductant, followed by smelting and slag separation in an electric furnace. A second electric furnace is usually employed for steelmaking.

SOURCES OF ENERGY AND REDUCTANTS

In the absence of discoveries of suitably located supplies of reductants and sources of electric energy, conditions in Western Australia seem unlikely to favour this type of process.

Natural gas resources at Barrow Island appear at this stage to offer some prospect of being adequate to support an iron ore processing industry. (See section "Local Supplies of Natural Gas" below). However, it is possible that resources may not live up to present expectations and unforeseen difficulties arise in the transmission of gas from Barrow Island to suitable plant sites on the mainland.

Under these circumstances energy and reductant will have to be brought in if an industry is to be established. This will make less attractive any early small scale development based on direct reduction processes and favour a later larger development based on a blast furnace unit of most economic size from the cost of production viewpoint.

LOCAL SUPPLIES OF NATURAL GAS

Notes prepared earlier this year (1965) suggested that natural gas from Barrow Island might be a convenient source of energy and reductant for a process such as the HyL (see Table for details). Estimates of the quantity of gas required at that time suggested that a 500 ton per day plant would require 10 million cubic feet of gas per day, plus 0.5 million cubic feet for electricity generation to carry the process through to steel production.

Estimates of cost prepared at this time suggested that Barrow Island natural gas would at least be competitive with fuel oil landed at a suitable plant site.

It is now obvious that reserves of natural gas required for such a plant would have to come from the Jurassic sandstone reservoirs penetrated by Barrow Island Nos. 1 to 3 wells. No reliable estimate of gas reserves has been made to date but it is considered by the Bureau that they are of now (December 1965) of the order of 100 billion cubic feet - recoverable. At the envisaged rate of consumption of 10.5 million cubic feet per day, these reserves would last over 25 years.

However, it should be noted that in some of the Agreements, an integrated steelworks with capacity of 1 million tons per year is mentioned, and this represents an operation some five or six times greater than that discussed above.

CONCLUSION

There are formidable techno-economic problems to be resolved when consideration is being given to the type of plant that might be installed in Western Australia in satisfaction of the undertakings given in the various Iron Ore Agreements. The size of market available to various types of product will have to be considered in the context of the processes available to treat the available raw materials with available sources of energy and reductant. Some or all of these latter materials may have to be imported. This will introduce further variables of local freight rates from various possible sources of materials of varying value to the possible processes. The relative efficiencies of the various technically practical processes will also have to be considered.

It may be that there is scope for a variety of processes producing different products for various markets. For example, partially reduced pellets from fines may be produced for export, while sponge may be produced by a different process from lump ore for charging hot into steelmaking furnaces.

The problem is a complex one which will no doubt be the subject of a number of market investigations, technical and economic feasibility studies, etc., as the years go by. One factor which has not so far been mentioned, but which may be of some significance is the availability of capital to the companies who have undertaken consideration of these further processing projects.

ACKNOWLEDGEMENT

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DIRECT REDUCTION PROCESSES FOR IRON ORE

Name of Process	Status	Feed	Product	Use	Fuel & Reducing Agent	Description of Process & Remarks
H-Iron	Large Scale Pilot Plants (50 and 110 tons per day)	Dry, finely divided high grade iron ore (usually concentrates) Free of S. and P. Mill Scale also used.	Iron Powder. May contain between 65 & 90% Fe. Degree of Reduction is controllable. Carbon Free.	High grade as substitute for scrap in Electric Steelmaking furnace. Also as iron powder for powder metallurgy.	95% pure hydrogen. Generated by partial oxidation of Coke oven or natural gas and water gas shift reaction.	Temp. 1000 F Pressure 500 p.s.i. No improvement in grade by elimination of gangue minerals. A batch-process. 3 Stage fluidized bed.
Madaras	Pilot Plant	Small lumps or pellets of iron ore.			3:1 mixture of hydrogen and carbon monoxide.	Batch Process in Vertical retort. Temp.1800°F Pressure 30 p.s.i. pulsating 21 times per minute. No elimination of gangue minerals.
Wiberg-Soderfors	Commercial in Sweden (150,000 tons/year)	High Grade Sinter or Pellets 62% Fe. Must be coarse and strong	Sponge 80% total Fe. 70% metallic Fe.		75:21 mixture of carbon monoxide and hydrogen. Produced from coke in electric arc heated producer.	A continuous process in a vertical shaft furnace. Units have 27 ton/day capacity. Spent gas recirculated through water gas producer. Max. temperature 1000C. Pressure slightly above atmospheric.
Strategic-Udy	Pilot Plant. Commercial plants being considered.	Fines, low grade ore, titaniferous ore etc.	Fed direct to electric furnace where pig iron is produced 1-2½%C Furnace of "Open arc type".	Second furnace required for steel production.	Carbonaceous reducing agent. Coke breeze, anthracite fines, chars, etc.	Ore plus reductant and flux may be passed through a direct fired rotary kiln where there is no attempt at complete reduction - emphasis on free flow of material through kiln. Exit temperature 1700°F.
Krupp-Benn	Commercial in Germany (2 plants) Spain and Japan	Low grade, high silica ores.	"luppen"-nodules of 92% reduced Fe. Freed from quenched slag by crushing and magnetic separation, Middling recirculated.	If ore low in S and P luppen may be used steelmaking. High S and P luppen used for blast furnace feed.	Carbonaceous reducing agent, added in excess. Gas, oil, or pulverized coal heating of kiln at discharge end.	High final temperature of 2280°F results in pasty slag in which "luppen" form. Luppen pick up S and P from reductant and ore, so these must be low.
Stelling	Pilot Plant in Sweden.	Hematite concentrates.	Metallic iron high in carbon.		Carbon monoxide.	Pre-reduction to FeO then FeC_3 produced in a fluidized bed at 1160°F and atmospheric pressure, this is removed, and mixture of FeO and FeC_3 heated to 1380°F at which these react to produce metallic iron.
R-N (Republic Steel-National Lead)	Pilot Plant in U.S.A.	Claimed suitable for a wide range of iron content, P and S content can be controlled. Size - 1 inch + 20 mesh.	Treated by crushing and magnetic separation Two products: Total Fe 95% 85% Metallic Fe 90% 70% Silica 8% Briquetted.	High Grade - open hearth or electric furnace. Low grade - blast furnace.	Solid Carbonaceous Material (Coke breeze, anthracite fines) mixed with limestone. Kiln is Gas or Oil fired.	Several times the required quantity of Carbon used, and recirculated. Temperature in kiln 1800°F to 2000°F. Process continuous in a rotary kiln, counter current fired, and fitted with air jets along length of kiln for control of temperature.
Kalling	Pilot Plant in Sweden. 10,000 t p year Plant in Kenya now idle.	Finely crushed sinter magnetite or hematite. Gangue to have a high melting point.	Contains 1% Carbon 85-95% Reduction obtained.	Kenya plant product used for Copper precipitation. Scrap iron can now be imported cheaper.	Considerable excess of coke breeze.	Continuous process in rotary furnace air introduced via a central pipe. Temperature at reduction zone 1920-2010°F. P and S are picked up by the product. Operates at atmospheric pressure.
HyL	Commercial in Mexico 200 & 500 tpd. Second 500 tpd plant projected, also in Mexico.	High grade lump ore, pellets, sinter - 1½ inch, maximum of 20% - ½ inch.	Sponge iron 85% reduced.	Charged hot into Electric Steelmaking Furnace - Substitute for part of an all scrap charge	Heating by hot oxidised gases, reduction by hydrogen-Carbon monoxide mixture produced by catalytic steam reforming of natural gas.	Batch process in fixed bed reactors through which the gases are blown. 5 reactors, each 15 tons capacity in original plant. Operating temperature 2000°F pressure atmospheric.

Name of Process	Status	Feed	Product	Use	Fuel & Reducing Agent	Description of Process & Remarks
Hogans or Tunnel Kiln	Commercial in Sweden and U.S.	High grade ore sinter, pellets.	Porous sponge iron	Sweden - used for steel making in electric furnace. U.S. - used for powder metallurgy.	Coke or charcoal mixed with flux and ore. Kiln heated partly by combustion of CO produced.	Ore, flux, reductant mixture placed in "Saggers" and heated in a tunnel kiln - Process simple and reliable, but inefficient and low capacity. Low capital cost for unmechanized plant. Temperature about 2100°F.
Freeman	One Pilot Plant in Canada. 33' x 4' kiln.	Pelletized ore; preferably high grade.	Sponge iron pellets 91½% reduced.	Commercial iron powder and feed for electric furnace steelmaking have been produced from different ores.	Solid carbon reductant added in excess.	Concurrent fired kiln. Excess coke, sponge iron and lime residue separated at discharge end. Claimed that sticking and ring formation in kiln avoided by firing method used.
Dwight-Lloyd McWane	Pilot plant	Ore, low grade coal, flux are mixed and pelletised in "Flying Saucer".	Molten pig iron.	Any of the usual pig iron uses.	Low grade coke used in sinter strand. Product charged to submerged are electric furnace.	50-70% pre-reduction of pellets obtained on sintering machine. Final reduction, melting, and slag separation are obtained in conventional electric furnace.
Or-Carb.	Pilotplant U.S.	Hot ore and flux mixed with low temperature coking coal fines for pelletizing in a balling drum.	Molten pig iron- 2% Carbon.	Any of the usual pig iron uses.	Pre-reduction of hot pellets in a rotary kiln heated by electric furnace gases. Temp. 1900°F.	75% pre-reduction of pellets obtained in rotary kiln. Final reduction etc. as for D.L.M. process. 1700-1900°F temperature in reduction kiln.
Nu-Iron	Pilot Plant (2 tons/day) 200 tpd plant has been designed. Cost of Hydrogen principal difficulty.	Fine ore (-10 mesh)	Iron powder briquetted when hot - 90 - 95% reduced.	Steelmaking furnace feed.	85% Hydrogen reducing gas. Natural gas for heating.	Ore preheated to 1600°F, reduced in two stage fluidized bed reactor, first to FeO then to Fe. 90% reduction obtained. Operating conditions 1300°F 15-25 p.s.i. pressure.
Esso Research-Little	Pilot Plant. Commercial Plant Designed.	Ore ranging 34-67% Fe has been used.	Iron sponge briquetted. Can be upgraded by magnetic separation 85% reduced.	Steel making furnace feed.	Reducing gas is a mixture of hydrogen, carbon monoxide and nitrogen. Natural gas or oil for heating, and reducing gas manufacture.	Three stage fluidized bed reduction - first to FeO, second and third beds to Fe. Temperature 1450-1650°F pressure 1-4 atmospheres. 85% reduction obtained. Reducing gas not recycled, but applied to other plant uses.
Direct Steel	Laboratory	Super high grade concentrates.	Steel sheet or rod.	Ready for sale commercially.	Reducing gas 70% carbon monoxide, 26% hydrogen.	Direct production of steel from suitable feed. Finished steel would command about twice the price of reduced iron.
Purofer	25 t.p.d. Pilot Scale in Germany.	Ore, Pellets. Preferably high grade	Sponge Iron	Steelmaking in Electric & Open-hearth Furnaces and as Coolant in Converters.	/Reformed Natural Gas, Coke ovengas or residual gas.	Reformed natural gas passed through shaft furnace, sponge iron discharged at bottom, cooled in reducing atmosphere before discharge.
Finsider (I)	Pilot Scale in Italy	High Grade Ore.	Sponge Iron.	Steelmaking.	Reduction by hydrogen produced from natural gas.	Rotary kiln process - high degree of reduction obtained. Development halted because of shortage of natural gas in Italy.
Jet Smelting.	Laboratory Scale only.	High Grade Magnetite.	Liquid Steel.		Methane and oxygen.	Magnetite, methane and oxygen burned together - difficulties with high operating temperatures and slag attack on refractories.
Lurgi-Calluser	Possibly Pilot Scale.	Lump ore or Pellets.	Sponge Iron.	Steelmaking.	Electric heating with reduction by methane.	Externally heated reactor with recycling gases cooling sponge iron discharged from bottom of shaft.
Echeverria	20,000 t.p.y. plant in Spain.	Lump or agglomerated hematite. 60% Fe.	Sponge Iron	Electric furnace Steelmaking	8-25mm anthracite for reduction, producer gas for heating.	Small diameter shafts externally heated Surplus solid reductant recovered after magnetic separation of sponge from gangue and ash.