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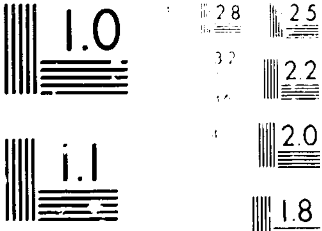
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COMPARATIVE STUDY EVALUATION OF INDUSTRIALLY OPERATIONAL TECHNOLOGIES OF THE DIRECT REDUCTION OF IRON ORES **

by

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TABLE OF CONTENTS

Page

LIST OF TABLES

APPENDICES

TABLE OF CONTENTS (continued)

Page

APPENDICES (Cont'd)

FIGURES

INTRODUCTION

Efforts to develop commercially acceptable direct reduction (DR) processes during the last quarter century are possibly a revival of efforts made in this direction some two centuries ago. Though the production of iron and steel in ancient times was based on reduction of iron oxide at temperatures below the melting temperature of iron and gangue materials, the early processes of solid state reduction did not have any significant impact on the iron and steel industry,mainly because of the developments in the blast furnace process. Some of the major reasons for the renewed interest in the direct reduction process during recent years are the dependence of the blast furnace on the exclusive use of metallurgical coke, the non-availability of good quality coking coal and increasing costs of coking coal; availability of other reductants in many countries; the growing problems of residual elements in steel scrap together with the vagaries of scrap market which have accelerated the search for an alternative melting stock; and the need for installing smaller capacity plants to suit the specific requirements of market and resources of many countries.

The term direct reduction has been generally employed to denote all ironmaking processes other than the blast furnace irrespective of the type and nature of the product. Some of these processes produce iron (in molten or solid state) for production of steel, while others provide pre-treatment of iron bearing raw materials and wastes and the products obtained are utilised as feedstock for iron smelting plants. For the purpose of this paper, however, the discussions are confined only to such DR processes which have reached the stage of commercial significance for the production of highly metalised solid product, referred to as direct reduced iron (DRI), to be used as melting stock in electric arc furnaces.

It may be mentioned that while a great deal of published information (1 to 65) is available on the technology, flow sheet, energy requirements and plant description of the various DR processes, **the information on the environmental aspects is scanty.** The details of pollution and its control presented in this paper have been specially obtained in most of the cases from process suppliers/plants (67 to 75) and their cooperation in this regard is gratefully acknowledged.

DR PROCESSES OF COMMERCIAL SIGNIFICANCE

The DR processes which have found industrial application, grouped under two heads according to the type of reductant used, are given in Table-1. The table indicates type of reduction unit and a list of industrial installations of each process. The processes are briefly described in Appendix-1 and their world wide installations are shown in Figure 1. The flow sheets of different processes are shown in Figures 2 to 10.

Gaseous Reductant Processes

From Table-1, it will be noted that there are six commercially significant gaseous reductant processes - Armco, FIOR, HIB, HyL, Midrex and Purofer. These processes use three different types of reduction units, namely retort, shaft furnace and fluidised bed. The shaft furnace is adopted by three processes, namely Armco, Midrex and Purofer. The HyL process - the first modern DR process and the only one using static bed reactors - has recently announced the development of HyL III process which is a shaft furnace process exploiting the advantage of the inherent efficiency of the counter current flow moving bed system. Thus, soon enough, the gaseous reductant processes may constitute shaft furnaces and fluidised bed units.

The shaft furnaces and retorts utilise either sized iron ore and/or pellets as the feed material and the fluidised bed processes utilise either natural ore fines or concentrates. Thus, from the oxide feed viewpoint, the fluidised bed processes offer the possibility of utilising a cheaper material. While the shaft furnaces produce DRI in cold or hot state which can in general be used as such as melting stock, the product obtained from fluidised bed reactors has necessarily to be briquetted before use. In all these processes, reformed natural gas is used as reductant. Either steam or recycled top gas is used as the reforming agent.

From a review of the industrial operations, it appears that at present the Midrex is the most established shaft furnace process. The industrial units adopting Armco and Purofer processes are not in operation at present. The retort process, HyL, has found wide application. The first industrial units, one each of the two fluidised bed processes, HIB and FIOR, have been built but till recently these units have been under modification.

Solid Reductant Processes

Though the Hoeganaes and Weiberg processes have been in industrial use for about 70 and 30 years respectively, these have not been included in this paper, as no new plants of these processes have been built for quite some time now. It is noted that most of the modern solid reductant processes utilise the rotary kiln for the reduction unit. Amongst these, the SL/RN and CODIR processes are in industrial operation.

The ACCAR process has been tried out for a very short period at Sudbury Metals Company, Canada in 1976, but the plant has since been shut down. The plant was based on the use of natural gas in a rotary kiln originally installed for use of coal.

The Kinglor Metor process, utilising retorts, has been industrially operated for a very short duration in a plant in Italy before being shut down. It is reported that another plant of this process has been recently set up in Burma. A similar process, Echeverria developed in Spain has had a short span of industrial life of about 7 years, before being closed down in 1965.

Emerging Processes

In addition to the processes indicated in Table-1, there are a few others which are poised for industrial application. A brief mention of these processes may be of interest. These include the following:

Gaseous reductant processes	Solid reductant processes
HyL III	ACCAR
NSC	DRC

These processes are also described in Appendix-1. Both the gaseous reductant processes, HyL III and NSC, are based on the use of the shaft furnace and high top pressure. No plants based on these processes are reported to be under construction at the moment.

It is reported that the HyL III process has been tried out at Monterrey by modifying a conventional HyL unit (2M). In this (HyL III) process, the conventional (HyL I) four-reactor unit is replaced by a two-zone single shaft reactor. The upper part of the shaft reactor is the reducing zone and the lower part is the cooling/carburising zone. These are separated by an isobaric zone. The shaft operates at high pressure (4 atm and higher). The top gas is recycled to the reduction zone.

The NSC process, developed by Nippon Steel Corporation, has been tried out in their demonstration plant at Hirohata, which is now shut down. In this process, the reducing gas is generated by steam reforming of natural gas, and the top gas after cleaning, cooling and removal of CO_2 is recycled into the shaft furnace after reheating. The shaft operates at a top pressure of 3 kg per sq cm g. In the pilot plant the product was cooled in an isolated chamber and for commercial plants hot discharge of products is proposed.

Both the emerging solid reductant processes, ACCAR and DRC, utilise rotary kiln as the reduction unit. The ACCAR process as installed as Sudbury Metals was based on the use of natural gas only. A new plant (150 000 tons/yr) based this process to utilise non-coking coal and fuel oil is now under construction in India. The use of coal as reductant has been tried out at the ACCAR pilot plant in Niagara Falls, Canada.

The DRC process was developed on the basis of the experience gained in processing ilmenite and a demonstration plant with capacity of 30 000/50 000 tons per year was built in Rockwood, USA in 1978. A 75 000 tons per year capacity plant is now reported to be under construction in South Africa.

Unit Sizes

The unit sizes of the industrial DR plants for different processes are also shown in Table-1. It will be observed that the most common unit size adopted by the shaft furnace processes is about 350 000/400 000 tons per year capacity. The largest shaft size in operation and under construction is of about 600 000 tons per year capacity. The Midrex process standardises its units on two sizes, designated as Series 400 and Series 600 module units.

The conventional HyL process utilising static bed reactors have four standard modules designated as A, B, C and D corresponding to annual production capacities of 290 000, 412 500, 515 000 and 625 000 tons respectively at 85% metallisation.

The fluidised bed plants are of different capacities; the FIOR plant is of 400 000 tons capacity, whereas the HIB plant is of 1 million ton annual capacity.

The commercial installation of rotary kiln processes vary widely in their unit sizes ranging between 30 000 and 400 000 tons per year capacity. However, the operating experience in units larger than 150 000 per year capacity has been marginal. The Kinglor Metor process uses a standard module of 20 000 tons per year capacity.

RAW MATERIALS

The two major raw materials required for DR processes are the iron oxide feed and the reductant. In the gaseous reductant processes, normally natural gas is used. Though there is a possibility of using , gas obtained from other fossil fuels, in industrial practice so far, only gas generated from heavy fuel oil has been utilised. In the solid reductant processes different types of coal are used. Besides, these processes require dolomite or limestone as a desulphurising agent.

The general characteristics of the oxide feed materials and the reductant used in the different processes are discussed below:

Iron Oxide Feed Material

The iron oxide feed material used in DR processes varies considerably and its selection depends on the requirements dictated by the type of the reduction process, the properties required to maximise the process efficiency and the quality needed to optimise the utilisation of the product in the subsequent steelmaking operations.

The reduction efficiency in a moving packed bed or in a static bed is greatly influenced by the bed permeability, higher permeability promoting the gas to solid contact. Therefore, in these processes the size distribution of the feed material, the ability of the oxide feed to resist degradation as well as decrepitation, and the physical behaviour during reduction at elevated temperatures are of importance. Preferably, the oxide feed material should be of narrow size range, and high amounts of fines are undesirable. Materials tending to stick, cluster and swell during reduction are to be avoided.

In the rotary kiln processes, materials of a wider size range than those for shaft furnaces can be accepted since the reaction rates are not influenced by the bed permeability. However, the materials should not generate fines either by degradation or decrepitation, as these would leave the kiln with the flue gas. Tendency to stick or to form cluster adversely affect the kiln operation due to accretion.

The fluidised bed processes require fines with consistent and appropriate size distribution. A high percentage of very fine material and narrow size distribution are not desirable. Not all types of ore fines are suitable for the fluidised bed processes; for example, fines tending to stick and forming agglomerates during reduction are to be avoided.

From the steelmaking viewpoint, the chemistry of the oxide feed material is important. It should preferably have a higher Fe content (between 66 to 69 per cent) with low contents of gangue, phosphorus, sulphur and residual elements (Pb, Cu, Sn, Cr, Co). The limit of the gangue content would depend on the proportion of DRI to be used. With only 50% DRI in arc furnace charge, the $(SiO_2 + Al_2O_3)/Fe$ ratio can be between 0.05 to 0.09, while for high DRI charge (70% or more) it should be below 0.05. The P content should be less than 0.03%. The residual elements rarely constitute a problem. The S content, however, can present a problem. From the DR process viewpoint, to prevent catalyst poisoning, the S content in the oxide feed stock should be below 0.015% for the Midrex standard flow-sheet and below 0.02% for Midrex alternate flow-sheet.

Keeping the above factors in view, it would be evident that for all the DR processes other than the fluidised bed processes, sized high grade iron ores and pellets with appropriate physical and chemical properties need to be utilised. Typical analyses of some of the pellets and ores utilised in the different DR processes are given in Table-2.

The general trends in the use of oxide feed in the different industrial DR processes are summarised below:

a) The HyL process started up with the use of 100 per cent ore. Later, it switched over to 100 per cent pellets and the present industrial practice is based on the use of pellets only.

b) The Armco process operated mainly with pellets; however, in certain periods, limited use of one type of sized iron ore has been made.

c) The Midrex process was developed with the use of 100 per cent pellets. Initially, only pellets obtained from a few specified sources were acceptable. Today, however, the process has shown its capability of utilising varied proportions of sized ore (0 to 100 per cent) with a wide range of pellets. A part of fines (3 to 6 mm) which were earlier rejected as screened out waste, are now acceptable as feed material in certain proportions.

d) The Purofer process operated in Brazil with 100 per cent iron ore and in Iran with 100 per cent pellets.

e) The fluidised bed processes have so far used only Venezuelan ore fines.

f) The rotary kiln plants (SL/RN and CODIR) generally use sized ore. The SL/RN plant has also used pellets and titaniferous magnitite concentrate.

The selection of the feedstock for a particular process is subject to conducting initially appropriate tests in the laboratory and later by testing in actual operations. Normally, the process suppliers carry out the tests. For rotary kiln process, however, the demonstration plant set up by the Government of India at Paloncha. Kothagudem, India, with UNIDO/UNDP assistance offers opportunities for large scale testing of raw materials to determine their suitability.

The stipulations generally made by different processes with regard to the characteristics of the oxide feedstock are summarised in Table-3.

Reductant

Natural gas: In the gaseous reductant processes, mainly natural gas is used as reductant. There has been so far only one plant in the world, Cosigua in Brazil, which operated with gassified heavy oil but this plant has now ceased working.

The natural gas has to be reformed to produce the reducing gas required for the process. The technology of reforming and the equipment used vary from process to process. On the basis of the technology of reforming, the gaseous reductant processes may be classified as follows:

a) Processes using steam reforming - HyL, Armco, HIB, FIOR and NSC.

b) Processes using top gas reforming - Midrex and Purofer.

All the reforming processes use a catalyst. The steam as well as the top gas reformers (Midrex) utilise a nickel-based catalyst. Depending on the reforming technology adopted, the processes stipulate the limits of the sulphur content in the natural gas, because the sulphur poisons the catalyst. The other undesirable constituents of natural gas are CO_2 and nitrogen. The characteristics specified by some of the DR processes on the natural gas quality are given in Table-4.

Coal: Coal is used as a reductant in the solid reductant processes. The suitability of coal is judged from the viewpoints of reactivity, ash content, ash fusion temperature and swelling index. The SL/RN plants are operating with sub-bituminous coals, except the unit in New Zealand which is utilising lignite char. The CODIR process uses anthracite coal as reductant and sub-bituminous coals as fuel. The characteristics of coals used in the rotary kiln plants are given in Table-5.

Keeping in view the larger reserves of coal (compared to natural gas) and the greater success achieved in the gaseous reductant processes, attempts are now being made to utilise gas generated from coal as reductant. Pilot plant trials have been made with the use of coke oven gas as reductant. The development and commercial acceptance of these technologies would be largely governed by the relative costs of gas generated from coal and natural gas.

PLANT PERFORMANCE AND PRODUCTS

Industrial experience indicates that with a new process, considerable efforts are needed to achieve sustained production of the desired quality of product at the rated output level as well as to master the technology. These processes are also highly sensitive to the quality of feed materials. Therefore, the gestation periods have varied depending on the local conditions and the status of industrial experience of the relevant DR technology. Most of the first DR plants adopting a new technology also have had to undergo significant modifications before achieving commercial success.

The Midrex plants have shown their capability of achieving the rated capacity within reasonable time at different locations. It must, however, not be forgotten that a great deal of effort had to be put in at the initial plants before they would reach rated output levels. The Armco unit at Houston took more than two years to reach 70 % rated capacity level and subsequently, it has not been operating. The Purofer units were operated for short durations and failed to achieve their rated annual capacities.

The HyL plants in Mexico have shown their capability of producing at the rated and even above the rated capacities. Similar success has, however, not been reported from the plants elsewhere.

HIB process has still not got over its problems, though nearly ten years have elapsed since its start-up. The FIOR plant is improving its performance and has achieved about 55% of the annual production capacity.

Performance of the rotary kiln plants have also followed a trend similar to the gaseous reductant units. The New Zealand plant achieved its rated output level in 5 years. The Brazil plant has achieved a 85% production level in about 6 years. The South African plant is reported to be operating at 80% capacity level.

The industrial experience on the Kinglor Metor process has been limited and the plants have not operated long enough to establish their performance capability.

The product qualities in respect of the degree of metallisation and the carbon content are governed by the process technology. Of the different processes discussed above, the HIB process produces the lowest metallised DRI - about 75%, which is not suitable for steelmaking. This is followed by the HyL process, generally achieving 85% to 87% metallisation. All other processes normally produce 90/92% metallised product. The degree of metallisation and the carbon contents generally achieved in different processes are indicated in Table-6.

Energy is required in two forms: gas/coal and electric power. The energy requirements of different processes depend on the type of reduction unit utilised, the quality of the feed material used and the quality of product. The general levels of energy consumption as achieved in industrial plants are indicated for different processes in Table-6.

The water consumption of DR plants depends on the process technology, the type of equipment used and the local conditions. On the one hand there are plants such as the Armco at Houston where a 'once-flow' system is adopted because of the abundant availability of water and as such, the water consumption is high. On the other, there is also a plant like the one in Qatar, where water-to-water heat exchangers are adopted for cooling of circulating water, and the system losses are minimum.

The general requirements of water for different processes are also indicated in Table-6.

ENVIRONMENTAL IMPACT

Whenever an industrial plant is established on a greenfield site, it disturbs the ecological balance in the area. This disturbance is generally described as pollution of the environment. The pollution can be due to discharge of material waste in the form of gas, liquides, solids or in the form of generation of heat, noise and odour: it can also be aesthetic. There has been a general trend all over the world to combat industrial pollution and guidelines have been established laying down the permissible level of pollutants that may be discharged by an industry into the surroundings.

While a great deal of published information is available on the environmental impact of the conventional iron and steelmaking processes, the magnitude and extent of pollution by the DR processes is not well documented. This is possibly because of the proprietory nature of these processes and their application predominantly in developing countries where environmental control regulations are not stringent.

In a DR plant, pollution is caused by several agents. Pollution of air is caused by dust generated from handling and processing of raw materials, and by emission of dust and gases from process equipment. Water used for equipment cooling and process requirements gets polluted. The effluent discharged is contaminated by suspended matter. Noise associated with the running machinery and relative motion is another source of pollution. The source, type and extent of pollution in a DR plant is dependent on the process technology and the equipment utilised.

A DR plant includes facilities for oxide feed storage preparation and handling; reductant storage, preparation and handling; reduction; and product handling, storage and screening. The equipment and facilities installed vary from plant to plant, depending on the type of feed used, the process adopted and the mode of utilisation of the produce. The elements of DR technology/

plant operations which have inherent potential for adverse environmental impact and the measures taken to control pollution are discussed below for each major section of the plant. The sources of pollution in typical DR processes are shown in Figures 11 to 15.

Emissions, Effluents and Wastes and Their Treatment

Customarily, the oxide feed storage, preparation and handling system comprise equipment such as conveyors, bins and screens. The screening of the oxide feed is carried out mainly to separate the finer fractions. In some cases, the plant may also include crushing facilities for lump ore, and rarely, concentration/beneficiation facilities. Generally, therefore, the pollutant from this section is the oxide dust. The amount of dust generated depends on the type and characteristics of the feed and the extent of preparation facilities at the plant. Dust is collected mostly in bag filters and sometimes through wet cleaning system. The dust thus collected is not suitable as such for use in the DR plant, and is generally dumped.

The finer fraction of the oxide feed stock separated out at the screening plant has also to be disposed off. At locations closer to integrated steel plants, these fines could be sold as sinter feed. In other cases, they may have to be dumped. Recently, the Midrex process has started using a part (3 to 6 mm) of the finer fraction as charge material to the shaft. This reduces the problem of disposal.

In the plants using solid reductant, the equipment used for the preparation and handling of reductant is similar to that used for oxide feed. The main pollutant in this section is dust and facilities similar to those discussed for oxide feed are utilised to combat it.

In the gaseous reductant plants, the common feature of all processes is the reforming facility. In addition, depending on the quality of natural gas, other pretreatment facilities such as those for desulphurisation are installed. The flue gas of the reformer is a pollutant. However, the particulate emissions from this flue gas are generally low, because natural gas and clean recycle gas are used as fuel. No facilities for cleaning the flue gas are, therefore, provided. Since the waste heat of the flue gas is also recovered, there is low thermal pollution. A possible source of pollution can, however, be the SO_2 content in the flue gas in some processes like the Purofer. For example, if the natural gas contains high sulphur (no pretreatment would be required for use in Purofer process, where high temperature is used for reforming) the reformer flue gas will contain SO_2. However, to combat pollution, in this case, desulphurisation of natural gas has to be carried out.

The desulphurisation facility depends on the type and content of sulphur in the natural gas and the acceptable limit of the sulphur in the natural gas and the acceptable limit of the sulphur in the treated gas for the DR plant. Bog iron ore, zinc oxide and activated carbon are the common desulphurising agents. Where the sulphur content of the natural gas is high and the process requirements (for the processes using steam reforming) are stringent, desulphurisation is carried out by mono-ethanol amine (MEA) wash followed by absorption of sulphur in zinc oxide. The bog iron ore and the zinc oxide have to be replaced periodically. The used up bog iron ore has to be dumped or used as sinter fe[illegible] or in some cases regenerated. The zinc oxide is regenerated by the manufacturer. From the MEA treatment plant, MEA sludge is obtained as a waste. This sludge is normally dumped. Otherwise, it can be incinerated or treated by bio-degradation before disposal.

For the plants using steam reforming, the bleed off f[illegible]he boiler feed water treatment plant and the boiler blow d[illegible] obtained as effluents. These have to be neutralised be[illegible]ischarge to the industrial and sanitary severage system.

In the case of gaseous processes, the gas coming out of the reduction unit is reused. This exit gas contains dust and is cleaned in wet scrubbers prior to recycling.

In the solid reductant processes, the exit gas from the reduction unit is led to a chimney stack and discharged into the atmosphere after cleaning. Various types of gas cleaning facilities are utilised. The flue gas from the rotary kilns contain SO_2 and SO_3, and the concentration of these depend on the S input. The scrubbing of the flue gas also removes sulphur oxides to a certain extent.

For all wet gas cleaning systems, the contaminated water is treated through clarifier and in most cases, the slurry from the thickener is filtered. The water recovered is recycled and the sludge/filter cake is dumped.

Dust is generated at the sponge iron discharge point as well as during storage, screening and conveying. Wet gas cleaning facilities are installed for abating the dust pollution. In the solid reductant processes, wastes in the form of non-magnetic materials such as ash and dolochar are obtained. These have to be disposed off in dumps.

The metallic fines cannot be used as such for steelmaking. Plants with small capacity tend to dump these fines. The possible uses of these materials are as feed to sinter plant, and in steelmaking furnaces, after briquetting. Attempts are now being made to pneumatically convey these fines for injecting into the arc furnaces.

Due to condensation of H_2O, there is an excess water in the process water circuit. This water, an overflow from the clarifier, is discharged as an effluent with high content of dissolved and suspended solids. In addition, to maintain the quality of the circulating water, the blow down from the cooling towers is discharged as an effluent to the storm water drainage system.

The types of pollutants, the general measures to combat pollution and the levels of particulate emissions before and after cleaning are given in Table-7. Detailed information on pollution and pollution control for the various DR processes are given in Appendix-2.

Noise Pollution

The noise levels in the DR plants vary considerably. Whereas in the general DR plant area, it can be about 80 to 100 dB(A), the noise levels are considerably higher at the compressors, fans, blowers etc, ranging from 100 to 130 dB(A). In most cases, the compressors are located in closed rooms. Special mention may be made of the Midrex plant in Emden where the noise levels have been brought down considerably by providing additional sound-proofing facilities. This was necessitated due to habitation near the DR plant. The noise levels of different DR processes are given in Table-8. The noise levels of a typical SL/RN plant is shown in Figure 16.

Investment on Pollution Control Facilities

Investment on the pollution control facilities varies depending on the process and the anti-pollution laws prevailing at the location. Data on the magnitude of investment for pollution control facilities is not readily available. This is partly because a substantial part of the pollution control equipment is in-built in the DR process technology, specially in the gaseous reductant processes. It is reported that for and 880,000 tons capacity Midrex plant with a total outlay of about DM 430 million (66), the total investment for pollution control could be around DM 5 million, of which about 66 per cent could be attributed to the waste gas cleaning systems and 33 per cent to the water treatment facilities. In the rotary kiln processes, this could be in the range of 10 to 30 per cent. For example, for SL/RN and CODIR, it is about 10 per cent and for DRC, 22 to 28 per cent of the plant cost.

Operating Costs

Estimation of operating costs for the environmental control facilities in the DR units is somewhat complicated, specially for the gaseous reductant processes. This is because, as mentioned earlier, the gas cleaning units are essentially required for the process purposes and are integral with the process equipment. However, some approximation is possible in the solid reductant plants, for example in rotary kilns where the gas cleaning facilities are not integral with the process equipment. The Sponge Iron India Ltd estimates the operating cost of these facilities at about Rs 30 (equivalent to about US $ 3.4) per ton DRI.

Furture Possibilities

The major areas of future development for environmental protection are expected to be in the fields of recovery of waste energy to reduce thermal pollution and the utilisation of solid wastes.

The possibility of recovering of waste energy is considered feasible in rotary kiln processes. The heat content in the waste gases and kiln discharge amount to about 35 per cent. The heat in waste gases can be recovered by a heat exchanger system upstream the after-burning chamber; and the chemical heat in the non-magnetic kiln discharge can be recovered in a pulvarised coal firing system (for example boiler). In this way total thermal efficiency can be increased from 40 to 60% (78). In some gaseous reductant processes there are similar possibilities as has been proposed for the integrated reformer for the HyL processes.

Utilisation of wastes are expected to develop primarily for the iron oxide fines and dusts. Cold briquetting of dusts and fines for reuse in the reduction furnaces is one such possibility. DRI fines are already being briquetted and the other alternative of injecting it into electric arc furnaces will be possible only in plants integrated with steelmaking facilities. The oxide and metallic fines obtained from DR plants are acceptable in sinter plants of integrated steel plants; however, this mode of utilisation is not universal. The possibilities of using the sludge collected from water treatment facilities need to be investigated and suitable processes developed.

APPLICATION FOR DR PROCESSES IN DEVELOPING COUNTRIES

Limited market demand and financial resources, non-availability of coking coal and availability of alternative reductants, as well as the vagaries in the international scrap market favour the installation of DR plants in developing countries. Such plants have been installed mainly from the viewpoint of domestic consumption of the DRI for production of steel. Some DR plants may be set up to meet the regional requirements of metallic charge.

The developing countries are already playing an important role in perfecting DR technologies on a commercial scale. It will be evident from the Table-1 that most of the DR plants are located in developing countries though all the process technologies, except one (HyL), originated in the industrialised countries. It may be noted that the plants based on Purofer process and the fluidised bed units are all located in developing countries. In the field of solid reductant processes, the plants in regular operation are only those which are located in developing countries. The first installations of the emerging processes, namely HyL III and ACCAR (using coal) are also in developing countries.

Location and Capacity

A review of the location of the existing and under construction plants will indicate that the DR plants have been installed with the use of locally available energy. It is, therefore, likely that in developing countries also a similar trend may prevail for future plants.

From Table-1, it will be noted that most of the gaseous reductant plants which have been installed are in the capacity range of 350 000/400 000 tons per year, though some units with larger capacity of up to 600 000 annual tons have also been built. In respect of the solid reductant plants, it would be noted that their capacities vary widely from plant to plant. It may also be mentioned that till date, the operating experience for reasonable period of time is available only for kilns up to about 150 000 tons per year capacity. The selection of plant capacities will have to keep these in view.

The selection of location and capacity of the DR plants in developing countries will also be influenced by the availability of raw materials and location/demand of the consuming centres of DRI. Therefore, DR plants could form a part of either an integrated mini plant, or a captive source to supply a number of mini plants in the country/region. The possibility of setting up DR plants for exporting the product will have to be judged from the viewpoints of domestic energy resources, market and other locational factors. It may be mentioned that in the recent past, the feasibility of overseas transportation of DRI has been reasonably established. DRI obtained from a number of processes have been transported over long distances including overseas locations. The experience in shipping indicates that though there are hazards in transportation, these could be overcome with appropriate precautions. In this context, it may also be mentioned that till now the trading in sponge iron has been carried out only as an interim measure from such sources where adequate steelmaking capacity is lagging behind the DRI capacity. The stability of the DRI will be an important factor in storage and handling for export. From these considerations, briquettes are favoured.

Raw Materials

Iron ore resources suitable for producing DRI of steelmaking quality are plentiful in the world. Therefore, in the long run, problems of availability are not foreseen. Brazil is the most important supplier of natural ore and is expected to continue to do so, because of its large reserves of marketable oxide feed in different forms. Guinea, which has a rich iron ore deposit, is expected to emerge as an important supplier. Venezuela has natural rich ores, but a large part of the produce would possibly be required to meet the domestic demand. The suitability of the South African ores for use in DR plants will have to be established.

In addition to the above-mentioned natural rich ores, DR plant feed may be obtained by beneficiating iron ores from various sources. These sources include Brazil, Sweden, Peru, Ivory Coast, India, Liberia, Canada etc.

From the viewpoint of the immediate future, however, there may be problems of obtaining suitable quality feed material. It is mainly from this viewpoint that the different DR processes are trying to widen their oxide feed materials bases by trying out sized ore and pellets from different sources. It may, however, be mentioned that it is somewhat difficult to predict the situation of the feed material for DR plants, because there has been considerable time lag between the announcement and completion of DR plants on one hand and a somewhat confused situation in respect of the development of pelletising capacity, on the other.

From the viewpoint of reductant, as mentioned earlier, local resources are generally expected to be utilised. Of course, there are instances, such as at Hamburg and Emden, where pipeline gas from other countries are used in DR plants. Similarly, the use of imported coal cannot be ruled out.

Environmental Considerations

The environmental control facilities installed in the DR plants in developing countries vary significantly. As the statutory requirements for environmental protection are not stringent in developing countries and the fact that additional costs (installation and operation) are involved. there may be a certain reluctance in installing these facilities. However, the general consciousness in these countries for protecting the environment is also growing. Therefore, the extent of pollution control facilities installed much depends on the entrepreneurs of the projects. To give an example, at Paloncha, where the sponge iron plant has been put up by the Government of India in collaboration with UNIDO, the DR plant is provided with most up-to-date environmental protection facilities which are described in Appendix-3. In the vicinity of the same plant, there is a ferro-silicon plant which is emitting large volumes of uncleaned smelter gas. Recognising that the recovery of by-product and its use can only make pollution control economically attractive, Sponge Iron India Ltd plant is now carrying out investigations to identify the possible use of the sludge collected from the dust cleaning facilities of the materials handling system and the reduction unit as a construction material. In the gaseous reductant processes, however, treatment and cleaning of gases is a part of process technology and therefore, these are installed in all plants at all locations.

A conventional integrated steel plant discharges a large volume of waste products, which contribute in a big way to environmental pollution. The bulk of this pollution is connected with the primary production of iron and steel. The more important and the major unresolved problems in the area of controlling emission in a conventional steel plant are resulting from coke oven operations. This step is totally eliminated in the DR process route. To control particulate emissions in modern blast furnace and BOF converter shops, extensive use of special pollution abatement systems such as fume extraction in cast house and local exhaust systems in various points, are essential. Similarly, in respect of the effluents from the coke ovens, the discharge water gets contaminated with toxic compounds such as phenols, thiocyanates and ammonia. These need bio-chemical treatment followed by biological treatment of the effluents. Compared to these, the pollution from a DR based plant will be considerably less, though the pollution problems encountered in raw materials handling and preparation are somewhat similar in both. In this context, it may be mentioned that many industrially advanced countries have been considering the possibility of shifting the primary operations of iron and steel production to developing countries, to avoid the problems of environmental pollution in their own countries.

Thus, it may be said that the market, energy and other resources, as well as the environmental considerations are more favourable for the installation of DR based plants in developing countries.

TABLE 1 - DR PROCESSES OF COMMERCIAL SIGNIFICANCE[a]

Process	Type of reduction unit	First industrial unit set up in	Existing industrial plants	Capacity '000 tons/yr
GASEOUS REDUCTANT				
Armco	Shaft furnace	1972	Armco Inc., Houston, Texas (USA)[b]	330
Fior	Fluidized bed reactor	1976	Fior de Venezuela SA, Matanzas (Venezuela)	400
HIB	Fluidised bed reactor	1971	Minerales Ordaz CA, Minorca, Puerto Ordaz (Venezuela)	1,000
HyL	Reactor	1960	HyLSA, Monterrey (Mexico) - 1M[b]	100
			- 2M[c]	270
			- 3M	450
			HyLSA, Puebla (Mexico) - 1P	335
			- 2P	700
			TAMSA, Vera Cruz (Mexico)	280
			USIBA, Salvador (Brasil)	325
			P.T. Krakatau Steel, Cilegon (Indonesia)	575
			State Company for Iron & Steel Khor-Al-Zubair (Iraq)[b]	375
			SIDOR, Venezuela - I[b]	1 x 360
			- II[b]	3 : 600
Midrex	Shaft furnace	1969	Oregon Steel Mills, Portland (USA)[b]	2 x 200
			Georgetown Ferroduction, South Carolina (USA)	400
			Hamburger Stahlwerke GmbH, Hamburg (FRG)	400
			ACINDAR, Villa Constitution (Argentina)	420
			Dalmine Siderca (Argentina)	330
			Sidbec Dosco I, Contrecoeur (Canada)	400
			Sidbec Dosco II, Contrecoeur (Canada)	600
			QASCO, Umm Said (Qatar)	400
			Iron & Steel Company, Point Lisas (Trinidad & Tobago)	420
			British Steel Corporation, Hunterston (UK)[b]	2 x 400
			SIDOR I, Orinoco (Venezuela)	400
			SIDOR II, Matanzas (Venezuela)	3 x 425
			EMDEN (FRG)	2 x 440
Purofer	Shaft furnace	1978	Cia Siderurgica de Guanabara, Cosigua (Brazil)[b]	360
			NISIC, Ahwaz (Iran)[b]	360
SOLID REDUCTANT				
ACCAR	Rotary kiln		Sudbury Metals, Ontario (Canada)[b]	260
CODIR	Rotary kiln	1973	Dunswart Iron & Steel Works, Benoni (South Africa)	150
Kinglor Metor	Silicon carbide shaft furnace	1976	Ferriere Arvedi & Cie SpA, Cremona (Italy)[b] Ministry of Industry, Burma	40 20
SL/RN	Rotary kiln	1969	New Zealand Steel Ltd, Gleenbrook (New Zealand)	125
			Falconbridge Nickel Mines, Falconbridge (Canada)[d]	400
			Acos Finos Piratini, SA., Porto Alegre (Brazil)	65
			Hecla Mining Co., Casa Grande, Arizona (USA)[b]	65
			The Steel Co. of Canada, Griffith Mines, Ontario (Canada)[b]	350
			SIDERPERU, Chimbote (Peru)	100
			SIIL, Kothagudem (India)	30

NOTES:

[a] For production of DRI for steelmaking.

[b] Plant presently not in operation.

[c] Converted to HyL III (Shaft).

[d] Converted to ACCAR process using natural gas.

TABLE 2 - TYPICAL CHEMICAL ANALYSIS OF IRON OXIDE FEED STOCKS USED IN DR PLANTS

	Fe %	SiO_2 %	Al_2O_3 %	CaO %	P %	S %
PELLETS						
CVRD, Brazil	68.00	1.46	0.79	0.66	0.047	0.006
Samarco, Brazil	66.50	3.00	0.75	...	0.07	0.05
Carol Lake, Canada	65.26	5.73	0.33	0.34	0.012	0.002
Hilton, Canada	67.08	2.18	0.25	0.22	0.005	0.006
Sidbec - Normine, Canada	67.00	2.50	0.50	...	0.025	0.006
Wabush, Canada	64.03	2.78	0.27	0.15	0.009	0.005
Alzada, Mexico	67.22	1.28	1.03	1.49	0.052	0.020
Pena Colarada, Mexico	66.00	2.09	0.84	1.97	0.041	0.016
Hierroperu, Peru	67.30	1.40	0.58	0.34	0.006	0.005
LKAB, Sweden	68.13	1.53	0.74	0.12	0.009	0.002
MPB, Sweden	66.00	4.00	0.60	0.20	0.015	0.005
MPR, Sweden	68.19	1.22	0.36	0.14	0.005	0.005
Savage Pina, Tasmania	67.10	1.50	0.35	...	0.006	0.03
OSKOL, USSR	66.79	3.82	0.19	0.31	0.008	0.005
LUMP ORE AND ORE FINES						
Aguas Claras, Brazil	67.81	0.65	0.96	0.05	0.041	0.009
CVRD Lump, Brazil	68.46	0.70	1.18	...	0.042	0.045
Espranca, Brazil	69.98	0.59	0.15	0.05	0.008	0.005
Piejao, Brazil	68.25	0.71	0.72	0.10	0.08	0.01
Mutuca, Brazil	67.50	0.90	1.50	...	0.05	0.09
Ironsand Concentrate, New Zeland[a]/[b]/	58.00	4.00	4.00	1.00	0.07	0.005
Cerro Bolivar, Venezuela[b]/	65.14	0.57	0.60	0.01	0.113	0.027
Elpao, Venezuela	66.38	2.18	1.02	0.12	0.026	0.005
San Isidro, Venezuela[b]/	66.41	0.32	0.42	0.01	0.049	0.035
Kromdrai, South Africa	67.30	0.60	0.30	0.50	0.04	0.14
Postmasburg, South Africa	65.37	3.62	1.45	0.20	0.026	0.012
Sishin, South Africa	67.16	3.29	1.12	0.02	0.029	0.011
Bayaram Ore, India	61.30	5.70	3.50	0.04	0.019	0.06

NOTES:

[a]/ Contain 8% TiO_2.

[b]/ Ore fines.

TABLE 3 - CHARACTERISTICS OF OXIDE FEED USED IN DR PROCESSES

	Shaft furnace	Reactor	Fluidised bed	Rotary kiln
A. CHEMICAL ANALYSIS				
Sulphur, max	i) 0.015%[a] (for standard flowsheet) ii) 0.02%[a] (for alternative flowsheet)	0.15% (preferable)	Preferable below 0.03%	Preferably low in view of steelmaking
Phosphorus	No limitation in regard to process but preferably low 0.03% max in view of steelmaking.			
SiO_2	A high silica content results in high slag volume during steelmaking. However, a very low silica content may result in excessive decrepitation, swelling and sticking during reduction.			
Al_2O_3	Not important for reduction, but preferably should be low to obtain low volume of slag in steelmaking.			
B. PHYSICAL CHARACTERISTICS				
Screen analysis	6 - 50 mm	5 - 50 mm with 12.7 - 50 mm at least 25%	Generally (less than 12.7 mm with -325 mesh (44 microns) less than 20%	5 - 25 mm
Compressive strength	250 kg min per pellet	200 kg min per pellet	Not relevant	218 kg min per pellet
ASTM Tumble Index (+6 mm %)				
- Pellet	90	90	Not applicable	90
- Ore	90	90	Not applicable	80
Reducibility under reducing condition	92	95	Not applicable	Preferably more than 90

NOTE:

[a] This level of sulphur indicated is relevant for Midrex process. For processes using steam reforming, the sulphur level may be up to 0.15% in the oxide feed.

TABLE 4 - CHARACTERISTICS OF NATURAL GAS

	Midrex	HyL
CH_4	80% max	88% min
C_2H_6	20% max	
C_3H_8 a/	10% max	2% max
C_4H_{10} a/	8% max	
C_5H_{12} a/		0.5% max
CO_2 b/	15% max	1.5% max
N_2	15% max	-
CO_2+N_2	20% max	-
Total sulphur c/ ..	15 ppm	8.5 ppm e/
H_2S	Not important	3 ppm max
CH_3S		
COS d/	3 ppm	3 ppm
Net calorific value (Kcal/Nm^3)	6,900 min	8,600 min

NOTES:

a/ Heavy hydrocarbons should be preferably low.

b/ Higher CO_2 content requires higher capacity process gas compressors, fans and blowers.

c/ If sulphur is present in appreciable quantity as COS, special treatment is required for its removal.

d/ In case of high temperature reforming such as in Purofer, where reforming process is carried out at 1200°C to 1400°C sulphur level up to 200 ppm can be tolerated.

e/ The sulphur limit in the reformer is 0.5 to 0.6 ppm. Up to 8 ppm sulphur level in natural gas, simple desulphurising facilities such as activated carbon bed is adequate. with sulphur higher than 8 ppm, elaborate desulphurising facilities such as MEA system to be employed.

TABLE 5 - CHARACTERISTICS OF COALS USED IN ROTARY KILN PLANTS

	Waikato, New Zealand[a]	Charqueadas, Brazil	Singereni, India	Duff, South Africa	Anthracite, South Africa	Forest Burg, Canada
A. Chemical Analysis (Wet %)						
Fixed carbon ..	40	36	44	53	73	39
Volatile matter ..	38	23	22	24	9	33
Ash	4	32	24	16	9	7
Moisture	18	9	10	7	9	21
Sulphur	0.3	0.4	0.4	0.7	0.75	0.37
B. Net Heating Value						
Calorific value, kcal/kg ..	6 631	4 600	6 000	6 300	7 100	5 975
C. Other Properties						
Ash softening point, °C ..	1 270	Above 1 250	1 160	1 150	1 260	1 130[b]
Reactivity ..	High	High	Moderate	Moderate	Moderate	High
D. Type	Lignite	Sub-bituminous	Sub-bituminous	Sub-bituminous	Bituminous	Sub-bituminous

NOTES:

[a] Char produced from this is used as reductant.

[b] Initial deformation temperature.

TABLE 6 - PLANT PERFORMANCE AND PRODUCTS OF SELECTED DR PLANTS

	HyL - I	Armco	Midrex	Purofer	FIOR	SL/RN	CODIR
Type of oxide feed	Pellets	Pellets and lump ore (10% max)	Pellets and lump ore (50%)	Pellets or lump ore	Fines	Pellets or lump ore or concentrate	Pellets or lump ore
Energy required/ton DRI							
Natural gas, G Cal	4.17(11)	3.1(2)	2.7(22)	3.3(31)	4.0(2)	-	-
Coal, G Cal	-	-	-	-	-	4.75(2)	4.0(2)
Electric power, kWh	40	40(2)	125(22)	130(31)	180(2)	50-70(2)	55(2)
Water required, cu m/ton DRI	2-3(2)	2.0(2)	1.5(2)	1.0(2)	5.5(2)	2.5-3.5(2)	1.5(2)
Product							
Metallisation, %	85-87	90-92	92-94	92-95	90-94	89-96	90-94
C, %	2-2.2	2.4-2.8	1.7 ± 0.3	1 ± 0.3	1 ± 0.3	0.2-0.3	0.2-0.3
Briquetting required - % of total production	2 to 3	2-3	5-10	100	100	10-15	10-15

TABLE 7 - MAJOR POLLUTANTS IN SELECTED DR PROCESSES

Source of pollutant	Pollutant	Method of treatment	Disposal/emission levels			Remarks
A. Raw Material Handling and Preparation						
i) Oxide feed (Ore/pellet)						
Screening station, storage silos and conveyor transfer points	Dust	Dry or wet dust collection system	Dust loading in waste gas:			Oxide feed handling and preparation system is more or less similar irrespective of type of DR process. However, there may be some additional classification facilities for oxide feed depending on the specific process requirements.
				Before treatment mg/Nm³	After treatment mg/Nm³	
			Midrex ..	30,000	50	
			HyL I ..	4,500	150	
			HyL III ..	10,000	50	
			NSC ..	5,000	100	
			FIOR ..	...	100	
			SL/RN ..	7,000	...	
			CODIR ..	...	160	
			DRC ..	Upto 0.5% plant feeds	No visible emission from baghouse	
ii) Coal						
Crushing and screening station, conveyor transfer points	Dust	Dry dust collection system	Dust loading in waste gas:			
				Before treatment mg/Nm³	After treatment mg/Nm³	
			SL/RN ..	7,000	...	
			CODIR ..	...	120	
			DRC ..	Upto 0.5% plant feeds	No visible emission from baghouse	
iii) Natural gas treatment						
Desulphurisation section	i) Solid waste	Spent activated carbon or zinc oxide catalyst or bog iron with sulphur deposits are disposed of to waste dump.	5 mg of activated carbon/Nm³ of gas treated 6 mg of ZnO per Nm³ of gas treated 1 gm of $Fe(OH)_3$ per Nm³ of gas treated			In case of activated carbon or ZnO or $Fe(OH)_3$ are adopted, the same is regenerated. However, after several regeneration, the material loses its absorption property and is discarded.
	ii) Sludge	Disposal of mono-ethanolamine (MEA) sludge to waste dump.	1.5 mg of MEA sludge generation per Nm³ of gas treated			
B. Reforming						
Stack	Flue gas	No treatment as particulate emission is low and is vented to atmosphere.	...			

Source of pollutant	Pollutant	Method of treatment
C. Reduction Unit		
Reduction unit including charging and discharging system	Dust	Dry or wet dust collection system
D. Product Handling and Preparation System		
i) Product		
Screening station, storage silos and conveyor transfer points	Dust	Dry or wet dust collection system
ii) Briquetting	Dust	Dry or wet dust collection system

Disposal/emission levels	Remarks

Dust loading in waste gas:

	Before treatment mg/Nm^3	After treatment mg/Nm^3
Midrex ..	100,000	50
HyL I ..	4,500	150
HyL III ..	10,000	50
NSC ..	5,000	100
FIOR ..	...	144
SL/RN ..	...	...
CODIR ..	...	50
DRC ..	10,000	50

Dust loading in waste gas:

	Before treatment mg/Nm^3	After treatment mg/Nm^3
Midrex ..	30,000	50
HyL I ..	4,500	150
HyL III ..	...	...
NSC ..	...	...
SL/RN ..	...	...
CODIR ..	...	120
DRC ..	10,000	Not visible emission

Product handling and preparation system is more or less same in all the DR processes. However, in case of solid reductant based processes magnetic separation is required in addition to storage conveying and screening facilities. In those processes where hot sponge is produced, the product is either directly transferred to SMS or hot briquetted.

Dust loading in waste gas:

	Before treatment mg/Nm^3	After treatment mg/Nm^3
Midrex ..	30,000	50
HyL I ..	4,500	150
FIOR ..	...	92

Cold briquetting technique employed by the various direct reduction plants is essentially same for both gas and solid based processes. The process parameters are governed principally by the extent of handling required. Thus, the generation of dust at the briquetting plant is expected to be same for all processes producing cold sponge.

Table 7 (continued)

Source of pollutant	Pollutant	Method of treatment	Disposal/emission levels	Remarks
E. Process Water Treatment and Colling System				
i) Boiler feed water treatment section	Waste water	Discharged to sewer after neutralisation		Relevent only in steam reforming process.
ii) Direct cooling water (DCW) circuit	a) Waste water	Excess water generated in the process is discharged to sewer after treatment in clarifier	High TDS and low suspended solids content in discharged water.	
	b) Solid wastes	Treatment of DCW in clarifier followed by sludge treatment facilities including dewatering of sludge which is disposed of to waste dump	Estimated quantity of sludge to be dumped is 20 ~ 40 kg/ton of sponge iron.	
iii) Cooling tower blowdown	Waste water	Certain amount of circulating water containing mainly high TDS is disposed of to sewer to maintain the quality of circulating water.		
F. Noise Level				
Belt conveyors, dedusting system, screening station, vibrating feeders, compressors, briquetting station etc.	Noise	Generally no sound pollution control system is adopted. However, depending on anti-pollution regulation prevailing in different countries, equipment emitting high noise level are either provided with silencers or kept in sound-proof buildings.	Approximate noise level data: Midrex .. 74 to 135 dB (A) HyL .. Upto 110 dB (A) MSO .. 100 to 105 dB (A) SL/RN .. ... CODIR .. 85 dB DRC .. 75 to 85 dB (A)	

TABLE 8 - NOISE LEVELS OF DIFFERENT DR PROCESSES[a]

dB(A)

	HyL I	Midrex	NSC	CODIR	DRC
Main air fan ..		133			
Compressors ..	92–107	130	100–105		
Preheaters ..	88–93				
Waste gas fan ..		130		85	75
Kiln product ..					80–83
Kiln drive ..				87	
Bag houses ..	93–110				
Wet dedusting ..	92–96	97–99			

NOTE:

[a] Without sound cover/silencing etc.

APPENDIX - 1

REVIEW OF THE DIRECT REDUCTION PROCESS OF COMMERCIAL SIGNIFICANCE

This review is confined to such direct reduction (DR) processes which have reached the stage of commercial significance for the production of highly metallised solid product, referred to as direct reduced iron (DRI) to be used as melting stock in electric arc furnaces. There are several DR processes which have been tried out industrially and a few others are poised for commercial application. The processes in both these categories grouped according to the type of reductant used and indicating the type of reactor used are listed below:

Type of reductant	Type of reactor	Processes tried out industrially	Processes poised for comm. application
Gaseous	Retort	HyL	
	Shaft furnace	Armco	HyL III
		Midrex	NSC-DR
		Purofer	
	Fluidised bed	Fior	
		HIB	
Solid	Rotary kiln	SL/RN	Accar a/
		CODIR	DRC
	Retort	Kinglor Metor	

Note:

a/ Accar process has a plant based on gaseous reductant which was converted from a solid reductant rotary kiln unit. No other gaseous Accar plant is reported under consideration, therefore it is not included under gaseous DR processes.

A great deal of published information (1-65) are available on technology, flowsheet, plant descriptions of these processes. Therefore, these processes are briefly discussed below:

HYL PROCESS

Hojalata-y-Lamina SA, Mexico (Hylsa) developed the HyL process and pilot plant of 30 tons per day capacity was set up in 1955. The first commercial plant of 200 tons per day capacity was installed in 1957 at Monterrey, Mexico.

Process Description

The HyL process uses a reducing gas obtained by steam reforming of desulphurised natural gas over a nickel-based catalyst. The reformed gas analyses generally 72% H_2 and 13% CO. The steam is condensed and the reformed gas is brought to a temperature of 870°C to 1,030°C. The reduction is carried out on batches of high-grade oxide feed held in fixed bed reactors. The reduction process is basically a 4-step batch operation. In order to provide continuity of gas flow and its effective utilization, four reactors are used, each passing through a 4-step cycle as follows:

Clean out and charging: Emptying the reactor of final reduced product and charging it with fresh unreduced oxide feed.

Secondary reduction: Heating of the fresh charge and partial reduction by preheated exit gas from reactor under primary reduction.

Primary reduction: Further reduction of the partially reduced charge by the preheated strong reducing gas from reactor under cooling.

Cooling: Cooling of hot sponge iron after primary reduction, by fresh reducing gas from reformer.

This arrangement envisages that at any instant, each of the 4 reactors is in one of the four stages of the cycle. A flowsheet of the HyL process is given in Figure 2.

The gas coming out of each reactor is scrubbed. It is heated in a preheater before entering the primary and secondary reduction reactors.

Special Features

The traditional HyL process (now referred to as HyL I) as based on operation of 4 static bed reactors through a cycle time of 12 hours. The process employs Pullman-Kellog type reformer using steam as the reforming agent. This has made the reformer independent of the reduction operation and has rendered a great flexibility in using high sulphur feed stock.

In general, the DRI produced in HyL process is of 85 to 87 per cent metallisation and carbon content varies between 1.8 and 2.2%. The cold sponge iron after screening is stored either in covered stockpile or in bins for subsequent despatch to steelmelt shop.

Plant in Operation and Under Construction

At present there are 20 HyL units with total annual capacity of about 9 million tons. Of these, only 9 were understood to be in regular operation in 1980-81 and the total production of HyL DRI in 1980 was about 2.26 million tons.

Three units in Iran were under construction and their completion has been delayed. An unit scheduled to be installed at TIKA, Zambia, is now reported to be abandoned. The units installed and under construction are given in Table 1-1 on the next page.

Energy Requirements

The energy consumption of the HyL units is of the order of 4.0 Gcal in terms of natural gas and 40 kWh of power for one ton of product. Depending on the extent of use of steam drives, the power consumption could be varied from 0 to 100/120 kWh.

Major Equipment and Facilities

Due to the process requirements, the screening facilities of HyL plant requires four size classification of oxide feed i.e. -5 mm, 5-12.7 mm, 12.7-50 mm and +50 mm. The fraction 12.7-50 mm is charged at the bottom of the reactor followed by 5-12.7 mm. The -5 mm and +50 mm fractions are not used.

Appendix-1 (continued)

TABLE 1-1 - WORLD-WIDE HYL INSTALLATIONS

Country and Company	Installed in	No. of units	Annual capacity tons
A. OPERATING/INSTALLED			
Brazil			
Usina Siderurgica de Bahia, SA Simoes Filho, BA (USIBA)	1974	1	300,000
Indonesia			
PT Krakatau Steel, Cilegon, West Java	1978	1	575,000
	1980	1	575,000
	1981	2	1,150,000[a]
		4	2,300,000
Iraq			
State Company for Iron and Steel, Khor Al-Zubair	1978[b]	4	1,485,000[b]
Mexico			
Hylsa, Monterrey, NL	1957	1	95,000[c]
	1960	1	270,000[d]
	1974	1	475,000
Hylsa, Puebla	1969	1	315,000
	1977	2	700,000
Tubos de Acero Mexico SA (TAMSA), Vera Cruz	1967	1	235,000
		7	2,090,000
Venezuela			
CVG Siderurgica del Orinoco SA (SIDOR), Matanzas	1977	1	420,000
	1979	3	2,100,000
		4	2,520,000[b]
B. UNDER CONSTRUCTION			
Iran			
National Iranian Steel Industries Co., NISIC, Ahwaz		3	1,000,000

NOTES:

[a] Expected to be commissioned in December 1981.

[b] Not being operated.

[c] Shut-down.

[d] Reported to have been converted to HyL III with an increased annual capacity of 300,000 tons.

The HyL reformer is of Pullman-Kellog design and uses nickel based catalyst for reforming of natural gas with superheated steam. There are four identical reduction reactors lined with refractory bricks. Each reactor vessel is provided with individual charge hopper and rotary loading chute as well as discharge device. Each reactor is equipped with a gas preheater and a dehumidifier. The product is cooled down to about 50°C in the cooling cycle by using cold reducing gas. The product is screened and the undersize (-5 mm) is either dumped or briquetted.

Raw Materials

Though the first commercial plant at Monterry commenced production using sized El Encino lump ore, later it was found that the use of pellets significantly improve the performance of HyL process. At present all the HyL plants are operated with pellets only. Alzada, Pena Colorade, CVRD and dolomitic LKAB pellets are being used in different HyL plants.

Product

The sponge iron obtained is of the same form as that of material charged. Typical analysis of sponge iron generally produced at Hylsa plants is given below:

Fe total	..	87.2%
Carbon	..	2.2%
Residual oxygen	..	3.7%
CaO	..	1.9%
Gangue	..	4.3%
Metallization	..	85.1%

Recent Developments

HyL II: In 1979, Hylsa proposed a modification to the conventional HyL I process with a view to reduce energy consumption. This new scheme was identified as HyL II. The major differences between HyL I and HyL II are:

i) The installation of integrated reformer in HyL II wherein the reformer and the gas preheaters are integrated through systems of waste heat recovery, instead of independent reformer and preheaters in HyL I.

ii) Installation of 2 centralised constant temperature process gas preheaters utilizing mainly the heat in reformer flue gas compared to 4 independent fuel fired gas preheaters each coupled with one reactor.

iii) Clustering the four reactors with a centralised charging and discharging system in HyL II instead of independent charging and discharging facilities with each reactor in the conventional design.

iv) Replacing a considerable part of steam drives of HyL I by electric motor drives in HyL II.

This process has not been tried out and can be considered as abandoned.

HyL III: In 1980, Hylsa announced the emergence of HyL III process which is basically a shaft furnace process designed for high pressure operation. It is a continuous process like any other shaft furnace process. The upper profile of the reduction reactor is same as in conventional HyL static bed reactor. The major changes are in the reduction facilities as given below:

- One moving bed counter current flow reactor instead of four static bed reactors.
- One gas preheater and one scrubber operating continuously instead of four operating intermittently.
- No air heater or combustion chamber.
- High pressure (4 to 6 atm) operation.
- In-built cooling zone like other shaft furnace processes.

The reformer for HyL III is integrated and coupled with pre-heater. A flowsheet of the HyL III process has been shown in Figure 3. An advantage claimed by the process promoter is that HyL III reactor can be retrofitted to an existing HyL I module. It is reported that the 2M unit at Monterry has been retrofitted to HyL III in early 1980 and is in operation.

ARMCO PROCESS

Armco Steel Corporation, USA developed the Armco process. A pilot plant with a capacity of 45 tons per day was put into operation in May 1964 at their Kansas City Works, Missouri, based on partial oxidation of natural gas by air. The pilot plant was modified in 1965 for utilizing natural gas reformed by the process off-gas in Pebble Stoves. The first industrial scale unit with a capacity of 1,000 tons per day was commissioned at Houston, Texas.

Process Description

The reducing gas for the Armco process is generated by the catalytic reforming of desulphurised natural gas with steam at 915-955°C. The temperature of the reducing gas before entering the reduction furnace through tuyeres at the bottom of the shaft is adjusted to 750-900°C by the addition of off-gas which has been cleaned and cooled to remove water vapour. The counter-current flow of the gas in the shaft accomplishes the preheating and reduction of the descending pellet bed. About 60 per cent of the off-gas drawn out of the furnace into a downcomer, after being cleaned in a venturi scrubber and cooled to remove water vapour, is used for firing the reformers. The balance, after being compressed and recooled, is used for mixing with the reducing gas to control its temperature and for cooling the reduced DRI pellets in the conical section at the bottom of the furnace. The DRI pellets are cooled to ambient temperature before being discharged through a gas-sealing device onto an apron conveyor. The DRI fines generated can be cold briquetted. A flowsheet of the Armco process is given in Figure 4.

Special Features

The counter-current shaft furnace is provided with a central insert for injecting reducing as well as cooling gas. The process employs Foster Wheeler reformer using steam in the stoichiometric proportion as reforming agent. This has made the reformer independent of the reduction operation and has rendered a great flexibility in using high sulphur feed stock.

The cold sponge iron after screening is stored in storage silos for subsequent despatch to steelmelt shop.

Appendix-1 (continued)

Plant in Operation and Under Construction

Today there is only one unit in operation at Houston based on the Armco process, with an annual capacity of 330,000 tons. No new module is under construction.

Energy Requirements

From the operation of Houston unit, it is observed that the average energy consumption is about 3.1 Gcal of natural gas and 35 kWh of power per ton of sponge iron.

Major Equipment and Facilities

The raw material handling and screening system is similar to other shaft furnace process. The preferable size range for the oxide feed is 6-32 mm. The reformer is of Foster-Wheeler design and uses a nickel oxide catalyst for catalytic reforming of desulphurized natural gas with steam.

Armco process employs a shaft furnace of circular cross-section comprising of reduction zone and cooling zone. The reducing gas enters the furnace through refractory-lined tuyeres from the bustle pipe as well as through the central inserts. A feed hopper at the top of the furnace receives the oxide feed which is fed into the furnace through distribution pipes. A steel apron conveyor located immediately below the discharge tube controls the rate of pellet movement through the shaft furnace.

The product is discharged by breaker rolls to a tube equipped with gas-sealing devices.

Appendix-1 (continued)

Raw Materials

The size range of oxide feed (ore as well as pellets) used at Houston is 6-32 mm. The oxide feed mix used at Houston consists of 80 per cent pellets and 20 per cent lump ore. The chemical analysis of Pea Ridge pellets from Missouri and graded Brazilian ore used at the Houston plant is given below:

		Pea Ridge Pellet Per cent	Brazilian Ore Per cent
Fe (total)	..	67.1	69.5
SiO_2	..	2.46	0.56
Al_2O_3	..	0.45	0.34
CaO	..	0.34	0.08
P	..	0.088	0.036
S	..	0.001	0.004
MgO	..	0.21	0.05
Mn	..	0.025	0.036
Na_2O	..	0.027	0.011
K_2O	..	0.028	0.005

Product

The sponge iron produced by the Armco process is of the same form as that of the material charged. Generation of sponge iron fines is about 5 per cent. Typical analysis of DRI produced at Houston is given below:

Fe (total)	..	91.5%
Fe (metallic)	..	84.2%
C	..	2.4%
Residual oxygen	..	2.3%
Metallization	..	92%

MIDREX PROCESS

The Midrex process was developed at the Toledo plant of the Surface Combustion Division of the Midland-Ross Corporation, USA in 1967. The first full-scale prototype plant of 200,000 tons per year capacity was installed at Portland, Oregon (USA) in 1969.

Process Description

The Midrex process is a continuous process in which oxide feed is continuously charged at the top of the shaft and the product is discharged from the bottom. The reducing gas is generated in a catalytic reformer using a mixture of natural gas and furnace top gas. The reducing gas is nearly 95 per cent hydrogen and carbon monoxide with a ratio of H_2 to CO of 1.5 to 1.6, which is maintained by controlling the H_2O saturation temperature of the cooled process gas. The temperature of the reducing gas leaving the reformer is controlled by means of a by-pass containing a gas cooling unit.

The Midrex direct reduction furnace is divided into 2 zones. The upper section is the 'reduction zone' and the lower section is the 'cooling zone'. The reducing gas enters the furnace at the bottom of the reduction zone and is withdrawn at the top of the shaft. This top gas is then cooled and washed in a scrubber, condensing the water vapour and removing particulates, and is mainly used for reforming to produce fresh reducing gas. The balance is used as a supplement fuel to heat the reformer. The descending metallised material is cooled to less than 50°C by cooling gas before it is discharged. The Midrex process flowsheet is shown in Figure 5.

Special Features

The residence time of the charge in the shaft furnace is about 6 hours.

The process uses reformer of Midrex design. It utilises the reduction furnace top gas as reforming agent. This restricts the acceptable sulphur content of feed stock to prevent poisoning of nickel catalyst used in the reformer tubes. This shortcoming has been overcome by adopting an alternate flowsheet.

In general, Midrex DRI is of high metallisation with an average degree of metallisation of 92% and carbon content varying from 1.3 per cent to 1.7 per cent.

Plants in Operation and Under Construction

At present there are 16 Midrex units of which 13 are understood to be in operation. The total installed capacity of Midrex DRI is about 7 million tons and the total production in 1980 was about 4 million tons of the 14 units under construction, three units in Iran are delayed. The units installed and under construction are given in Table 1-2 on the next page.

Energy Requirements

The average specific energy consumption ranges between 2.6 and 2.8 Gcal with electrical energy consumption varying between 110 and 140 kWh.

Major Equipment and Facilities

The oxide feed used is generally in the size range of 6 - 50 mm and the under size as well as the over size fractions are rejected. However, in some plants the 3 to 6 mm fraction is being recovered and charged in the shaft.

The Midrex process basically employs a shaft furnace where the oxide feed is heated and reduced by an ascending stream of hot reducing gas on the principle of counter-current flow. The shaft furnace has a circular cross-section comprising a refractory-lined reduction zone extending for more than one-half the height of the furnace and an inverted conical cooling zone. A conical hopper at the top of the furnace receives the charge material and feeds it to a chamber for uniform distribution through a number of feed pipes. For smooth descent of the burden, feeders are provided at three levels of the shaft furnace. The top of the furnace is sealed to prevent escape of reducing gas and infiltration of air. Each reduction furnace is provided with top gas and cooling gas scrubbers and compressors for process gas and cooling gas.

TABLE 1-2 WORLDWIDE MIDREX INSTALLATION

Country and Company	Start-up	No. of units	Annual capacity Tons
A. OPERATING/INSTALLED			
Argentina			
Acindar-Industria Argentina de Aceros, SA - Villa constitucion	1978	1	420,000
Dalmine Siderca, Compana	1976	1	330,000
		2	750,000
Canada			
Sidbec-Dosco Ltd., Contrecoeur	1973	1	400,000
	1977	1	650,000
		2	1,050,000
Republic of Germany			
Hamburger Stahlwerke GmbH, Hamburg	1971	1	400,000[a]
Norddeutsche Ferrowerke GmbH, Emden	1981	2	880,000
		3	1,280,000
Qatar			
Qatar Steel Co Ltd, Umm Said	1978	1	400,000
Trinidad and Tobago			
Iron and Steel Co of Trinidad and Tobago Ltd, Point Lisas	1980	1	420,000
United Kingdom			
British Steel Corporation, Hunterson, Ayrshire		2	800,000[a]
United States			
Korf Industries Inc. Georgetown Ferro-reduction, Georgetown, SC	1971	1	400,000
Oregon Steel Mills, Portland OR	1969	2	300,000[a]
		3	700,000
Venezuela			
CVG Siderurgica del Orinico SA, (SIDOR), Matanzas	1977	1	355,000
	1979	3	1,200,000
		4	1,555,000
B. UNDER CONSTRUCTION			
Iran			
National Iranian Steel Industries Co (NISIC)		3	1,200,000[b]
Nigeria			
Federal Ministry of Industry, Warri	1981	3	1,100,000[c]
Saudi Arabia			
Saudi Arabia Industrial Development Co, Al-Jubail	1983	2	800,000
Malaysia			
Sabah Iron & Steel, Lebun Island, Sabah	1984	1	600,000
USSR			
Ministry for Iron & Steel, Kursk	1982	4	1,600,000
Trinidad and Tobago			
Iron and Steel Co of Trinidad & Tobago Ltd, Point Lisas	1982	1	420,000

NOTES:

[a] Not being operated.
[b] Delayed and expected to be in operation by 1984.
[c] Reported to be under commissioning.

The reformer is of Midrex design and uses furnace top gas as reforming agent. The nickel based catalyst is packed in reformer tubes arranged in rows. The sensible heat of reformer flue gas is recovered by a recuperator system.

The cold product discharged from the cooling zone is first stored in product storage silos under controlled atmosphere and then screened. The undersize is generally briquetted. Alternatively, the fines can be injected into the electric arc furnace by pneumatic lance. The practice of the pneumatic injection system is yet confined to trial runs.

Raw Materials

The Midrex process started with the use of 100 per cent pellets. At present these plants are using a mixture of pellets and sized ore. The extent of ore use varies from plant to plant and is of the order of 40 to 50%. Pellets, like CVRD, LKAB, SIDBEC Normine, Fire Lake, Wabush etc and lump ore such as Aguas Claras, Mutuca, Feijao, CVRD, Esprance etc have been successfully used.

Product

Midrex process generally produces sponge iron with degree of metallisation of 92% and above with carbon content varying from 1.3 to 1.7%. Typical analysis of Midrex sponge iron using CVRD and LKAB pellets are given below:

Chemical analysis	From CVRD pellets %	From LKAB pellets %
Fe_{total}	92.46	93.83
Fe_{total}	86.12	87.47
SiO_2	1.71	1.16
Al_2O_3	0.91	0.88
CaO	0.65	0.40
MgO	0.28	0.25
P	0.017	0.01
S	0.003	0.008
Cu	Trace	Trace
Metallisation	93.0	93.1

Midrex have developed a passivation technique called 'Chemaire process'. The first commercial plant with Chemaire process is now in operation at Emden.

Recent Development

The major recent developments are; the alternate flowsheet, briquetting of sponge fines which has been adopted in operating plants such as SIDBEC, ACINDAR, SIDOR, the extra reforming capacity by insitu reforming, preheating of feed and process gas, oxide fines briquetting, and the use of screw compressor for inert gas.

PUROFER PROCESS

The Purofer process was developed by Thyssen Purofer GmbH, West Germany. A semi-commercial shaft furnace plant with a capacity of 500 tons per day was constructed at Oberhaussen, West Germany in 1970. The first two commercial plants, each with a capacity of 350,000 tons per year, were put into operation in Brazil and Iran, in 1977 and 1978 respectively. At the plant in Iran, the reducing gas is generated by catalytic reforming of natural gas with process off-gas, whereas at the plant in Brazil, gasification from heavy oil by Texaco reformer was employed for generation of reducing gas.

Process Description

The Purofer process uses shaft furnace for reduction. The reducing gas is fed in the furnace at a temperature of about 1,000°C. The product is discharged hot into special containers at about 800°C temperature. The charging of oxide feed is similar to that of blast furnace.

When using natural gas, the process off-gas from the shaft furnace is cleaned and cooled to remove water vapour, and about one-third is then mixed with natural gas in stoichiometric proportions to reform the natural gas for generation of reducing gas. There are two reformers which are alternately under heating and reforming. The reducing gas contains about 95 per cent H_2+CO (H_2/CO about 1.4).

In the Purofer process, hot sponge iron discharged from the furnace is collected in a container. The container is handled by a specially designed truck. The primary intention of the Purofer process is to use hot sponge iron in the electric arc furnace to save steelmaking power consumption. In case the sponge cannot be charged hot, the same is hot briquetted in the briquetting plant and then stored.

The process flowsheet using natural gas is given in Figure 6. When using oil (as in Brazil) the raw gas produced from partial oxidation of heavy fuel oil at 1,400°C is cooled and scrubbed for removal of soot, sulphur and CO_2. It is then mixed with a portion of the process off-gas which has been cooled to remove water vapour and also scrubbed for CO_2 removal. The mixture, before being introduced into the shaft furnace, is heated to about 1,000°C in a gas heater fired by a portion of the process off-gas.

Special Features

In the Purofer process, the main features are as follows:

- The product is discharged and if used as such offers the possibility of saving electrical power for steel making.
- Briquettes produced from hot sponge are very stable.
- Uses regenerative principle for reforming. However, the time lag in switching on and off of reformers causes loss of process gas by about 20/25%.
- Because of high temperature reforming process (1200-1400°C) sulphur level of feed gas even up to 200 ppm does not require any desulphurisation and also there is no restriction on sulphur in feed stock.
- The reformer does not require a large volume of catalyst like other process; sometimes only nickel ceramic pebbles inserted in the joint of refractory bricks are adequate. In case of high sulphur feed gas, some of the refractory bricks are coated with a catalyst.

The hot sponge produced in the Purofer that is generally of 90% and above degree of metallisation with carbon content in the vicinity of 1%.

Appendix-1 (continued)

Plants in Operation and Under Construction

Two commercial Purofer plants were installed during 1976-77, each with a capacity of 330,000 tons Fe per year in Brazil and in Iran. The unit at Brazil (based on the use of heavy oil) is now abandoned and the Iran plant is not in operation. No plants are under construction.

Energy Requirements

From the limited operation of Iran unit, it can be inferred that the average gas consumption is of about 3.1 Gcal and power of the order of 110/120 kWh per ton of sponge iron.

Major Equipment and Facilities

The oxide feed used in this process is in the range of 6.3 to 30 mm. Fines (-6.3 mm) need to be avoided and a screen is provided after the oxide day bins. The reformer system consists of two regenerating which are alternately used for reforming and reheating. The Purofer process employs a refractory-lined shaft furnace of rectangular cross-section (with rounded corners) widening progressively from the top to the bottom to prevent sticking of the charge. The raw materials are fed into the furnace from the top by a double-bell charging system similar to that of a blast furnace. Two scrapper bars provided at the bottom remove the hot reduced product from both sides of the shaft and the hot reduced product is transported in these containers either to the briquetting plant or directly to the steelmaking furnace for hot charging.

Raw Materials

The Purofer process can be operated with either pellets or lump ore. While pellets and sized ores from various other sources have been tested in the pilot plant, commercially, Piezao ore was used in Brazil and Swedish pellets in Iran.

NSC-DR PROCESS

The NSC-DR process was developed by the Nippon Steel Corporation, and a 150,000 tons per year demonstration plant was set up at the Hirohata works of Nippon Steel Corporation in April 1977 which operated intermittently till July 1978 and is since dismantled. Today there is no commercial NSC-DR plant.

Process Description

The NSC-DR process employs a shaft furnace which is operated under high top pressure of about 4 to 6 atmospheres. The oxide material is fed into the shaft furnace from the top by means of a system of a gate valve and gas seals. The material is reduced by the counter-current flow of reducing gas, generated by steam reforming of natural gas.

The natural gas after being desulphurised is mixed with steam which is generated in the heat recovery section of the reformer. The mixture is then catalytically reformed in presence of nickel based catalyst in the reformer tubes. It is reported that NSC-DR proposes use Topsoe reformer. It needs to be mentioned that in the demonstration plant at Hirohata works, reducing gas was generated by cracking heavy fuel oil in Texaco gasification unit. Topsoe reformer was not used for generation of reducing gas for the Hirohata plant. A flowsheet of the NSC-DR process using natural gas as reductant is given in Figure 7. Like the Purofer process, NSC-DR now advocates production of hot sponge. The DRI product is discharged from the furnace through gas-sealed collection hoppers into sealed steel containers. This was also not tried out at Hirohata.

Special Features

The special features of NSC-DR are:

- Feed gas pressure of up to 6 atmospheres.
- Partial use of top gas as recirculated reducing gas in the shaft furnace.
- Addition of soot (unburned carbon) for preventing raw materials clustering.
- Double seal valve system for charging and discharging.
- Hot briquetting of sponge iron (which was not tried out in the pilot plant).

Plant in Operation and Under Construction

At present, there are no commercial NSC-DR units. Currently the Government of Malaysia is considering for setting up a 600,000 tons per year NSC-DR module at Trengannu.

Energy Requirements

The average energy consumption achieved at Hirohata was of the order of 3.5 Gcal per ton of sponge iron, based on use of oil for generation of reducing gas in Texaco reformer.

Major Equipment and Facilities

Material handling system is similar to other shaft furnace processes. For steam reforming Topsoe reformer will be used, which is similar to Pullman-Kellog reformer in principle. The cleaned off-gas is desulphurised, CO_2 washed, reheated (in a heat exchanger) and mixed with the reducing gas before entry into the shaft furnace. The top of the shaft is equipped with a double-lock hopper charging system which is pressurised with inert gas to prevent air infiltration and reducing gas leakage. A table at the bottom of the reduction shaft supports the burden and scraper bars mounted in a gas-tight chamber surrounding the bottom of the shaft, scrap the reduced material off the table and drop it into a conical section that funnels into sealed hot discharge containers through gas-sealed collection hoppers. Briquetting plant for hot briquetting of sponge iron is proposed without the use of binders.

Raw Materials

In the demonstration plant only 5 types of pellets, CVRD, LKAB, Carol lake, Wabush, Samarco and Granges Strassa (Sweden), and 3 types of lump ore CVRD, MBR and Mount Newman were tried out. There are no limitations in the sulphur contents of the ore feed as the recycled top gas is desulphurised during carbondioxide removal by the MEA process before being used in the shaft.

Appendix-1 (continued)

Product Quality

The product quality achieved at the pilot plant generally had a degree of metallisation about 94%. The total carbon content varied between 0.7% and 3.65% depending on the type of oxide feed, operating temperature, gas composition etc.

FIOR PROCESS

The FIOR (Fluid Iron Ore Reduction) process was developed by Esso Research and Engineering Company. A semi-industrial scale demonstration plant was commissioned at the Imperial Oil Enterprises Ltd, Dartmonth, Nova Scotia in October 1965 with a capacity of 300 tons per day and was abandoned in end 1969. The first industrial unit was installed in Venezuela in 1976.

Process Description

The FIOR process uses a reducing gas rich in hydrogen for reduction of iron ore fines in a series of fluidised bed reactors. The hydrogen-rich make-up reducing gas is produced by steam reforming of natural gas over a nickel based catalyst packed into the reformer tubes. The natural gas feed is desulphurised in zinc oxide beds prior to reforming. The reformed gas is then shift-reacted using an iron oxide catalyst where CO and steam react to produce additional hydrogen and carbondioxide. The exit gas from the shift converter is further treated in a CO_2 removal unit where a hot carbonate solution in circulation absorbs the CO_2 and makes the exit gas from this unit rich in hydrogen.

The dried ore fines (-12 mesh) from the dry ore storage bins are discharged into a lock-hopper system and pressurised to the reactor system operating pressure (10 atmospheres at 880°C). The pressurized ore is then metered to the uppermost reactor where it is preheated to the reduction temperature by combustion of natural gas and preheated air, thus removing the L.O.I. and a major portion of moisture in the flue gases. The flue gases are quenched and scrubbed to remove any iron ore fines, and are depressurised before letting off to the atmosphere.

The fluidised and preheated iron ore from the preheat reactor is steam-stripped to remove entrained air, and is introduced into the first of the 3 fluid bed reducing reactors, where it flows downwards by gravity and is reduced by the ascending reducing gas. The process off-gas leaving the uppermost reducing reactor is cooled, scrubbed, compressed and reheated before being reused in the lowermost reactor. The reduced iron ore fines from the lowermost reactor are depressurised through a product let-down system into the briquetter feed drum, operating at atmospheric pressure. The briquetting is done at temperatures over 550°C. The flowsheet for the FIOR process is given in Figure 8.

Special Features

The FIOR process is suitable for use of oxide fines (-4 mesh with maximum 20% by weight - 325 mesh). The DRI product must be agglomerated before use in steelmaking furnaces and the dense FIOR briquettes can be stored and shipped as merchant products without any pretreatment similar to Purofer briquettes.

Plant in Operation and Under Construction

There is only one commercial plant in operation at Matanzas, Venezuela. The annual capacity of the unit is 400,000 tons. The plant produced about 220,000 tons in 1980. No FIOR unit is under construction.

Major Equipment and Facilities

The major equipment required in the FIOR process are:

i) Ore drier, for removal of surface moisture in the ore.

ii) Lock-hoppers, for pressurising the ore feed to the preheat reactor operating pressure.

iii) Preheat reactor, for removing bound moisture and for raising the ore temperature to the reducing reactor temperature.

iv) Three reducing reactors, in series, for reduction of the ore in contact with the counter-current reducing gas.

v) Natural gas reformer and shift converter, for converting natural gas to a hydrogen-rich reducing gas by means of steam and catalysts.

vi) Briquetting machine, consisting of double-roll presses.

vii) Briquette cooler, where the hot briquettes are cooled on a circular grate and passivated with air.

Raw Materials

The ideal feed for the FIOR process is of high-grade natural ore fines which contain less than 5% gangue and can pass through a 4 mesh screen. The size should be such that it contains less than 20% by weight minus 325 mesh material.

Fines and concentrates having more than 20% by weight of minus 325 mesh material are considered too fine for direct use in the FIOR process, but still can be used if semi-agglomeration (size enlargement) is added to the ore preparation circuit. Agglomerated materials used only sufficient strength to withstand and deterioration in the fluidised bed reactors.

Cerro-Bolivar ore fines are used in Venezuela.

Product

The DRI product from the FIOR process before briquetting is in a powdered form containing 24-25 per cent less than 325 mesh. The FIOR briquettes produced in Venezuela plant were generally of metallisation more than 92% with carbon content between 0.5 and 2 per cent. The briquette produced has high density in the range of 5 gm/cc and can be easily stored in open in all weather.

HIB PROCESS

The HIB (High Iron Briquette) process is a modified version of the Nu-Iron process developed by the US Steel Corporation during 1953-56. The first HIB plant was constructed in 1971 at Puerto Ordaz, Venezuela with an annual capacity of 1,000,000 tons of sponge iron.

Process Description

The HIB process is based on reduction of iron ore fines in a fluidized bed with reducing gas generated by steam reforming of desulphurized natural gas. The ore fines of minus 12 mm size are dried in a rotary kiln and then ground to minus 10 mesh (-2 mm). The fine ore is then transported to the first stage of a 2-stage fluidized bed preheating system by an inert gas pneumatic lift.

Appendix-1 (continued)

The first stage preheats the ore with the off-gas from the second stage to about 320°C. The second stage heats the preheated ore to about 870°C by direct combustion of natural gas in the bed.

Reduction of Fe_2O_3 to FeO is accomplished in the first stage by contact with the spent gas from the second stage. Reduction of FeO to Fe is accomplished in the second stage by contact with fresh hot reducing gas introduced at the bottom of the reactor at a pressure of about 4 atmospheres. The hot fine DRI from the reactor at about 700°C is hot briquetted in briquetting machines. The hot briquettes are cooled to approximately 65°C before storing. The flow sheet of HIB process is given in Figure 9.

Special Features

The HIB process, by virtue of its being a fluidized bed process, accepts ore fines as the charge material. Degree of metallisation of the DRI is generally low about 75 per cent and is, therefore, suitable for use in ironmaking.

The HIB briquettes are dense and can be easily stored in open in all weather.

Plant in Operation and Under Construction

The only HIB direct reduction plant in operation is located at Puerto Ordaz, Venezuela. No new plant is reported to be under construction.

Major Equipment and Facilities

The HIB process utilises ore fines and as such raw material handling and preparation system are provided with crushing, grinding, separation and drying facilities. The size of ore fines should be of 10 mesh.

The HIB process employs two stage preheaters for preheating the ore fines to reduction reaction temperature. The reduction reaction is carried out also in a 2-stage reactor, which is a tall refractory lined steel vessel of 6.7 m diameter and 50 m in height.

Appendix-1 (continued)

The reducing gas is generated in a steam reformer, and as such is provided with heat recovery system for generation of steam.

The entire HIB product is to be essentially hot briquetted at about 700°C like FIOR process. The plant at Venezuela is provided with three hot briquetting machines.

Raw Materials

Rich iron ore fines of minus 12 mm size, containing 58.5 per cent Fe and 8 per cent moisture is ground to minus 10 mesh (-2 mm) size to be charged into the fluidized bed reactor.

Product

The HIB briquettes are of following characteristics:

Size, mm	80.9 x 40.6 x 20.0
Weight of briquette, gm	206.3
Density, tons/cu m	5.0
Degree of metallisation	75-80%

A typical chemical analysis of the HIB briquettes produced at Puerto Ordaz are given below:

Fe (total)	86.5%
Fe (metallic)	60.5%
SiO_2	1.83%
Al_2O_3	1.93%
CaO	0.29%
MgO	0.27%
S	0.02%
P	0.13%

SL/RN PROCESS

The SL/RN process was jointly developed by the Steel Company of Canada, Lurgi Chemie, Republic Steel Corporation and the National Lead Company in 1969. It is a combination of the RN process developed between 1920 and 1930 for beneficiation and heat treatment of ores with a low iron content, and the SL process developed about 1960 for production of high-grade sponge iron for steelmaking furnaces.

Process Description

The SL/RN process employs a rotary kiln for the reduction of iron ore/pellet, with solid carbonaceous materials such as coal or lignite. The flowsheet for the SL/RN process is given in Figure 10. There are 2 major steps in the process corresponding to the two major zones of the kiln: the 'preheat zone' where the charge is heated to 900°C - 1,100°C; and the 'metallization zone' where the temperature is held fairly constant at 1,050°C - 1,100°C.

At the start-up of the operation, it is necessary to fire the kiln with the central burner using a fluid fuel, for bringing the charge materials to the reaction temperature. After a steady state is attained, the heat produced by the combustion of a portion of the fuel charged with the burden is sufficient to raise the temperature of the incoming material to the required temperature.

The charge consisting of a mixture of iron oxide pellets and/or lump ore, limestone and/or dolomite and high-volatile coal or lignite are introduced into the preheating zone of the kiln where the moisture is driven off, and H_2 and hydrocarbons are formed by the thermal dissociation of the coal. A portion of the combustible gases from the coal is burned on the freeboard above the charge by controlled quantities of air introduced through air pipes spaced evenly along length of the kiln. The combustion of these gases radiate heat to the surface of the bed of material and to the exposed surface of the kiln refractory lining. During rotation of the kiln, the lining transfers the heat to the solid materials by conduction.

The off-gases from the kiln are drawn out at 900°C - 1,000°C at outlet end. These are passed through a coarse dust settling chamber, and then into an after-burner where the combustible gases and then the soot are burned. The gas is then cooled, cleaned before exhausting it to the stack.

The hot kiln discharge about 1,000°C is then fed directly through an enclosed chute into a rotary cooler which is externally cooled with water sprays. The discharge from the cooler is subjected to screening and magnetic separation, to obtain sponge iron, char and rejects containing ash and calcined flux. A flowsheet for rotary kiln process is given in Figure 10.

Special Features

In SL/RN process, generally the kiln is long and as such the maintenance of temperature profile is not easily achieved. The performance of the kiln is extremely sensitive to type of oxide feed. SL/RN kiln is operated at high temperature. The product is of lower carbon (of the order of 0.2%) and of high metallisation at about 1,100°C.

The proportion of fines in the metallised product from the reduction kiln would depend upon the nature of raw materials used, especially the decrepitating characteristics of the lump ore. In general, the proportion of fines generated in the rotary kiln processes for production of sponge iron is about 100 - 150 kg per ton of product (about 10 per cent to 15 per cent.

Plants in Operation and Under Construction

At present there are six SL/RN plants for production of steelmaking grade sponge iron as given in Table 1-3 on the next page of which two are shutdown. The unit sizes vary widely from 30,000 to 360,000 tons per year, the operating experience is limited to 125,000 ton units. The production in 1980 was about 233,000 tons from an installed capacity of about 750,000 tons.

Appendix-1 (continued)

TABLE 1-3 - WORLD-WIDE SL/RN INSTALLATIONS

Country and Company	Installed in	No. of units	Annual capacity Tons
OPERATING/INSTALLED			
Brazil			
Acos Finos Piratini SA Charqueadas, RS ..	1973	1	65,000
Canada			
The Steel Co of Canada Ltd Red Lake, Ontario ..	1975	1	360,000 [a]
India			
Sponge Iron India Ltd Paloncha, Kothagudem, AP ..	1980	1	30,000
New Zealand			
New Zealand Steel Ltd, Glenbrook	1969	1	125,000
Peru			
Empresa Siderurgica del Peru, Chimbote ..	1979	1	100,000
USA			
Hecla Mining, Casa Grande, Arizona	1975	1	65,000 [a]
Total ..		6	745,000

NOTE:
[a] Not being operated

Major Equipment and Facilities

The main unit of the SL/RN process is the refractory-lined rotary kiln ranging in size from 2 m to 6 m in diameter and 50 m to 125 m in length, inclined downwards from the feed end to the discharge end by 2.5 per cent to 3.5 per cent. The kiln can be rotated at a variable speed of 0.3 - 0.9 rpm. The kiln shell is provided with air pipes made of heat resistant steel, spaced evenly along its length for temperature and process control. A central burner is located at the kiln discharge end for supply of air during normal operation and for supply of light fuel during start-up.

The exit gases are handled in a dust settling chamber and then in a 2-stage afterburner before scrubbing and exhausting it to the stack.

The hot kiln discharge is cooled in a horizontal rotary cooler with external water sprays on the upper surface, and the lower surface is immersed in a water trough. The size of the cooler may vary from 2 m to 4 m in diameter and 20 m to 60 m in length, depending on the plant capacity. The cooled material is subjected to screening and then to magnetic separation.

Raw Materials

The principal burden materials from the process are iron ore and/or pellets. Iron sands are used commercially in the plant in New Zealand. Pellets are used in Peru and Brazil and sized ore is used in India.

Semi-bituminous coals and lignite char are being used as reductants in commercial installations. Limestone and dolomite are used as desulphurising agent.

Product

The quality of sponge iron produced at selected commercial SL/RN direct reduction plants is given below:

Company		Degree of metallization Per cent	Carbon content Per cent
New Zealand Steel	..	89 (minimum)	0.60
Acos Finos Piratini	..	91 (minimum)	0.14
Sponge Iron India Ltd	..	90 (average)	0.20

Recent Developments

Recent experiments indicate that if air is admitted through the ports below the bed in the preheat zone when utilizing coals containing more than 15 per cent volatile matter, it will burn some of the gases that would otherwise leave the kiln unburnt and would result in a less waste of energy. It is claimed that the admission of air through such a system may also permit the use of lignite with up to 60 per cent moisture without preliminary drying. The volatile matter in coal is burnt at 300°C - 800°C directly within the charge and transfers the heat of combustion to the raw materials to be preheated. This technique of Submerged Air Injection is expected to improve the efficiency of the process by shortening the preheat time.

In the existing SL/RN kilns in the areas of inserts like air tubes/nozzles, sample ports and thermocouples, castables are used as refractory lining. Modern kilns to be installed would incorporate 100 per cent castable linings.

CODIR (KRUPP) PROCESS

The CODIR (Coal-Ore-Direct-Iron-Reduction) process was developed from the Krupp-Renn process, and the only commercial installation till date started operating at the Dunswart Iron and Steelworks Ltd., Benoni (South Africa) since 1973 with an annual capacity of 150,000 tons of DRI. This process is very similar in equipment features and operational characteristics to SL/RN rotary kiln process, except some minor variations in the hardware. No CODIR kiln for the production of sponge iron for steelmaking is either in construction or planned.

ACCAR PROCESS

The ACCAR (Allis Chalmers Controlled Atmosphere Reduction) process was developed by the Allis Chalmers Corporation, USA and a demonstration plant of 50,000 tons per year capacity was installed by Niagara Metals Ltd, Canada in 1973 at its Niagara falls works.

Process Description

The ACCAR process employs a rotary kiln with ports for production of DRI. It provides a preheat stage in the unported zone and an active stage in the ported reduction zone. The ore and coal are screened to a uniform size range, and delivered to the reactor at a controlled rate. The incoming bed of ore and coal is heated by counterflow process gases to about 1,000°C. Fluid hydrocarbon fuel is injected into the ore through radial ports situated under the bed. Intimate contact with the hot charge causes the fuels to gasify and dissociate into reducing components which extract oxygen from the ore. As the ports pass over the bed, they admit air to combine with the reducing gases leaving the charge. The resultant product discharges from the reactor into an unlined rotary drum cooler where it is cooled to about 90°C with external water sprays and fed to the product system. The reduced product is then magnetically cleared of coal ash, screened and delivered to storage. Process off-gases are quenched and scrubbed before releasing to the atmosphere through a stack.

Special Features

The rotary kiln is provided with fuel as well as air injection ports, thus offering the advantage of recovering the thermal value of excess reducing gas enabling close control of the temperature profile of the rotary kiln. The air and fuel injection ports are situated beyond the preheating zone.

Retention dams are provided for maintaining a desired bed depth in the reduction kiln. Carbon of the product can be increased up to 2.5% by adjusting the air to fuel ratio along the length of the kiln.

The process so far was operated industrially with hydrocarbon fuel. Very limited campaign was made with coal firing in the demonstration plant at Niagara falls.

Plants in Operation and Under Construction

In 1976, the SL/RN kiln at Falconbridge was converted to ACCAR but was operated only for a limited period and finally shut down in 1978. In India a 150,000 ton capacity ACCAR kiln is under construction and is expected to be commissioned very soon. This kiln is designed to be operated with 100% coal charge.

Energy requirements

From the operation of the demonstration plant at Niagara falls, it may be said that with coal and oil the energy consumption was of the order of 3 Gcal per ton of sponge.

Appendix-1 (continued)

Major Equipment

The major facilities are basically same as other rotary kiln plants.

Raw Materials

The requirement of physico-chemical characteristics of oxide feed and coal are essentially same as in other rotary kiln processes.

Product

Carbon content in the ACCAR iron is adjustable to specified levels between 0.01 - 3 per cent by adjusting temperatures, fuel input and fuel distribution in the reactor. Other characteristics of ACCAR iron are similar to the produce obtained in SL/RN or CODIR. ACCAR iron is stable in storage and during transportation by ship, barge, rail or truck.

DRC PROCESS

The DRC process was developed by the Direct Reduction Corporation, U.S.A. from a method of processing ilmenite concentrate to obtain DRI. A demonstration plant of 50,000 tons per year capacity based on the DRC process went into operation at Rockwood, Tennessee, USA.in 1978. Recently in March 1981, DRC has been awarded a contract for installing a 75,000 tons per year plant at Scaw Metals Ltd., South Africa, which is expected to go into operation in 1983.

Like the CODIR process, the equipment features and the operational characteristics of the DRC process are similar to the SL/RN rotary kiln process. However, there is one significant variation - the DRC kiln is fatter and is provided with more number of air fans compared to other rotary kilns.

KINGLOR-METOR PROCESS

The Kinglor-Metor process was developed by Danieli and Company S.p.A. at Butrio. A pilot plant of 20,000 tons capacity was set up in 1973.

Process Description

The process utilizes vertical shaft furnaces made of silicon carbide which are heated from the exterior by gaseous or liquid fuels. Weighed batches of lump ore or pellets are mixed with approximate amounts of reductant (fine coal and char) and lime-stone, and charged into the top of the shaft through a feed bin. The charge is raised to a temperature of 350°C in the preheating zone at the top of the shaft. The reduction section is heated by the combustion of natural gas (or oil) in the burners located in several rows of the annular space between the silicon carbide shaft and the outer shell to a controlled temperature of 1,050°C. The process is continuous, but the product is discharged in batches due to the cooling system design. The product is discharged from the cooling section at about 50°C and is screened, if required. The DRI is magnetically separated and the char is recycled.

Special Features

Can be installed in modular concept of 20,000 tons of sponge iron per year from each module.

Requires a considerable quantity of oil or natural gas for heating the retorts from outside. The average consumption of LPG in the pilot plant at Buttrio was 134 kg/hr.

Requires more maintenance and the operating cost of the small modular concept plant is invariably much higher compared to the continuous process like rotary kilns.

Plants in Operation and Under Construction

The first commercial plant based on this process went into operation in 1976 at the Ferriere Arvedi and Company S.p.A., Cremona (Italy) with an annual capacity of 40,000 tons consisting of 2 modules of 20,000 tons capacity each. At present these units are abandoned and offered for sale. It is reported that one module of 20,000 tons annual capacity has already been commissioned in Burma. Another module of 20,000 tons is also being planned to be set up at the same location in Burma.

Appendix-1 (continued)

Major Equipment and Facilities

The Kinglor-Metor process employs a retort in which the reduction section is a vertical rectangular shaft made of silicon carbide with 6 reactors. The shaft tapers outwards at the bottom. The shaft is surrounded by a refractory-lined steel furnace, slightly larger, but following the same contour as that of the shaft and thereby providing an annular space which is used as a combustion chamber. The heat provided by radiant burners in the annular chamber is transmitted to the charge through the silicon carbide walls of the shaft.

The upper section of the shaft, which is the preheating zone, is made of refractory steel. Inert gas from the reduction zone is cooled and cycled through the cooling section, located below the reduction zone. The DRI product is discharged through a lock hopper for screening and magnetic separation, and the char is recycled.

Raw Materials

The Kinglor-Metor process uses screened lump ore, iron ore pellets or briquettes in the size range of 6 - 25 mm coal and recycled char are employed as reductant, and if necessary, limestone is used desulphurizing agent.

Product

From the operation of demonstration plant, it is observed that DRI product has an average metallization of 90 per cent and the carbon content of the order of 1%.

APPENDIX - 2

DR PROCESS - ENVIRONMENTAL POLLUTION AND THEIR TREATMENT(66) to (75)

Process	Type of pollutant	Source of generation	Details of pollutants	Method of treatment	Level prior to treatment	Level after treatment	Remarks
A. GAS BASED							
HyL	Ore/pellet dust	Discharge to pellet silos Discharge to reactors Conveyors and junction houses for handling of ore/pellets	Dust particle size distribution (Wt %): Range (in microns) / DRI pellets / Iron oxide pellets Less than 2.8 to 5.5 .. 41.0 / 28.8 5.5 to 11.0 .. 24.0 / 22.2 11.0 to 22.0 .. 22.0 / 25.9 22.0 to 44.0 .. 9.0 / 18.1 44.0 to 62.0 .. 1.5 / 5.0 62.0 to 176.0 2.5 / - 100.0 / 100.0	Dust extraction system with bag filters and cyclone separators			
	Ore/pellet dust with process gases causing water pollution	Reactors; Reformers	Size distribution of solids in the effluent from the reactor (Wt. %): Range (in microns) / Wt. % Less than 44 .. 65.0 44 to 105 .. 8.1 105 to 149 .. 5.5 Above 149 .. 21.4 100.0	Direct water sprays in the reformer and reactors quench towers. The pollutants are passed off to water circuit and recirculated in the plant with clarifier	Water analysis of boiler blow down: Phosphates .. 30 ppm pH .. 10.5 T.D.S .. 1,500 ppm SiO_2 .. 25 ppm Chlorides .. 50-150 ppm Quantity .. 1.5 cu m/hr	This water may be neutralised with HCl or other acids and then mixed with 3.7 cu m/hr of BFW treatment plant bleed off which is considered neutral. This effluent is, therefore, not considered to be a pollutant and may be collected in the industrial or sanitary sewers without any further treatment	The iron ore fines collected in the sewer contain Fe_2O_3, Fe_3C and gangue. The cake also contains Fe, FeO, Fe_3C and gangue. Both these effluents may be sent to a pelletizing or sintering, or can be sold to the cement industries
	Zinc oxide and sulphur	Desulphurizers		Removed from the desulphurizers in every two years (approx 10 tons of zinc oxide)			Zinc oxide and sulphur may be sent to catalyst manufacturers for its regeneration
	Steam	Process	Quantity very low	Let off to the atmosphere			
	Carbon-dioxide	Reducing gas	Not very hazardous from the hygenic point of view	Carried away along with the water spray in the scrubbers	Approx. 7 per cent		Presence of CO_2 lowers the pH value in the water circuits. 250 ppm of CO_2 in the water at the direct reduction plant at SIDOR resulted in the lowering the pH value to 3.5 from the normal level of 7

<table>
<tr><th>Process</th><th>Type of pollutant</th><th>Source of generation</th><th>Details of pollutants</th><th>Method of treatment</th></tr>
<tr><td colspan="5">A. GAS BASED (Cont'd)</td></tr>
<tr><td></td><td>Noise</td><td>All major equipment such as belt conveyors, scrubbers, reactors, reformers etc and pipelines</td><td></td><td>Enclosing the noise generating equipment in housings and casings, and by insulation of pipelines</td></tr>
<tr><td>MIDREX</td><td>Exhaust gases</td><td>Shaft furnace, stack, screening station, silos, transfer points</td><td>About 3,000 N cu m/ton of Fe at 400°C containing 12.9% CO2, 4% O2, 65.7% N2, 17.4% H2O (NOx+S - nil). Dust content is about 4 mg/N cu m (12 gms/ton of Fe)</td><td>Wet scrubbing is employed for all waste gases. The waste gas from the plant stack does not need any further cleaning. Scrubbers are located at exit of reduction furnace, screening stations and product silos</td></tr>
<tr><td></td><td>Particulate emission</td><td>Stack, dust collection systems, storage and load-out collection system, screening dust collection system</td><td>For a 400,000 tons/yr module, the particulate emissions for between 3-5 kg/hour

Point source emissions to the air (kg/ton DRI):
<table>
<tr><th></th><th>Particulates</th><th>SO2</th><th>NOx</th></tr>
<tr><td>Material handling</td><td>0.001</td><td>0.001</td><td>0.002</td></tr>
<tr><td>Combustion system</td><td>0.012</td><td>0.035</td><td>0.172</td></tr>
<tr><td>Dust collection system</td><td>0.016</td><td>Trace</td><td>0.001</td></tr>
</table></td><td>Dedusting systems</td></tr>
<tr><td></td><td>Waste water</td><td>Surface water; sanitary water; industrial waste water</td><td>Depending on the cooling water arrangement:
<table>
<tr><td>Avg. clarifire water</td><td>0.9 cu m/t of Fe</td></tr>
<tr><td>Avg. suspended solids in effluent water</td><td>50-150 mg per litre</td></tr>
<tr><td>Solids from clarifier</td><td>40-70 kg/t of Fe</td></tr>
</table>
Point source emissions to water:
<table>
<tr><th></th><th>Suspended solids mg/lit</th><th>Flow cu m/t DRI</th></tr>
<tr><td>Process water blow down</td><td>50</td><td>0.15</td></tr>
<tr><td>Clarifier blow down</td><td>100x10³</td><td>0.26</td></tr>
<tr><td>Effluent from plant</td><td>15</td><td>0.5-0.6</td></tr>
</table></td><td>Surface water cleaned by rail buffer bin, sand filter and back-washing rank; sanitary water cleaned by a biological sewage treatment before being discharged to the main waste water pipe station; industrial waste water is cleaned by an automatic gravity filter</td></tr>
</table>

Level prior to treatment		Level after treatment		Remarks
		85 dB (A) maximum		
	Dust gms/Nm³		Dust mgms/Nm³	Investment costs for waste gas cleaning for a plant of 880,000 tons/yr is DM 3.32 million
Shaft furnace ..	100	Shaft furnace	50	
Stack ..	15	Stack ..	15	
Screening station	30	Screening station	50	
Silos ..	30	Silos ..	50	
Transfer points	30	Transfer points	50	
			kg/hr	Dedusting systems are designed in order to limit dust emissions to atmosphere at 150 mgs/N cu m under normal operating conditions
		Stack ..	0.5	
		Dust collection systems ..	2.5	
		Storage and load-out collection systems ..	1.0	
		Screening dust collection systems ..	1.0	
Surface water	Max.400 mgs/litre solids	Surface water	5 mgs/litre solids	Investment costs for a plant of 880,000 tons/yr is DM 1.6 million
Sanitary water	Biological waste	Sanitary water	BSB5 25 mgs/litre	Slurry of iron oxide collected in the dust collecting system is dewatered and then either sold or agglomerated and used as feedstock
Industrial waste water	50 mgs/litre solids	Industrial waste water	5 mgs/litre solids	

Process	Type of pollutant	Source of generation	Details of pollutants	Method of treatment
A. GAS BASED (Cont'd)				
	Noise	Conveyors, scrubbers, feeders, fans, compressors, reformer, screening station, pumps, air stations		Providing housings on conveyors; noise protection hoods, and buildings on machinery; insulation of pipework
NSC-DR	Solids	Top gas; pressure equalizing gas; raw materials screen		Wet scrubbers
	Water	Scrubbing water		Thickener
		Boiler water from the demineralizer and the boiler drum		Neutralization

Level prior to treatment		Level after treatment		Remarks
Without casing or housing		Inside housing		The noise levels outside the housing are approx. 20 dB (A) lower
Belt conveyors	74 dB (A)	Natural gas reducing station	104 dB (A)	
Wet dedusting	97-99 dB(A)	Briquetting plant	94 dB (A)	
Vibrating feeders	100 dB (A)	Screening station	88-96 dB(A)	
Waste gas fan	110 dB (A)	Process gas and cooling gas section	106 dB (A)	
Main air fan	133 dB (A)	Pump station	98 dB (A)	
Process and cooling gas compressors	130 dB (A)	Main air station	105 dB (A)	
		Instrument air station	99 dB (A)	
		With casing		
		Vibrating feeders	91 dB (A)	
		Waste gas fan	100 dB (A)	
	gms/Nm^3		gms/Nm^3	Main pollutants are the solids contained the top gas. This gas should be inevitably be scrubbed basically for reuse/recirculation, and not for pollution control
Top gas ..	5	Top gas ..	0.01	
Pressure equalizing gas ..	5	Pressure equalizing gas ..	0.10	
Raw materials screen ..	5	Raw materials screen ..	0.10	
1,000 ppm (average)		100 ppm		Solids transferred from the top gas to the scrubbing water should be removed for recirculation of the water. In this sense, investment for facilities such as the top gas scrubber or the thickness for scrubbing water are considered as requirements for the main direct reduction process and not for pollution control. Therefore, magnitude of investment for the pollution control facilities is not large
pH 6-11		pH 7		

Process	Type of pollutant	Source of generation	Details of pollutants	Particulate type
A. GAS BASED (Cont'd)				
	Noise	Gas recirculation compressor		
PIOR	Particulate emissions	Ore drier, ore crushing, ore storage and feed system, ore feed lock hopper, preheat reactor, let-down scrubber, quench-drum scrubber, briquetter ventilation and briquetter cooler	Ore drier, ore crushing, ore storage and feed system, ore feed lock hopper, preheat reactor	Iron oxide
			Let-down scrubber, quench-drum scrubber, briquetter ventilation and cooler	Reduced iron
ARMCO	Exhaust gases	Shaft furnace, stack, screening station, product silos, transfer points	About 3,200 N cu m/t of Fe. The gas contains no NOx or S. Dust content is about 30 mg/N cu m (100 gms/ton of Fe)	
	Waste water	Mostly from scrubbers	Scrubbing water	

Method of treatment	Level prior to treatment	Level after treatment	Remarks
Installation of silencer and/or sound proof covers	100-105 dB (A)	85-95 dB (A)	
All these particulate effluents are processed through cyclones and/or wet scrubbers. A closed circuit water system utilizing settling ponds services and the wet scrubbers		Source — Particulate loading gms/Nm3 Ore drier .. 0.7068 Ore crushing 0.28272 Ore storage and feed system .. 0.28272 Ore feed lock hopper 0.28272 Reheat reactor 0.7068 Let-down scrubber .. 0.7068 Quench-drum scrubber .. 0.7068 Briquetter ventilation 0.7068 Briquetter cooler .. 0.7068 5.08896	The levels of discharge emission fall well below typical environmental limits such as those in force in the United States. To achieve these levels, low capital cost equipment is utilized, such as wet scrubbers and cyclones
Venturi scrubber		30 mg/N cu m of dust (100 gms/ton of Fe)	Based on published information
Clarifier		Avg. clarifier water 1 cu m/ton of Fe Avg. suspended solids in effluent water 93 mg/litre	

Process	Type of pollutant	Source of generation	Details of pollutants	Method of treatment
B. COAL BASED				
SL-RN	Dust	Handling of raw materials (iron oxide, coal and limestone, dolomite); handling of products (char, iron fines, dolochar); dust in dry condition separated from waste gas	Under conditions of FRG, the dust load should be limited to 8 mg/cu m. Operating data on SIIL indicate generation of 0.2-0.3 ton of sludge per ton of DRI produced. The sludge (pH 9-11) from the dedusting system contains 0.07 to 0.11 gms/litre of suspended solids	Inplant dedusting system installed in each plant to which all transfer points and specially dust producing machinery are connected. Separation of dust from the air stream can be effected by scrubbing, electrostatic precipitation, baghouses or multicyclones, depending on the environmental regulations or available funds for investment
	Waste gases	Rotary kiln	Should be maximum 150 mg dust/cu m at the stack. Temperature of flue gas about 70°C. Analysis of the flue gas CO_2 - 28%, O_2 - 2.84%, N_2 - 67.74%. Generates about 0.6 ton of sludge per ton of DRI produced.	Treatment of solid and gaseous combustibles by oxidation under controlled conditions, cooling and separation of dusts in several consecutive steps. Gas cleaning after cooling by similar equipment as for inplant dedusting needs to be designed at a higher operating temperature level
	Waste water	Dedusting and waste gas systems; cooler	Dust and waste gases generated as above. About 2.25 cu m of water per ton of DRI produced is consumed at SIIL	Thickener; neutralisation
	Noise	All major equipment		Silencer and/or sound proof covers

Level prior to treatment	Level after treatment	Remarks
	Sludge contains 0.07 to 0.11 gms/litre of suspended solids at the kiln operating at SIIL (India). Under German conditions, limited to 8 mg/cu m	Separated dust is dumped either in the form of slurry or a paste, depending on the equipment choosen. The amount of waste material generated depends on type of plant and the reductant used. If the ash content is high, all the dust and non-magnetic product generated can be considered as waste material
Analysis of sludge (%): Fe (t) .. 18-24 Fe2O3 .. 28-34 CaO .. 15-62 SiO2 .. 32-34 Al2O3 .. 12-14 L.O.I .. 6-7	Accepted level is 150 mg/cu m	Cost of operation of dedusting and waste gas systems at SIIL is about Rs 30 per ton of DRI Sulphur is washed down by water to a certain extent
pH value of waste gas system sludge before neutralization - 2.3 - 4.5	pH value after neutralization .. 5-7 Solid content of waste gas system sludge disposal: Suspended solids gms/litre Clarified water .. 0.14-0.39 Sealed water 1.97-2.74	Investment cost of dedusting and waste gas cleaning system is about 10 per cent of the total investment for mechanical and electrical equipment
125 dB (A)	108 dB (A)	

Process	Type of pollutant	Source of generation	Details of pollutants	Method of treatment	Level prior to treatment	Level after treatment	Remarks
B. COAL BASED (Cont'd)							
CODIR	Dust	Material screening equipment and transfer points of material transportation system	Dust of ore, coal, dolomite, sponge iron and ash developed during material handling. The air in,rese-velocity of extraction points about 1 m per second	Dust developed during material handling is extracted at numerous locations of the plant by means of fans which draw dust-bearing atmosphere through bag filters. The dust collected in filters and respective bins is either discharged in dry status into tankers or moistened in screws before being discharged into transportable containers	Amount of ash and dust generated per ton of DRI (Dry): Ash - 85 kg/ton DRI Dust in waste gas filter - 110 kg/ton DRI Dust in other dedusting equipment - 2 kg/ton DRI About 50-60 gm/N cu m with a composition of: F.C. - 24-30% V.M. - 3-6% Ash - 65-75% Fe - 40% Size distribution of the dust (in microns): Less than 10 - 20% 10-30 - 25% 30-100 - 25% More than 100 - 30%	About 50-150 mg/N cu m with the following size distribution (in microns): Less than 10 - 27% 10-30 - 56% 30-50 - 14% More than 50 - 9%	Magnitude of investment for pollution control facilities normally installed ranges between 8-10 per cent of the total investment costs
	Waste gas	Kiln	Contain hydrocarbon compounds, carbon and coal dust	Waste gas from kiln process dust settling chamber is afterburnt for combusting the hydrocarbon compounds, carbon monoxide and coal dust. After cooling either in waster heat boilers, by water-spraying of the gas, in bag filters or by electrostatic precipitators. Dust precipitated in filters is either discharged in dry status into tankers or moistened in screws before being discharged into transportable containers	About 2,750 N cu m/ton Fe (dry). Gas composition as follows: CO_2 - 25-26% CO - 0.5-0.8% O_2 - 0.5-0.8% CH_4 - 0.4% max H_2 - 0.4% max SO_2 - 0.07% max N_2 - Balance Dust in waste gas filter is about 110 kg/ton of DRI. The exhaust gas temperature is of the order of 850°C	About 3,250 N cu m/ton Fe. Clean gas composition is as follows: CO_2 - 20-22% CO - 0.4% O_2 - 4-5% CH_4 - 0.4% max H_2 - 0.4% max SO_2 - 0.06% max N_2 - Balance	
	Waste water	Scrubbing water	Slurry from wet cyclone or wet scrubber	Waste gas of cooling drum is separately extracted, if direct cooling by spray water is applied. Gas passes through wet cyclones or wet scrubbers before being released to the stack. Slurry is discharged into containers for transportation. In case of indirectly cooled rotary coolers, the gas enters the main gas stream of the kiln. No other contaminated water circuit does exist in the plant	Blow-down of open-cooling water circuit for indirectly cooled rotary coolers amounts to 1 cu m/ton of DRI containing about 60-80 mg/litre of suspended solids	Max. 50 mg/N cu m. Slurry from indirectly cooled cooling drum is about 40 kg/ton of DRI with 1 kg of dry substance per ton of DRI	

Process	Type of pollutant	Source of generation	Details of pollutants	Method of treatment
B. COAL BASED (Cont'd)				
	Noise	All major equipment		Silencer and/or soundproof covers
DRC	Dust	Raw material storage and in-plant material handling (at all transfer points)	Fugitive emission	Water spray (wet suppression) for raw materials receiving and outdoor stockpiles; baghouses for plant bins, feeders and transfers
		Product handling, screening and separation	Fugitive emissions - coal ash, carbon and limestone fines; gas volume set depending on the equipment selected	Baghouses
	Waste gas, dust	Kiln off-gas	Gas; the suspended solids comprise coal ash, iron and iron oxide fines, carbon and limestone, the coal friability determines the dust load; the gaseous components are unburned hydrocarbons and condensable hydrocarbons	Method I: Complete afterburning of the unburnt hydrocarbons, direct gas quenching with water up to 250°C, and collection in insulated baghouse Method II: Complete afterburning of hydrocarbons, cooling and heat recovery by waste heat boilers up to 300°C, direct gas quenching with water up to 250°C, and insulated baghouse
	Noise	Kiln off-gas fan, kiln product, general plant grounds		Fan discharge silencers on small baghouses

Appendix-2 (continued)

Level prior to treatment	Level after treatment	Remarks
	Noise levels at: 2 metres from kiln drive - 87 dB (A) Noise emission protected fans (waste gas - 85 dB(A) and shell fans)	
Up to 0.5 per cent of the total plant feed	No visible emission from the baghouses	Installed cost for pollution control facilities is about 22-28 per cent of plant installed cost
About 100-[illegible] kg/ton of DRI	No visible emission	
Solids: 100-200 kg/ton of DRI Unburned hydrocarbons and condensible hydrocarbons up to 2,000 ppm Gas temperature - 150°C Volume - 5.82 Nm^3/kg coal feed	Solids: Less than 50 mg/cu m Gases (treatment by Method II): Less than 250 ppm SO_2 Less than 15 ppm SO_3	Wet scrubbers of electrostatic precipitators could replace baghouses. These devices may, however, prove unreliable and uneconomical in the long-run
	Kiln off-gas fan - 75 dB (A) Kiln product - 80-83 dB(A) General plant grounds - 60-80 dB (A) Average - 75 dB (A)	

APPENDIX - 3

POLLUTION CONTROL FACILITIES AT SPONGE IRON INDIA LTD., INDIA

Waste Gas Treatment System

The waste gas leaving the rotary kiln is subjected to waste gas treatment in the following sequence before releasing the gases to atmosphere through the stack:

- After burning of the gases
- Cooling
- Cleaning

The system is designed for the wet cleaning the gases to a cleanliness of 150 mg/Nm^3.

In the after burning chamber (ABC) all the combustibles are burnt out; hydrogen and CO are converted to CO_2 and S is burnt to SO_2. The temperature of the gases leaving the ABC is controlled by spray of water through the nozzles.

There is an emergency cap on top of ABC which opens automatically if the temperature of gases entering the waste gas cleaning system exceeds 80°C.

The cooling and clearing of waste gases is done in a radial flow scrubber. Cooling is carried out by spraying water through a set of three nozzles located at the top of the scrubber. There is an additional nozzle to provide around 5 cu m/hr water at event of any increase in the gas temperature beyond 70°C. If, however, the temperature of gases goes beyond 80°C, the damper at the inlet of the fan closes and emergency cap opens.

Waste gases cleaning system consist of the following facilities:

- After burning chamber
- Dust removing facilities under ABC (wet scraper conveyor)
- Emergency cap on the stack over ABC

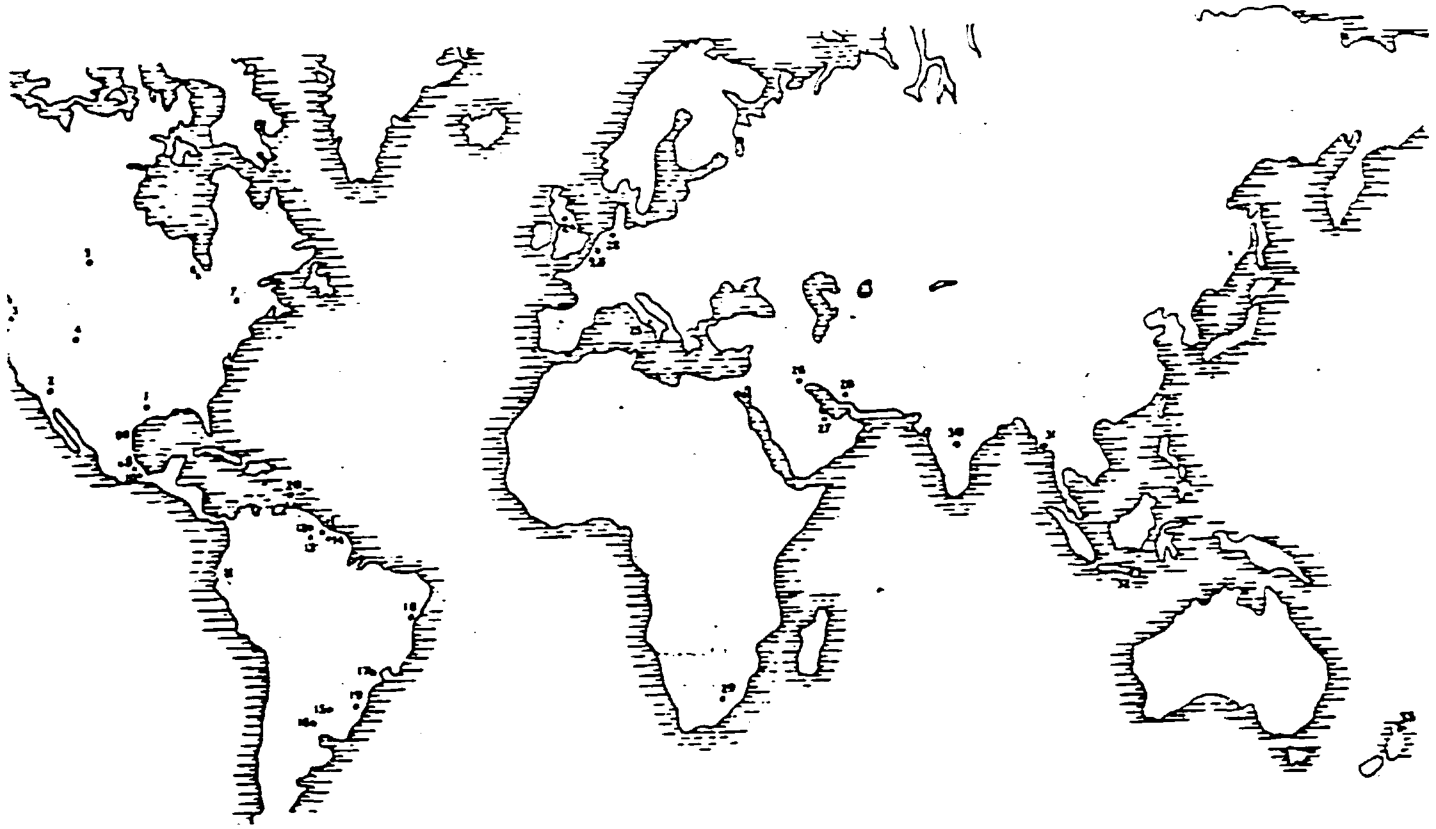
- Radial flow scrubber
- Waste gas fan
- Stack with water cyclone

Water Consumption

The waste gas cleaning system is provided with three water spraying nozzles to spray 100 cu m of water per hour. The underflow water, which is in the form of slurry flows down to a slurry basin - it is then pumped into a thickener. This water is neutralised by lime as it is acidic in nature. Clear water is collected in a tank and recirculated in the system.

De-dusting System

In the raw material preparation plant, the fines generated during crushing and sizing is removed by washing in a scrubber. From the reduction area as well as from the material handling system the dust from the transfer points and the discharge points are connected to the centralised de-dusting system. The dust collected from the various points are separated in a scrubber and discharged in the form of a slurry.



USA

1 ARMCO – HOUSTON
2 MIDREX – GEORGETOWN
3 MIDREX – GILMORE
4 SL/RN – CASA GRANDE

CANADA

5 SL/RN – GRIFFITH MINES
6 ACCAR – SUDBURY
7 MIDREX – CONTRECOEUR

MEXICO

8 HyL – MONTERREY
9 HyL – PUEBLA
10 HyL – VERACRUZ

VENEZUELA

11 FIOR – PUERTO ORDAZ
12 HyL – "
13 MIDREX – "
14 HIB – "

ARGENTINA

15 MIDREX – VILLA CONSTITUTION
16 MIDREX – CAMPANA

BRAZIL

17 PUROFER – GUANABARA
18 HyL – SALVADOR
19 SL/RN – PORTO ALEGRE

TRINIDAD

20 MIDREX – POINT LISAS

PERU

21 SL/RN – CHIMBOTE

WEST GERMANY

22 MIDREX – HAMBURGH
23 MIDREX – EMDEN

UNITED KINGDOM

24 MIDREX – HUNTERSTON

ITALY

25 KINGLOR METOR – CREMONA

IRAQ

26 HyL – BASRAH

QATAR

27 MIDREX – UMM SAID

IRAN

28 PUROFER – AHWAZ

SOUTH AFRICA

29 CODIR – BENONI

INDIA

30 SL/RN – KOTHAGUDEM

BURMA

31 KINGLOR METOR

INDONESIA

32 HyL – CILEGON

NEW ZEALAND

33 SL/RN – GLENBROOK

FIG. 1. MAP OF WORLD SHOWING LOCATIONS OF INSTALLED DR PLANTS

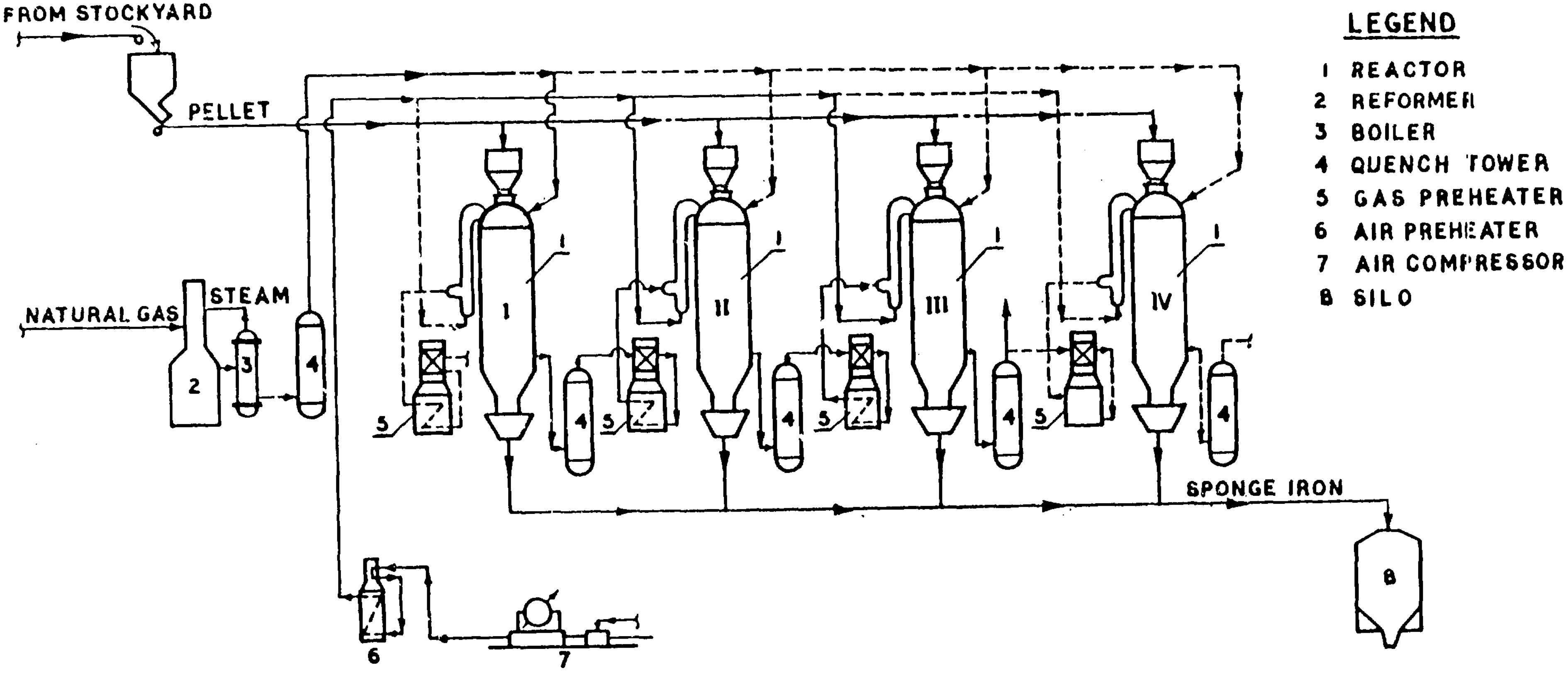


FIG. 2. HyL PROCESS FLOW SHEET

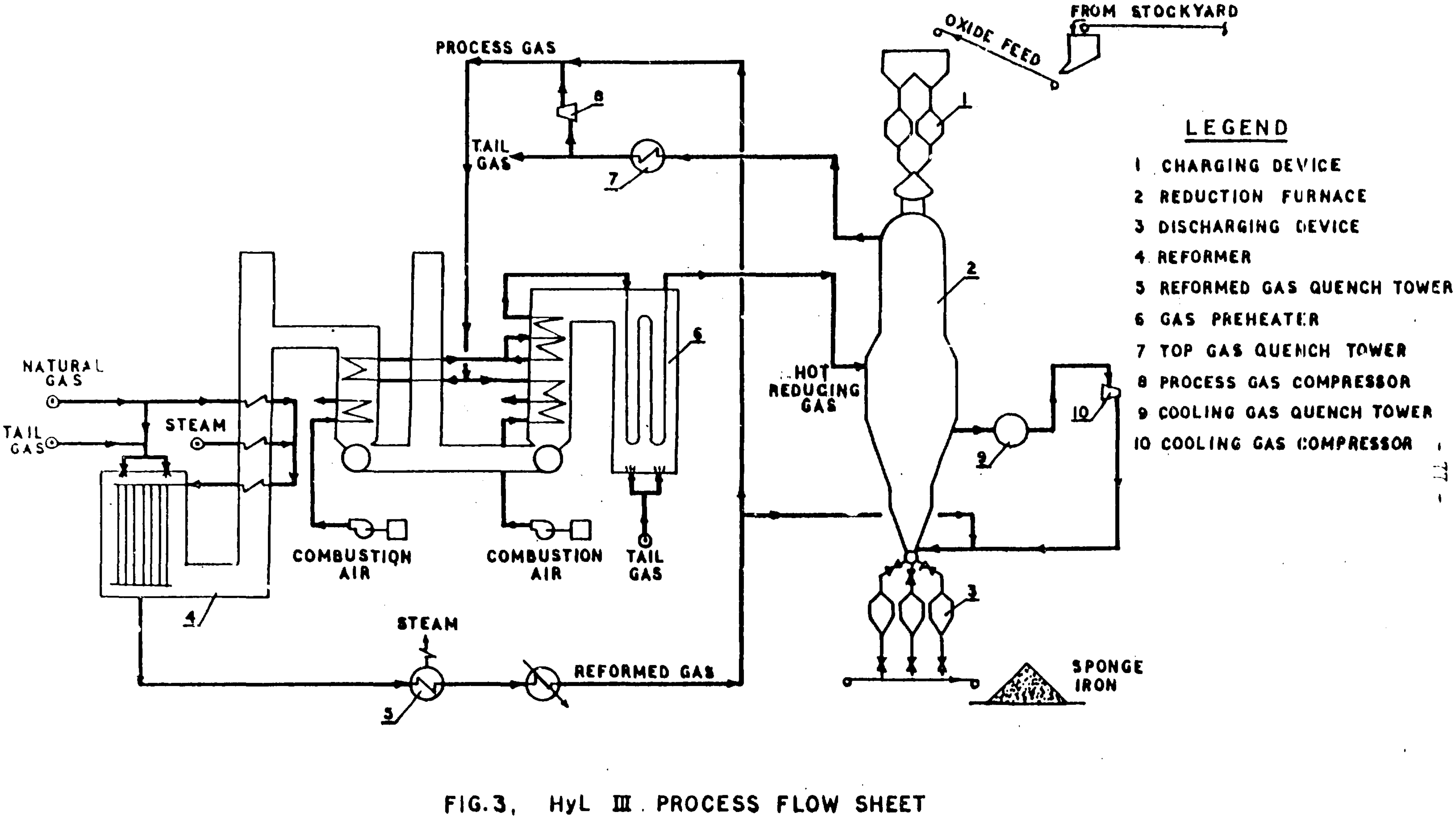


FIG.3, HyL III. PROCESS FLOW SHEET

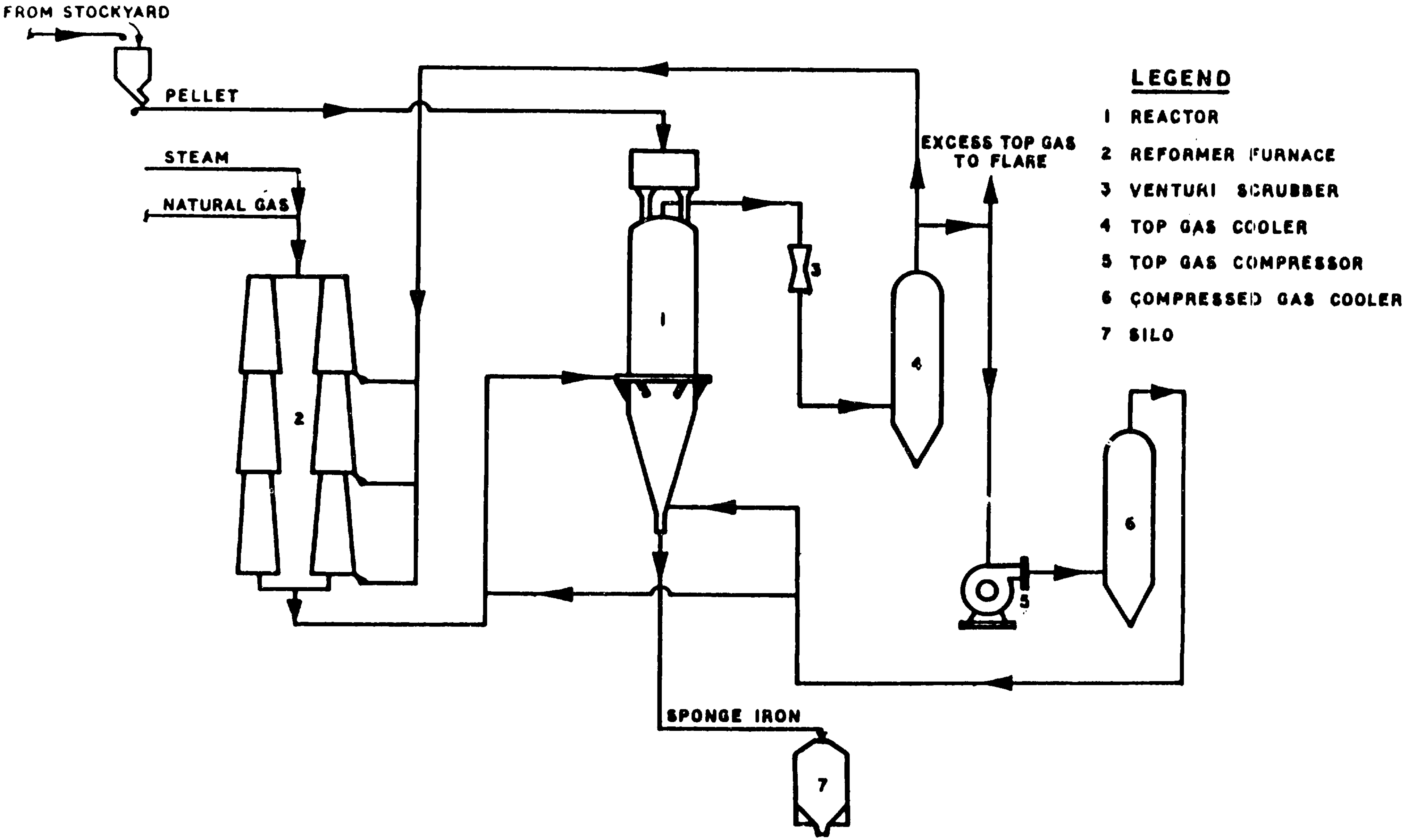
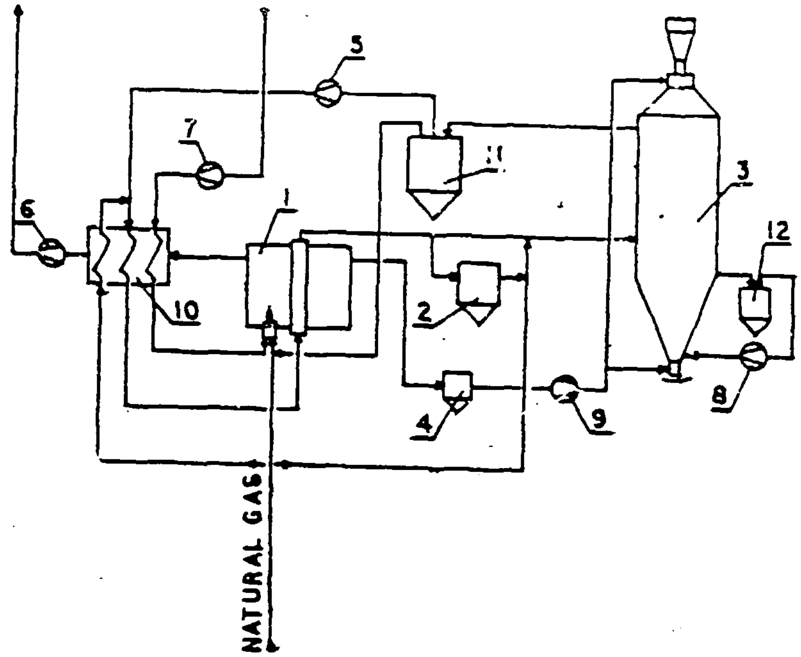


FIG. 4. ARMCO PROCESS FLOW SHEET

STANDARD FLOW SHEET



LEGEND

1 REFORMER
2 REFORMED GAS COOLER
3 REDUCTION FURNACE
4 SEAL GAS COOLER
5 PROCESS GAS COMPRESSOR
6 FLUE GAS FAN
7 MAIN AIR BLOWER
8 COOLING GAS COMPRESSOR
9 SEAL GAS COMPRESSOR
10 RECUPERATOR
11 TOP GAS SCRUBBER
12 COOLING GAS SCRUBBER
13 PROCESS GAS COOLER

ALTERNATE FLOW SHEET

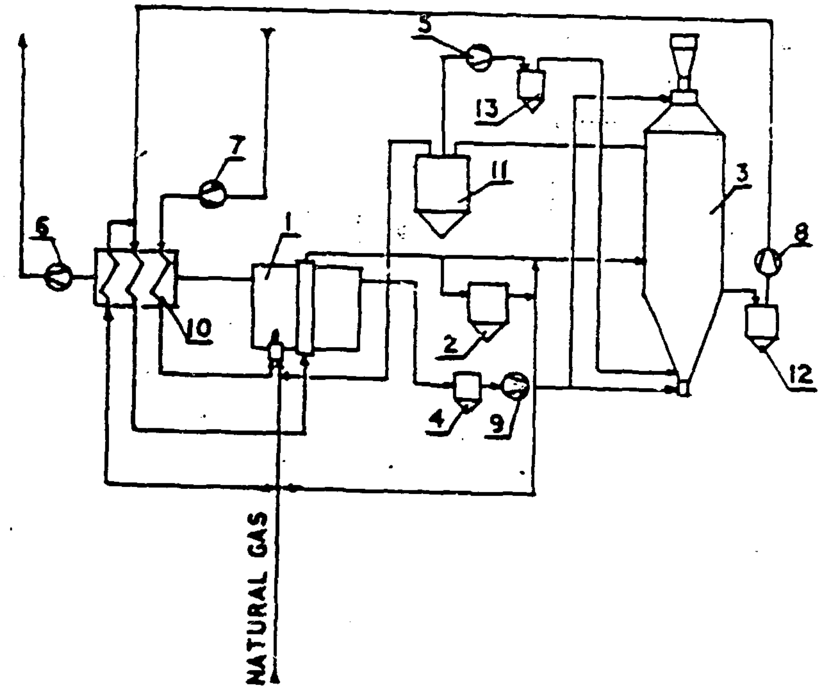
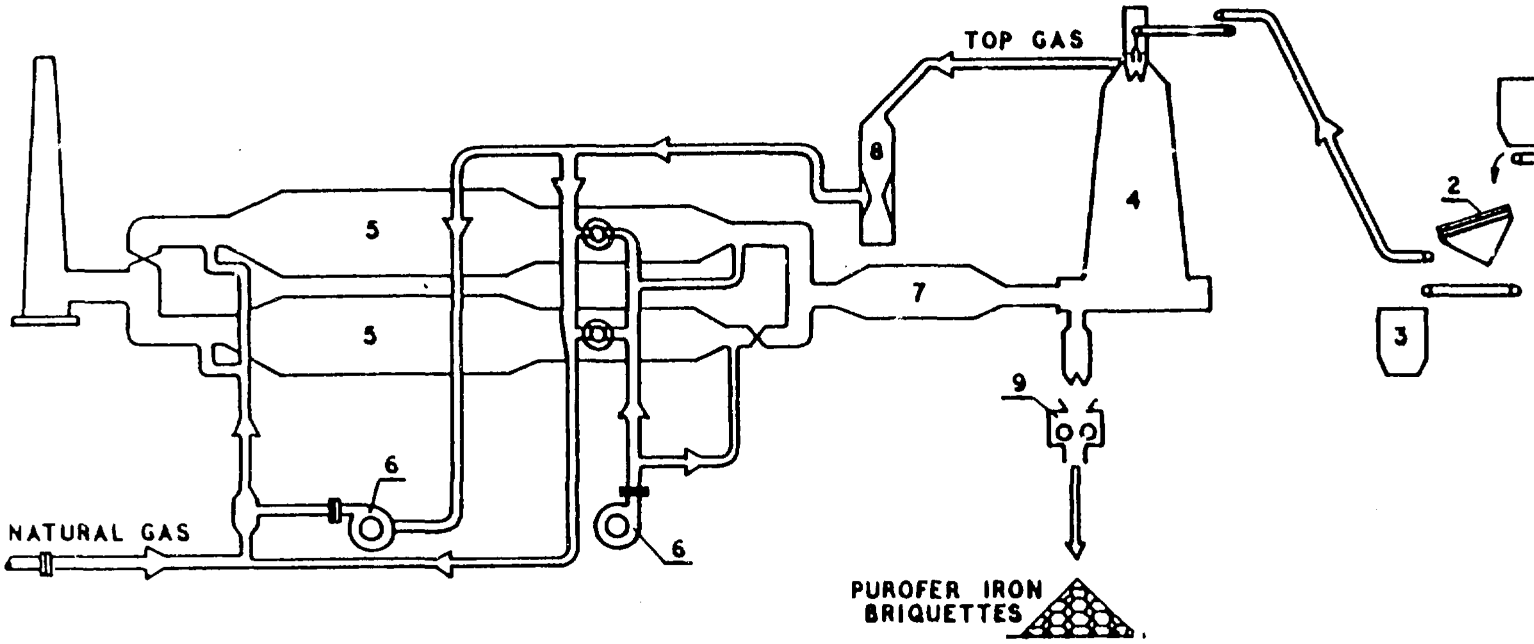


FIG.5. MIDREX PROCESS FLOW SHEETS



LEGEND

1	IRON ORE / PELLET BIN
2	SCREEN
3	FINES BIN
4	SHAFT FURNACE
5	REFORMER
6	COMPRESSOR
7	TEMP. EQUALIZING CHAMBER
8	TOP GAS SCRUBBER
9	BRIQUETTING MACHINE

FIG.6. PUROFER PROCESS FLOW SHEET

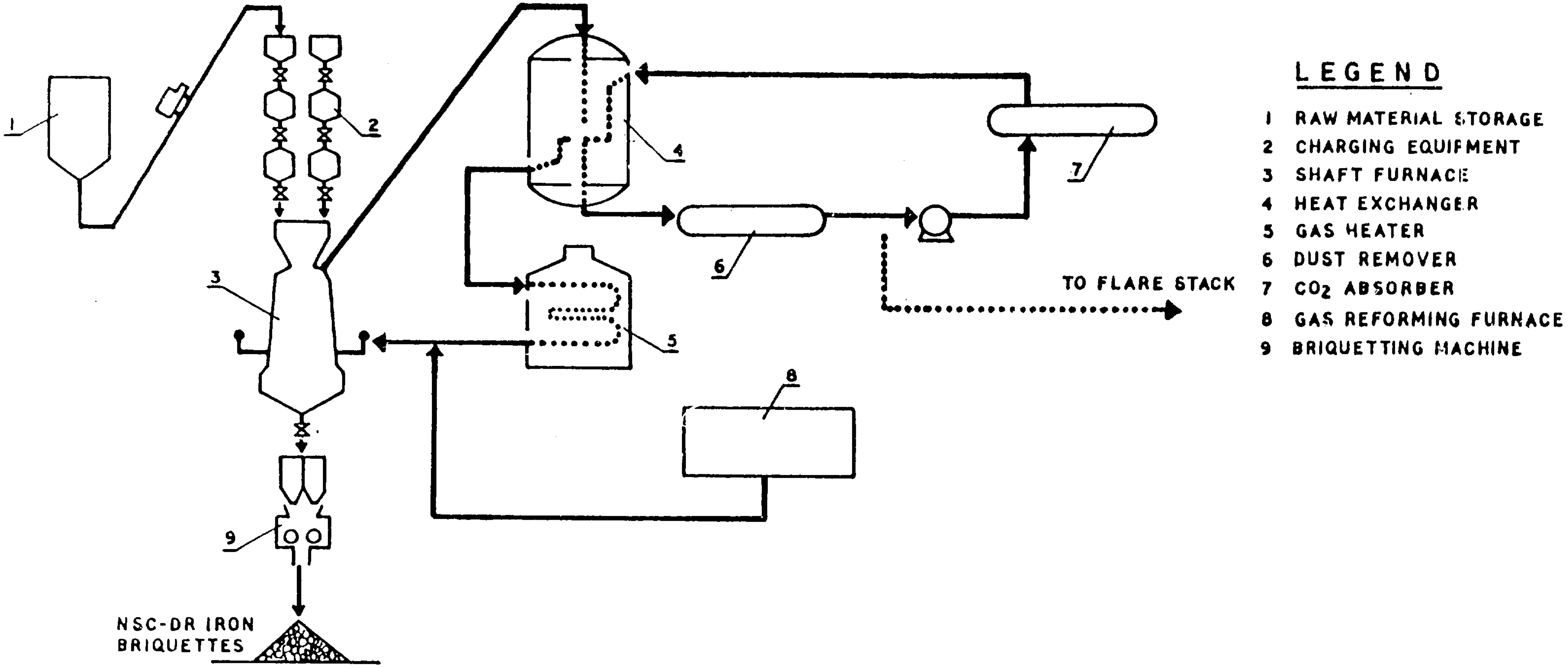


FIG.7. NSC-DR PROCESS FLOW SHEET

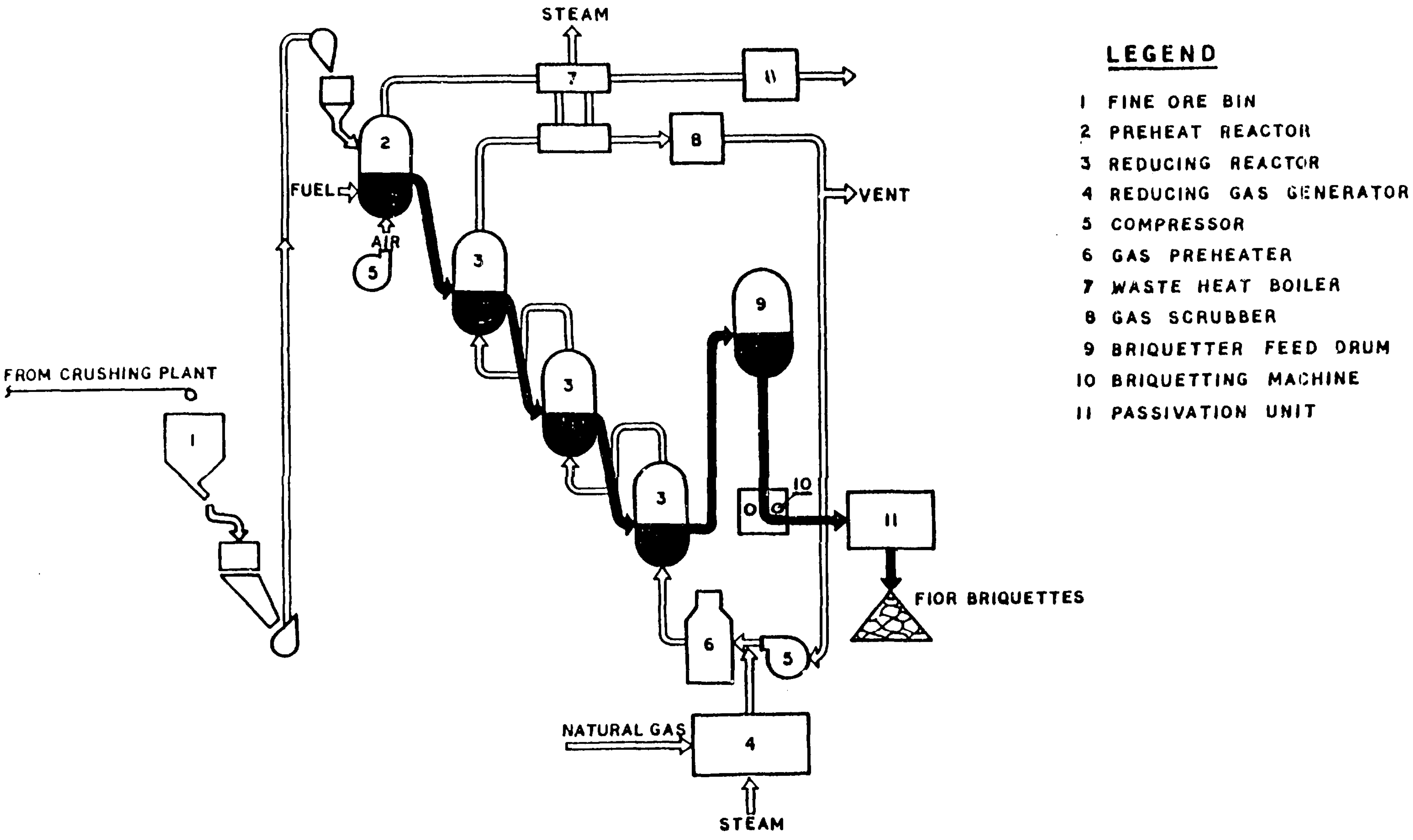


FIG. 8. FIOR PROCESS FLOW SHEET

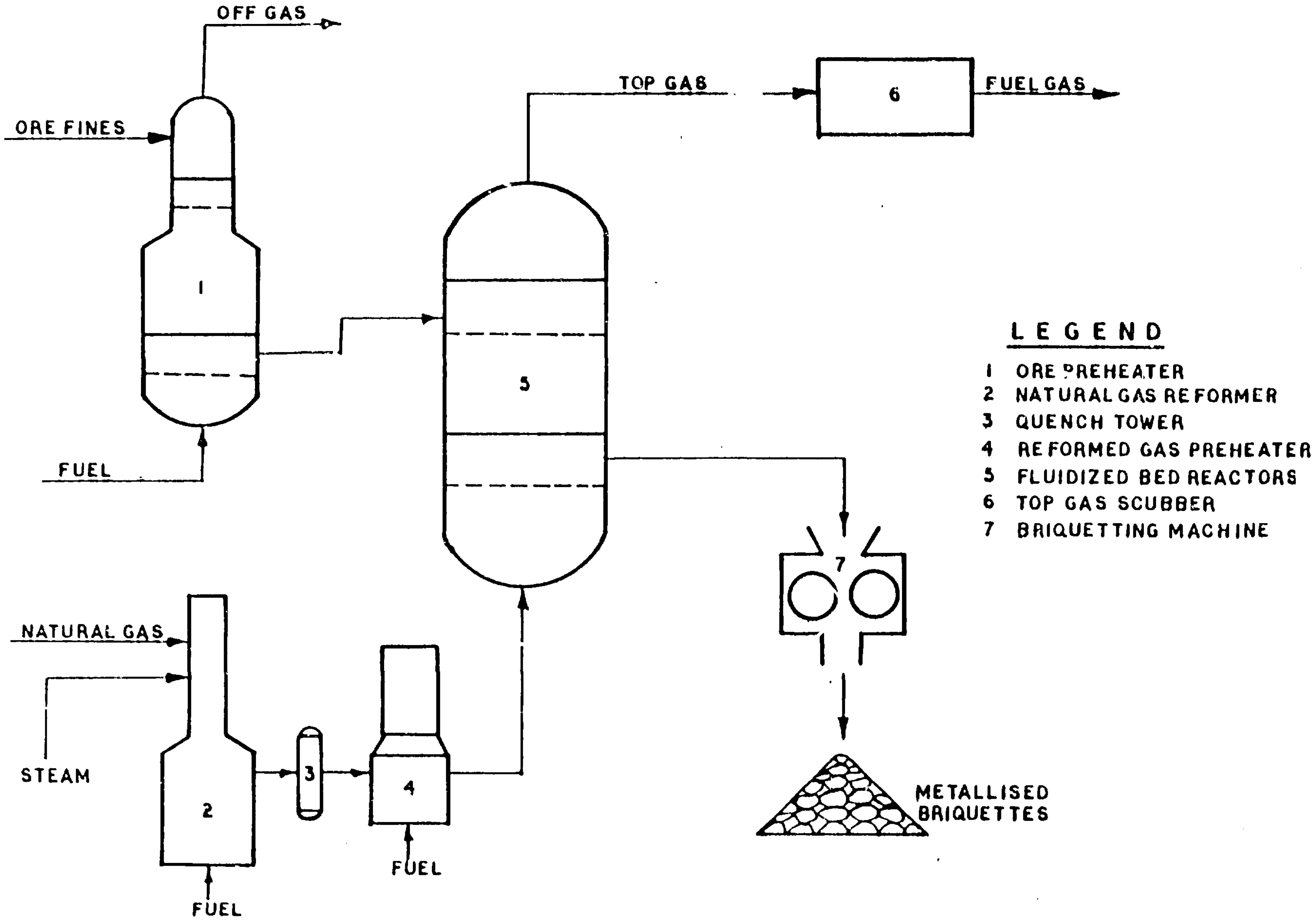
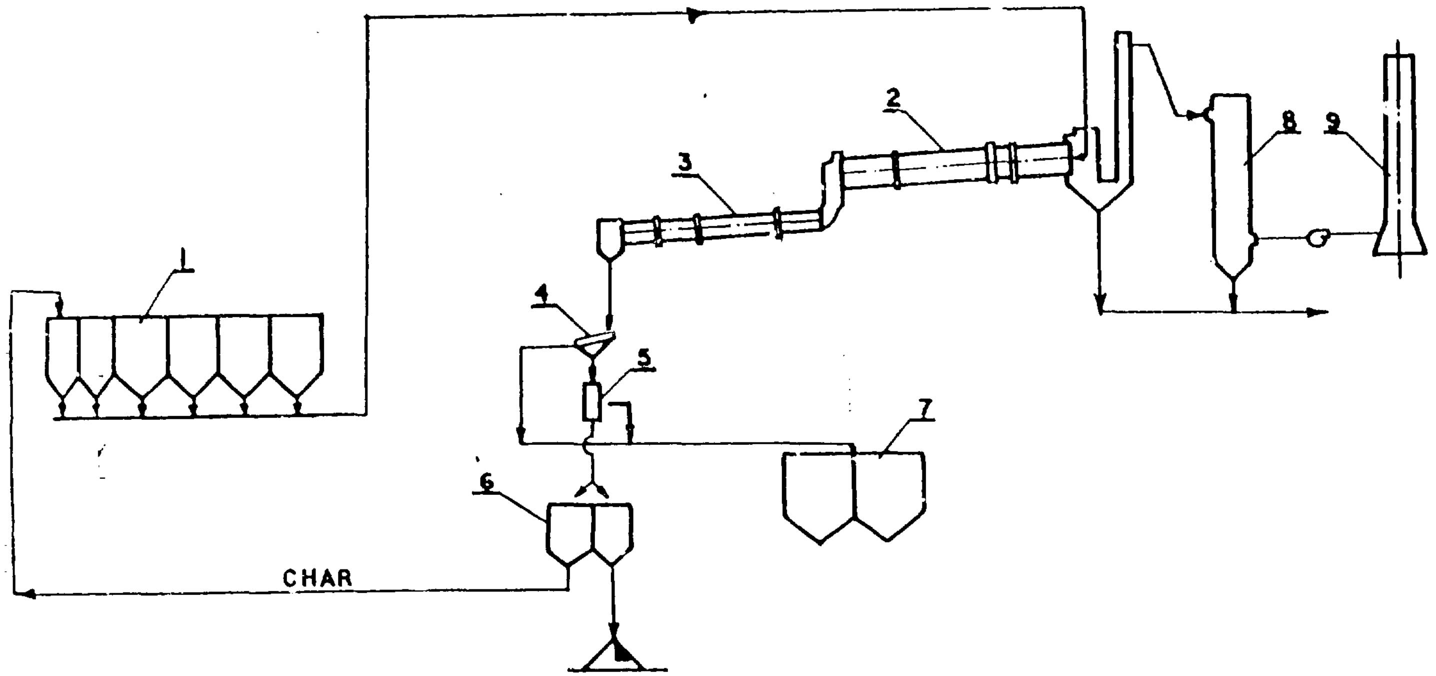


FIG. 9. HIB PROCESS FLOW SHEET



LEGEND

1 ORE/PELLET, COAL, FLUX & CHAR BINS
2 REDUCTION KILN
3 ROTARY COOLER
4 SCREEN
5 MAGNETIC SEPARTOR
6 TAILING & CHAR BINS
7 SPONGE IRON BINS
8 WASTE GAS COOLER
9 STACK

FIG. 10. ROTARY KILN PROCESS GENERAL FLOW SHEET

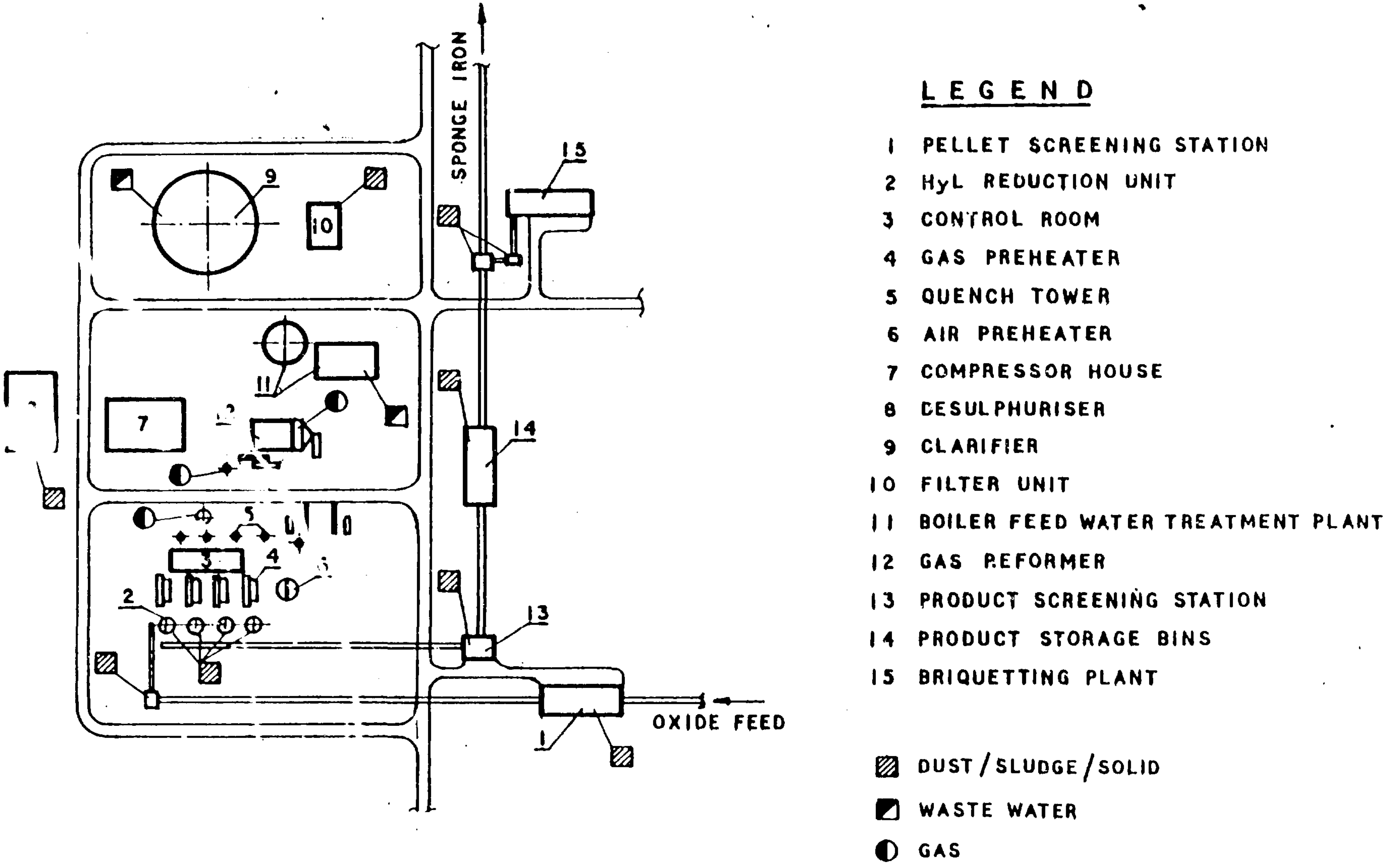


FIG. 15. TYPICAL HyL PLANT – SOURCES OF POLLUTION

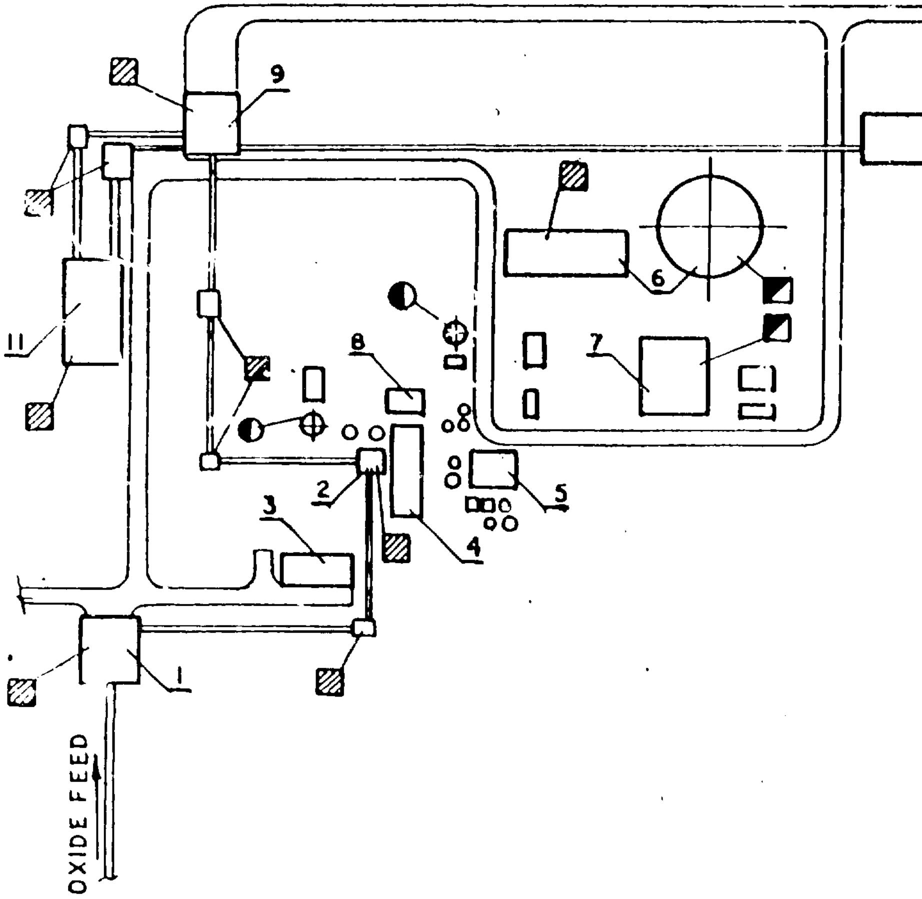
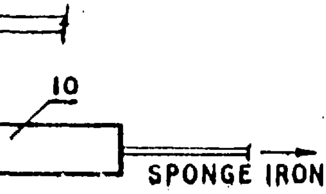


FIG.12. TYPICAL HyL III PLANT



LEGEND

1 PELLET SCREENING STATION
2 H_yL REDUCTION UNIT
3 CONTROL ROOM
4 PREHEATER
5 COMPRESSOR HOUSE
6 WATER TREATMENT PLANT
7 BOILER FEED WATER TREATMENT PLANT
8 GAS REFORMER
9 PRODUCT SCREENING STATION
10 PRODUCT STORAGE BINS
11 BRIQUETTING PLANT

▨ DUST / SLUDGE / SOLID
◩ WASTE WATER
◐ GAS

SOURCES OF POLLUTION

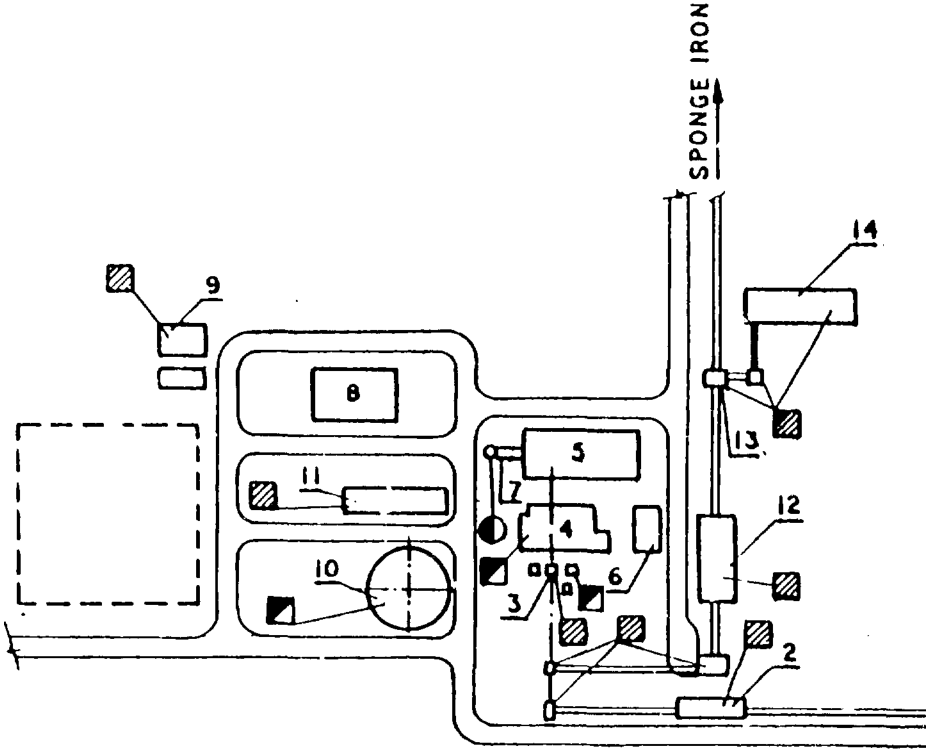
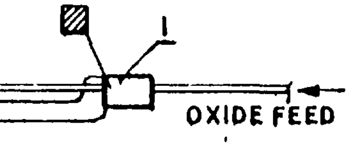


FIG. 13. TYPICAL MIDREX PLANT -



LEGEND

1 SCREENING STATION
2 DAY BINS
3 MIDREX REDUCTION FURNACE
4 BLOWER AREA
5 GAS REFORMER
6 BLOWER HOUSE
7 RECUPERATOR & STACK
8 CONTROL ROOM
9 DESULPHURISER
10 CLARIFIER
11 WATER TREATMENT PLANT
12 SPONGE IRON STORAGE BINS
13 PRODUCT SCREENING STATION
14 BRIQUETTING PLANT

▨ DUST/SLUDGE/SOLID
◪ WASTE WATER
◐ GAS

SOURCES OF POLLUTION

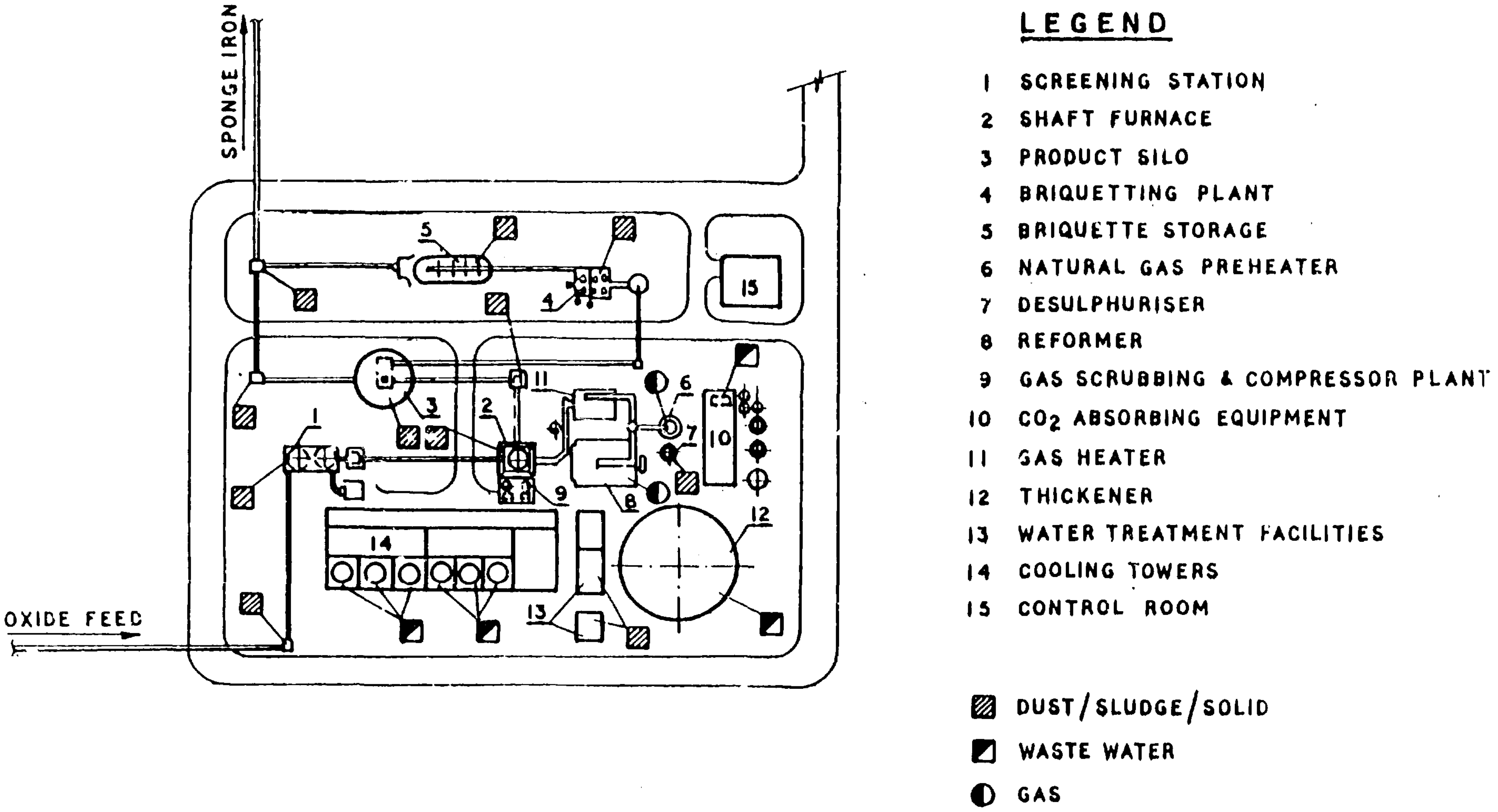
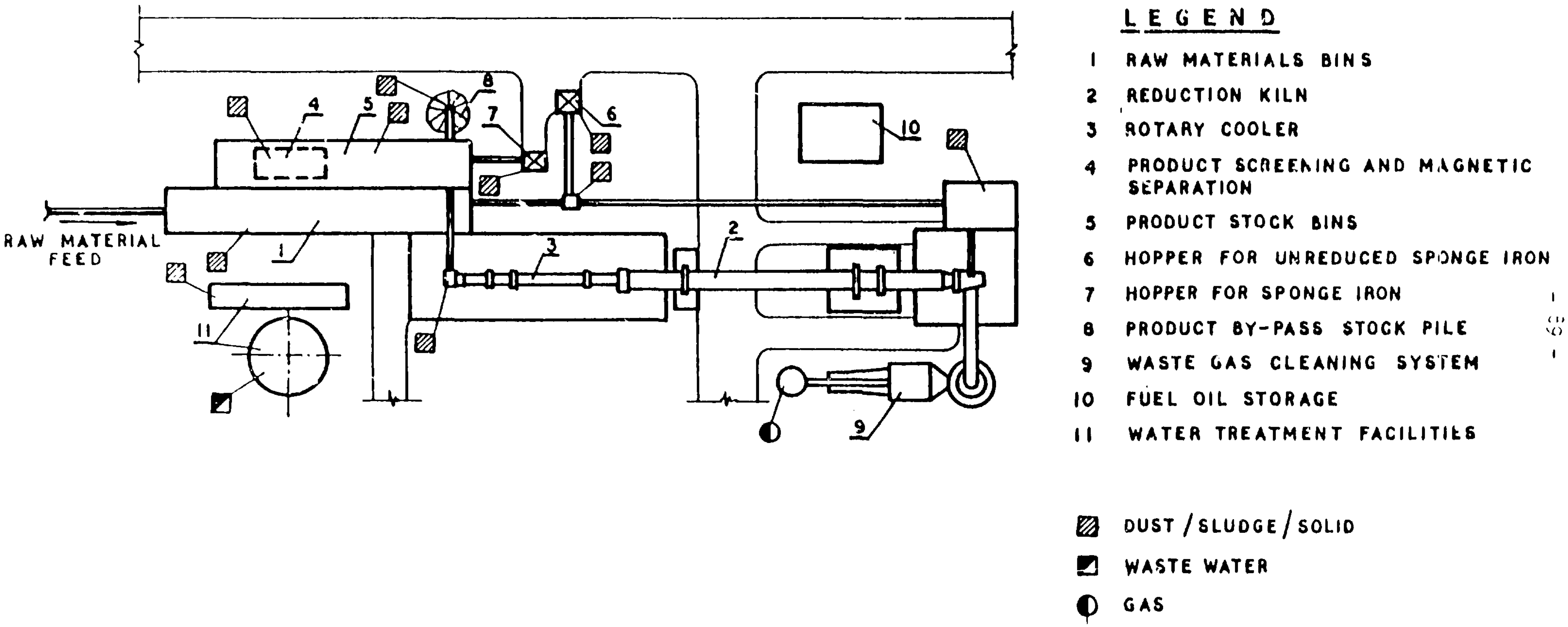
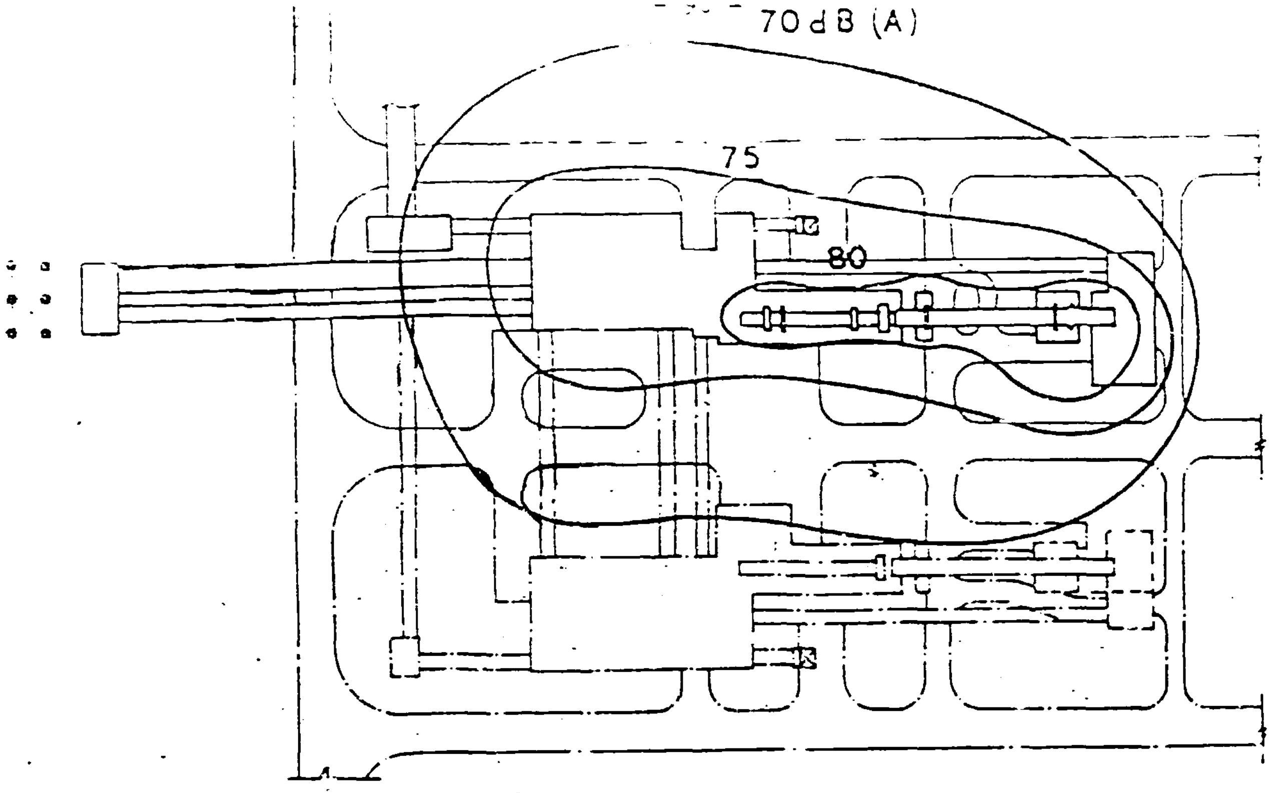


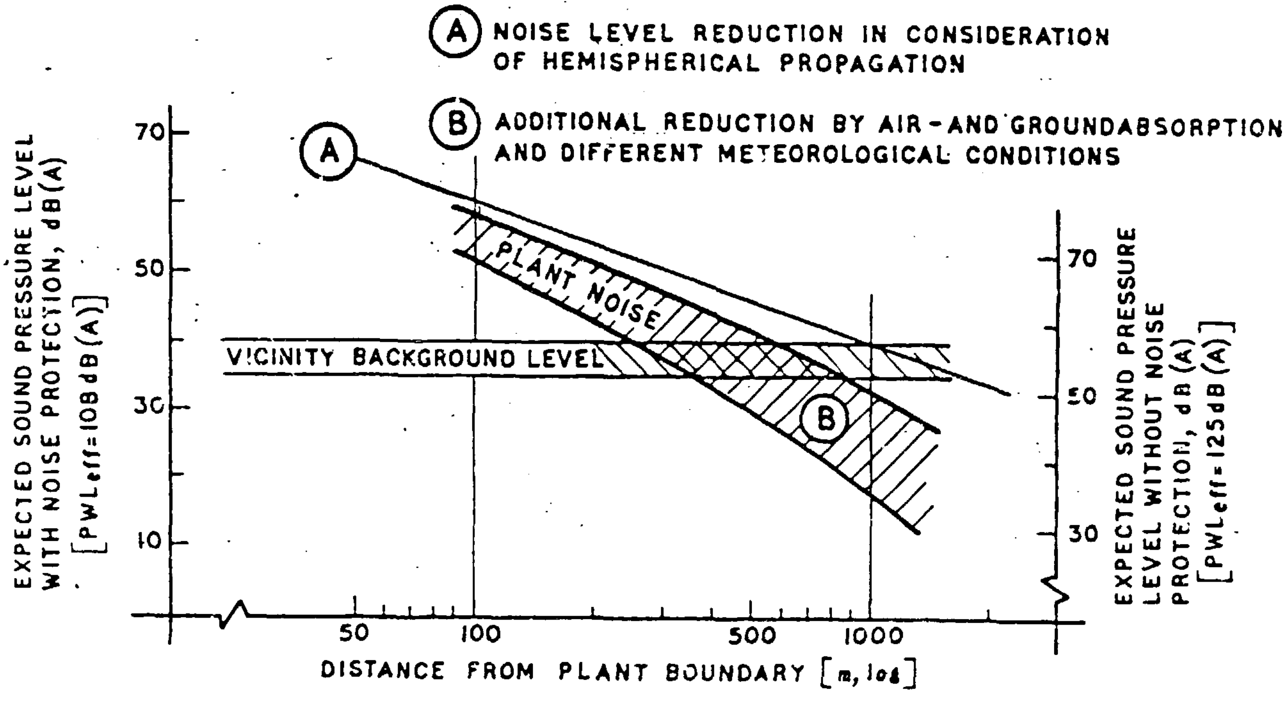
FIG. 14. TYPICAL NSC-DR PLANT – SOURCES OF POLLUTION



.FIG.15. TYPICAL SL/RN PLANT – SOURCES OF POLLUTION



NOISE EXPOSURE CONTOURS



PWLeff = EFFECTIVE SOUND POWER LEVEL

SOUND PROPAGATION

FIG. 16. NOISE EXPOSURE AND SOUND PROPAGATION IN A TYPICAL SL/RN PLANT

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