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ENVIRONMENTAL ASPECTS OF THE DIRECT REDUCTION ROUTE TO STEEL MAKING

A Technical Review

UNITED NATIONS ENVIRONMENT PROGRAMME

UNEP - Industry & Environment Technical Review Series

Environmental Aspects of the Direct Reduction Route to Steel Making

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FOREWORD

In accordance with the decision 87 (V) A of the United Nations Environment Programme (UNEP) Governing Council at its 5th session, a review was undertaken of the environmental aspects associated with the iron and steel industry and a workshop of Governmental and industrial experts, as well as those from relevant international institutions, on the subject was held (Geneva, 17 - 20 October 1978) (1). One of the issues identified at this workshop for further review, where environmental management guidance was considered necessary, was the direct reduction route to steel making and a meeting of experts was organized in co-operation with the United Nations Industrial Development Organization (UNIDO), in order to provide that guidance. The meeting was held in Puerto Ordaz, Venezuela, 24 - 30 April 1982, at the invitation of the Venezuelan authorities and Siderurgica del Orinoco. Experts represented all the major commercialized industrial direct reduction processes.

For the industrial sector environmental reviews, UNEP has established a consultative process amongst the main interested parties, namely : Governments, industry and the international institutions concerned. Through this process a wide range of information on the environmental aspects of the iron and steel industry has been collected, including information on the direct reduction approach.

Several background reports were prepared for the meeting, as follows :

a) Comparative Study Evaluation of Industrially Operational Technologies of the Direct Reduction of Iron Ores, prepared by Mr. Das Gupta (M. N. Dastur & Company (P) Ltd., Consulting Engineers, India) for UNIDO (see UNIDO/I.O. 490 ; UNEP/WG/I.S.3).

b) Direct Reduction of Iron and Environmental Control, prepared by Dr. V. V. Danshin (USSR State Commission on Science and Technology) for UNEP (see UNEP/WG/I.S.4).

c) Assessment of Electric Arc Furnace Melt-Shop Pollution Abatement Technology, prepared by Dr. L. Hütten-Czapski, (Sidbec-Dosco, Quebec, Canada) for UNEP (see UNEP/WG/I.S.5).

d) Energy Conservation in the Iron and Steel Industry - Some Global Data and Considerations, prepared by Dr. B. R. Nijhawan for UNIDO (see UNEP/WG/I.S.6).

e) Some Recent Developments in the Field of Direct Reduction for Sponge Iron Production, prepared for UNIDO (see UNEP/WG/I.S.7).

f) Potential Pollution Problems Met With in Sponge Iron Production Based on Direct Reduction, compiled from data of the Environmental Protection Agency in the USA (UNEP/WG/I.S.8).

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(1) "Environmental Aspects of the Iron and Steel Industry, Workshop Proceedings", UNEP - Industry and Environment Workshop Proceedings Series, Volume 1 Parts 1 and 2, Paris 1980.

The information collected and the background documents were synthesized by the Secretariat, with the help of consultants, in the form of a first draft Secretariat report on the environmental aspects of the direct reduction route to steel making. This gave an overview of the environmental aspects and highlighted the main environmentally related issues involved in the process of producing liquid steel from iron ore by the direct reduction route. The report was examined at the meeting of experts and environmental management guidance for the direct reduction route to steel making was drafted (2). A period of two months was allowed for participants to submit additional material for inclusion in a revised draft of the Secretariat report, which was also amended in accordance with the comments and discussions of the meeting. The revised draft report and the environmental guidelines were finalized through a procedure of correspondence, which included also experts not able to participate in the meeting itself. The report is published here as the UNEP technical review on the subject. The environmental guidelines have been published separately in the UNEP Industry and Environment Guidelines Series (3).

Whilst the potential environmental impacts of the direct reduction route to steel making are less serious than those of the classical blast furnace and scrap melting routes, there remain some environmental problems. Supplementary information can be found in the UNEP overview and technical review on the environmental aspects of the iron and steel industry, currently under preparation.

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(2) "Record of the UNEP/UNIDO Meeting of Experts on the Environmental and Resource Aspects of the Direct Reduction Route to Steel Making", UNEP/WG/I.S.9 (Final).

(3) "Environmental Guidelines for the Direct Reduction Route to Steel Making", UNEP Industry and Environment Guidelines Series, Paris 1983.

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Dr. John A. Haines was the UNEP Senior Programme Officer
responsible for the activity.

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ABBREVIATIONS

M	million 10^6
G	giga 10^9
t	metric tons
DR	direct reduction
DRI	direct reduced iron
EAF	electric arc furnace
J	joule
kWh	kilowatt hour
th	thermie
k cal.	kilo calories : 10^3 calories
h	hour
y	year
m	meter
Nm^3	normal cubic meter
BTU	British thermal unit
LPG	liquid petroleum gas

PART I : INTRODUCTION

THE DIRECT REDUCTION ROUTE TO STEEL MAKING

COMPARATIVE DESCRIPTION OF DIFFERENT ROUTES TO STEEL MAKING

1. There exist in the world three principal routes for the production of liquid steel from iron ore, namely :

(a) the classical route based on blast furnace iron making and conversion of pig iron to steel ;

(b) a second route based on melting of scrap ;

(c) a new route with direct reduction of iron ore and melting of reduced products.

(a) Classical Route

2. As it is indicated on the left hand side of Figure 1, the classical route is based on reduction of iron ore to a high carbon primary metal, liquid pig iron in the blast furnace, followed by conversion of this hot metal to steel in steel making furnaces (principally oxygen converters, but also open hearth furnaces). This route is producing the major part of the steel in the world, 710 Mt in 1980, but it needs coal preparation, including coking in coke ovens, and ore preparation, including sintering or pelletizing plants. Economically it is imperative to increase the unit size and the production of each plant so as to work with bigger and more efficient blast furnaces, as well as with larger and higher capacity oxygen converters. In this way, the most economical production capacity of one integrated installation consisting of a sintering plant, a coke oven battery, a blast furnace and an oxygen converter, is between 2 and 4 Mt steel a year.

(b) Scrap Melting Route

3. Scrap is directly melted in electric arc furnaces and, more and more rarely, in open hearth furnaces. Initially small, the capacity of electric arc furnaces has greatly increased and can attain 400 t per heat.

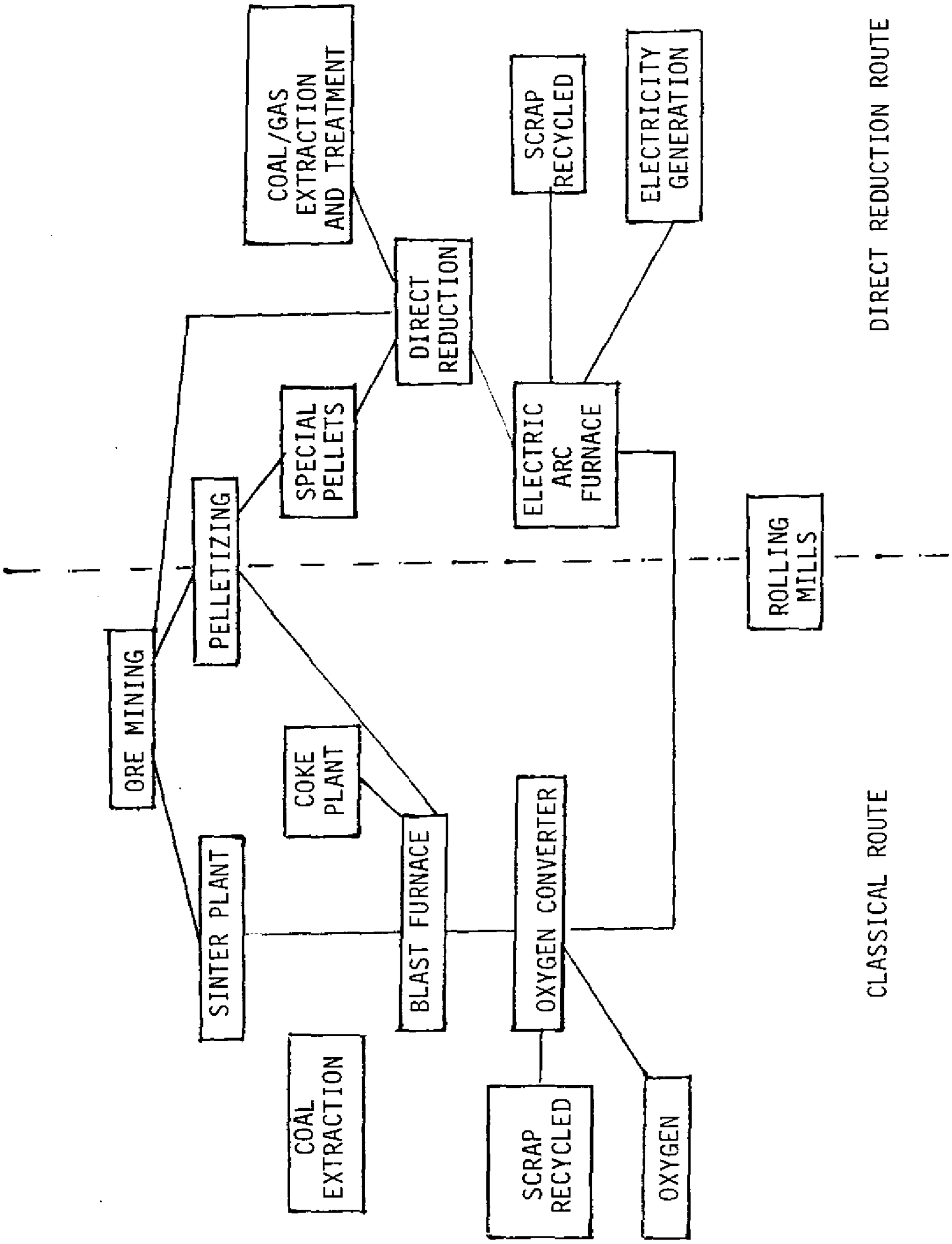
(c) Direct Reduction Route

4. As opposed to the classical route based on the use of iron ore, a new combination of technologies is used in the direct reduction route, as is indicated on the right hand side of Figure 1. Within a first stage, iron ores are directly reduced in the solid phase, and in a second stage an electric arc furnace (EAF), whose operating practice is adapted to the melting of pre-reduced products, instead of only scrap, is used for refining to steel.

5. In comparison with the classical route, this new technology has three principal advantages, which are :

FIGURE 1

VARIOUS ROUTES TO PRODUCE STEEL FROM IRON ORE



(i) the simplicity of the flow sheet without the need for coke ovens and blast furnace ;

(ii) the smaller size of the plants (units of 0.2 to 0.4 Mt annual capacity are quite economical) ;

(iii) the possibility of using local energy sources.

Such a technology provides an interesting approach to the implantation of plants in developing countries. 7.13 Mt of direct reduced iron was produced in 1980, i.e. accounting for only about 1% of the world steel production.

6. In comparison with the scrap melting route, this new technology, along with the electric arc furnace, permits an interesting flexibility between the combined uses of scrap and of direct reduced iron (DRI). It appears particularly interesting for developing countries, which have a shortage of scrap, and because DRI is virtually free of the unwanted residual alloys or tramp elements contained in scrap, its use can extend electric-furnace melting to a broader range of steel output.

Economic Considerations+

7. An important advantage for the new route in comparison to the classical route is the lower investment cost, as shown in Figures 2 and 3, taken from G. Wolters (1). For instance, in an example given by L. Hütten-Czapski and L. Rouillier (2), the capital cost per annual ton of capacity for the direct reduction electric arc furnaces route is only 64% of that for the conventional route. Table 1 gives an example of an economic comparison between both routes, on the one hand with blast furnace/basic oxygen furnace and on the other with direct reduction/electric arc furnace.

Resource Considerations

8. Comparisons of the direct reduction with the classical route may be made in respect of four resources :

(i) manpower ;

(ii) ore ;

(iii) energy, including reductant ;

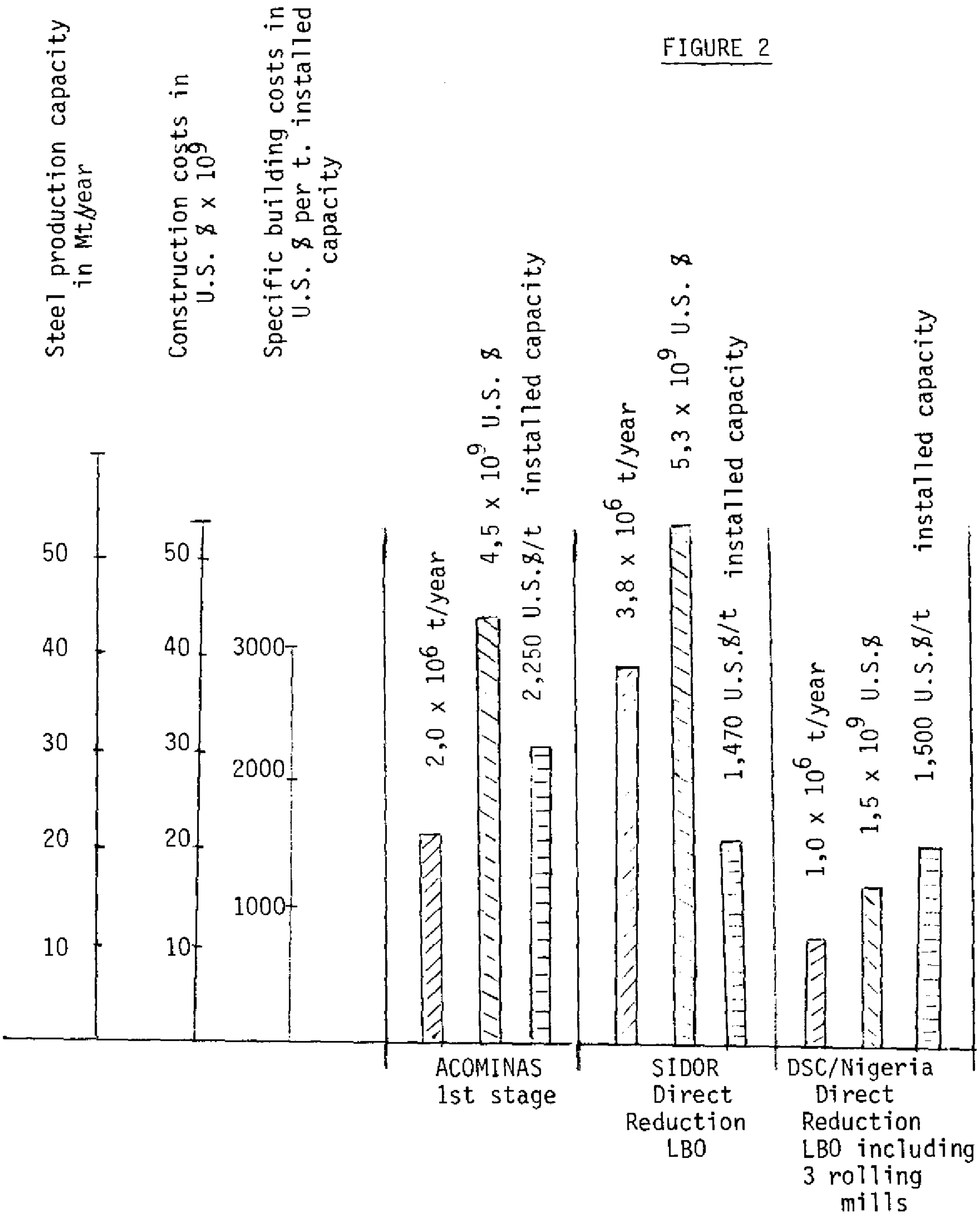
(iv) water.

(i) Manpower

9. The direct reduction route requires fewer people than a classical plant, both in total, but also per ton of steel, according to W. Korf (3), for instance, the productivity in t/year/man is about 500 - 1,500 instead of 300 - 1,000 with the classical route. However, the qualifications and training of the manpower have to be at the same level as for a classical plant. Manpower training is essential for the DR route, especially if it is a new plant designed to operate in a developing country.

\+ Strict comparison of costs is difficult to make and this report quotes original currency, as reported, with the appropriate date.

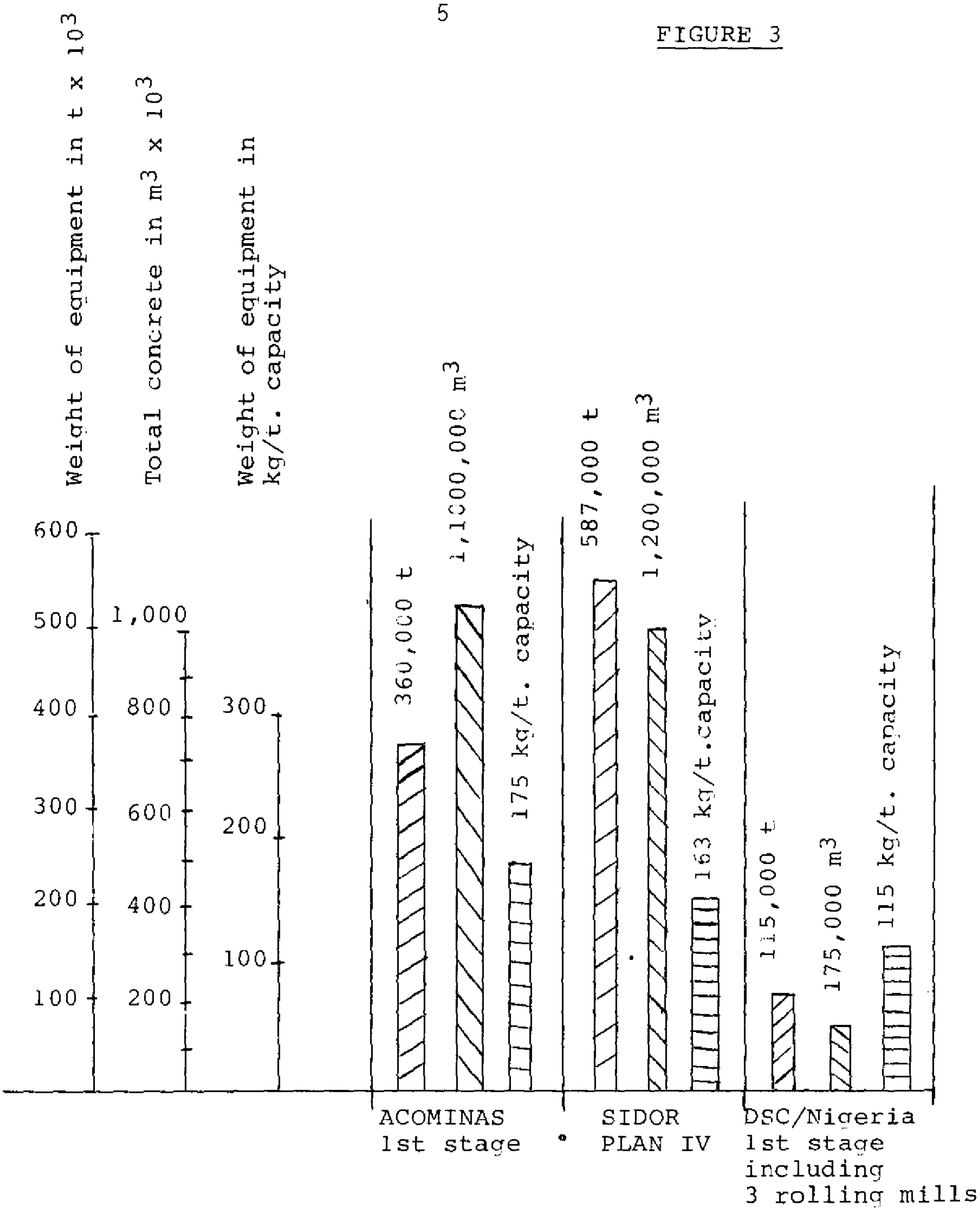
FIGURE 2



REVIEW OF THE CONSTRUCTION COSTS OF SELECTED IRON AND STEEL WORKS

Taken from G. Wolters (1)

FIGURE 3



WEIGHT OF EQUIPMENT AND QUANTITIES OF CONCRETE OF SELECTED IRON AND STEEL WORKS

Taken from G. Wolters (1)

TABLE 1

BLAST FURNACE/BASIC OXYGEN FURNACE VS. DIRECT REDUCTION/ELECTRIC ARC FURNACE

IRONMAKING MATERIALS	UNIT COST	BLAST FURNACE CONSUMPTION PER TONNE HOT METAL	BLAST FURNACE COST PER TONNE HOT METAL	MIDREX DIRECT REDUCTION CONSUMPTION PER TONNE DRI	MIDREX DIRECT REDUCTION COST PER TONNE DRI
Iron Oxide - BF Pellets (65% Fe)	$40.00/t	1.49 t	$59.60	-	-
Iron Oxide - DR Pellets (67% Fe)	43.00/t	-	-	1.43 t	$ 61.49
Coke	130.00/t	0.60 t	78.00	-	-
Natural Gas	12.00/Gcal	-	-	2.4 Gcal	28.80
Electricity	0.025/kWh	10 kWh	0.25	100 kWh	2.50
Labor	7.00/MH	0.3 MH	2.10	0.2 MH	1.40
Limestone	6.00/t	0.2 t	1.20	-	-
Maintenance and Supplies	-	-	5.75	-	3.50
Gas Credit	8.00/Gcal	0.95 Gcal	(7.60)	-	-
Fixed Capital Cost	-	$150 at 20%	30.00	$100 at 20%	20.00
TOTAL IRONMAKING COST			$169.30		$117.69

STEELMAKING MATERIALS	UNIT COST	BASIC OXYGEN FURNACE CONSUMPTION PER TONNE HOT METAL	BASIC OXYGEN FURNACE COST PER TONNE HOT METAL	ELECTRIC ARC FURNACE CONSUMPTION PER TONNE HOT METAL	ELECTRIC ARC FURNACE COST PER TONNE HOT METAL
Hot Metal	$169.30/t	0.75 t	$126.98	-	-
DRI	117.69/t	-	-	0.7 t	$ 82.38
SCRAP	100.00/t	0.25 t	25.00	0.3 t	30.00
Sub-Total			$151.98		$112.38
Sub-Total Yield Effect		93% Yield	$163.42	92% Yield	$122.15
Additives	-	-	3.50	-	3.50
Burnt Lime	50.00/t	0.03/t	1.50	0.03 t	1.50
Electricity	0.025/kWh	30 kWh	.75	600 kWh	15.00
Labor	7.00/MH	0.5 MH	3.50	0.55 MH	3.85
Electrodes	1500.00/t	-	-	0.006 t	9.75
Oxygen	30.00/t	0.075 t	2.25	0.05 t	1.20
Maintenance and Supplies	-	-	10.00	-	12.00
Fixed Capital Cost	-	$100 at 20%	20.00	$100 at 20%	20.00
TOTAL LIQUID STEEL COST			$204.92		$188.95

(ii) Ore

10. Whilst in theory any ore could be adapted for use in a direct reduction process, it being essentially a question of economics, each process has a range of raw material physical and chemical specifications which need to be met, and deviations from these specifications may give rise to environmental problems which protection measures originally incorporated into the process may not be adequate to control.

(iii) Energy

11. Table 2, taken from L. L. Teoh (4) gives the consumption of the reductants and energy of ten direct reduction processes. Tables 3 (a) and 3 (b), modified by the author, J. Astier (5) and table 4, from L. Hütten-Czapski and L. Rouillier (2) give comparisons of energy balances for a modern classical plant and for the new scheme with direct reduction and the electric arc furnace, to obtain 1 ton of liquid steel. In both cases, primary energy consumption is within the same order of magnitude, with an advantage for the mini-steel route with direct reduction when electric power is taken at its useful value (3400 BTU/kWh). Such a situation is reversed when the heat value of electric energy is assessed at 10,000 BTU/kWh. It is reasonable to use the higher value when fossil fuels, which could be employed in steel making, are used in electricity generation.

12. However, the direct reduction electric arc furnace route offers more opportunities to use different sources of energy alone or in combination, such as natural gas, coal and electricity. Research and development will probably widen again the range of energy possibilities (non-coking coal, liquid or gaseous fuels, heat from nuclear energy, biomass etc.).

(iv) Water

13. Water is an essential raw material in steel manufacture. Classical integrated works may require as much as 150 - 200 t/t steel produced ; but only about 3 t of water/t of steel is permanently lost, mainly by evaporation and it is possible by plant design and good water management to reduce the demand on water resources far below the total requirement. The direct reduction and electric arc furnace plants require inherently much less water, e.g. 1.5 m^3/t direct reduced iron for the Midrex process. Under the special circumstances of the Qatar plant, the water make-up is 0.2 m^3/t direct reduced iron.

14. It must of course also be borne in mind that ore processing, especially beneficiation, requires large amounts of water. Conservation and water economy can reduce demands on resources.

Environmental Considerations

15. The comparison between the environmental impacts with both routes is shown in Figure 4.

(a) Classical Route

16. The complexity of large classical plants gives an important impact on the environment, namely in terms of :

- emission of particulate matter and discharge of solid wastes from coke ovens (coke breeze), from blast furnaces (slag and dust) and from oxygen converters (slag and dust) ; some of the solid wastes are not readily recycled or re-utilized and, because of their toxic nature, present problems of disposal ;

TABLE 2

REDUCTANTS AND ENERGY CONSUMPTION OF VARIOUS DIRECT REDUCTION PROCESSES

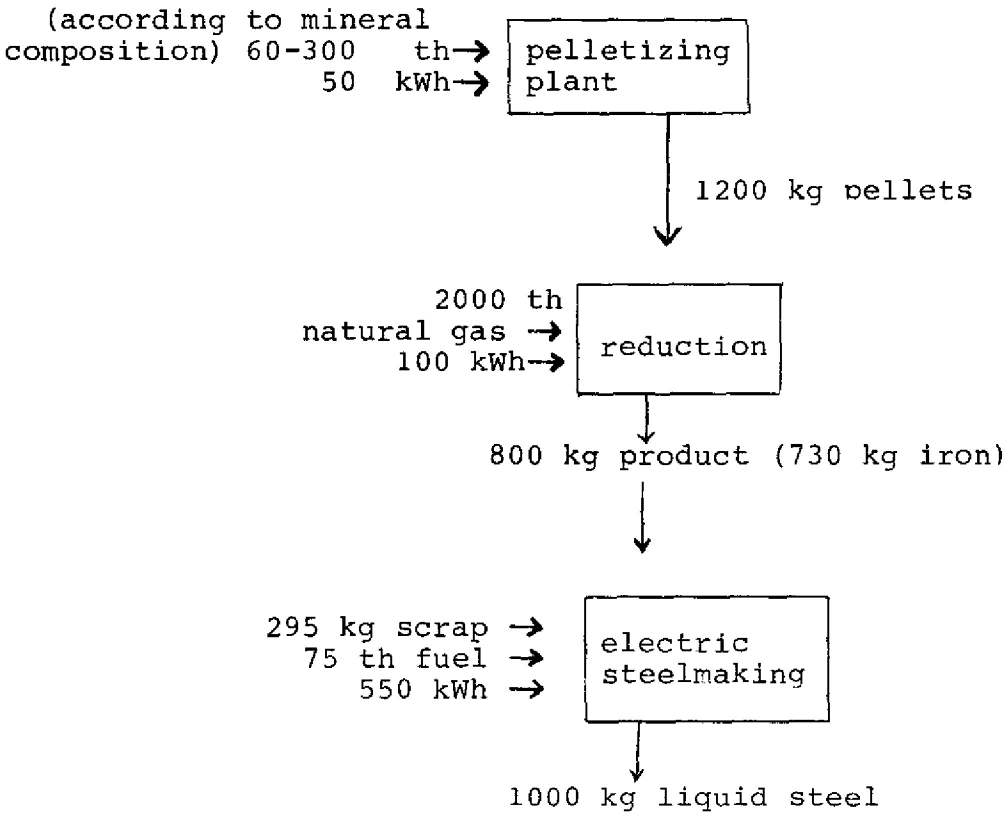
Process	Reductant	Energy Consumption		
		Total energy consumed net Gcal/t	Type	Electrical energy kWh/t
HyL III	natural gas, coke oven gas, gasified coal or tar	2.4 to 2.6	natural gas	80
MIDREX	natural gas, coke oven gas, gas from naptha or LPG, gasified heavy oil or coal, low shaft off gas	2.4	natural gas	100
Purofer	natural gas, coke oven gas fuel oil	3.3 3.1 3.5	natural gas coke oven gas fuel oil	130 270
NSC - DR	natural gas, light oil coal gasification	3.0	reformer gas	90
FIOR	primarily H_2 which can be prepared by catalytic steam reforming, partial oxidation or coal gasification	4.0	natural gas	180
SL/RN	High volatile coal anthracite, coke breeze lignite	4.75	coals	50 - 70
CODIR (Krupp)	Steam coals, bituminous and sub-bituminous coal	3.8 - 4.0	coals	55
ACCAR	natural gas, fuel oil, coal	2.75 - 3.25 3.00 - 3.25 3.50 - 3.75	oil and coal oil natural gas	35
DRC	coal	3.06	coals	not available
Kinglor-Metor	coal, coke breeze, lignite	3.8	coals, plus oil or gas	80

Taken from L. L. Teoh (4)
and modified by the manufacturers

TABLE 3(a)

ENERGY BALANCE FOR A PLANT BASED ON DIRECT REDUCTION AND ELECTRIC ARC FURNACE

Direct reduction + Electric Arc furnace



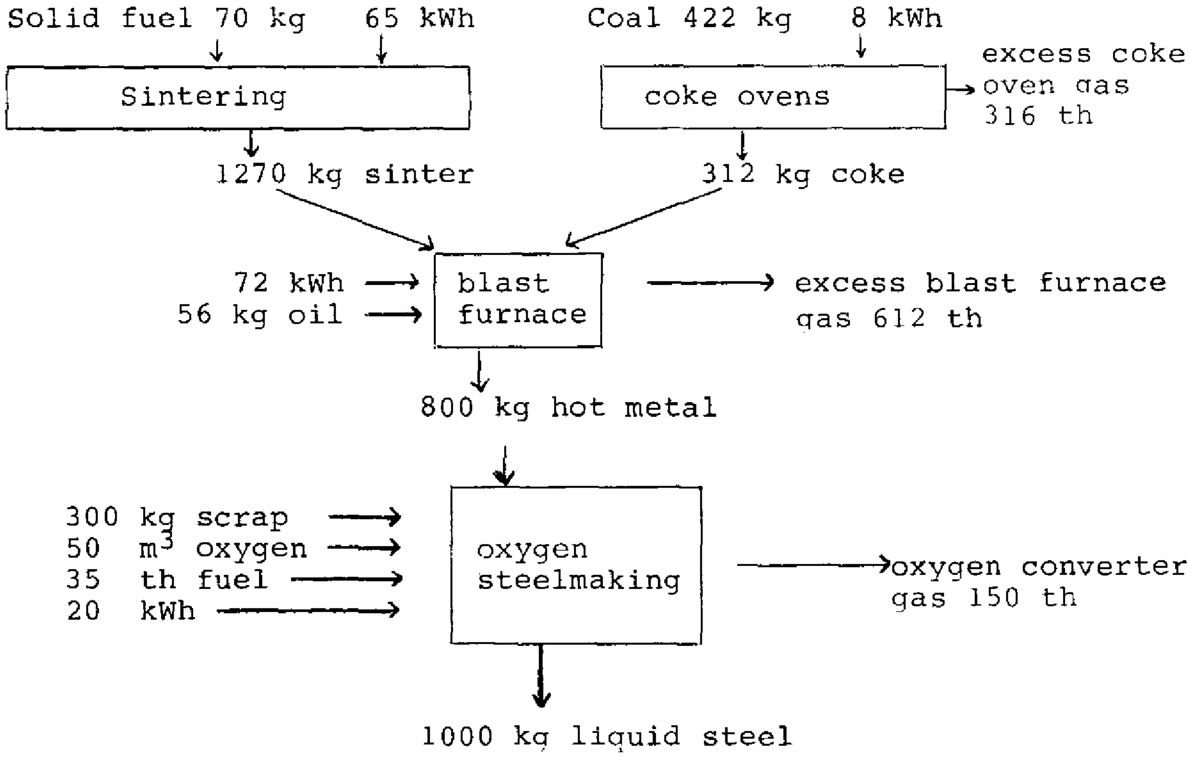
fuels	quantity	th or 10^3 kcal/t liquid steel	remarks
natural gas	2060 - 2250 th	2060 - 2250	
electrical energy	(700 kWh (	600 1500	860 kcal/kWh 2300 kcal/kWh
Total	((	2250 - 2850 3860 - 3850	860 kcal/kWh 2300 kcal/kWh

Taken from J. Astier (5)
and modified by the author

TABLE 3(b)

ENERGY BALANCE FOR A MODERN CLASSICAL IRON AND STEEL PLANT

Blast furnace + Oxygen steelmaking



fuels	kg	th or 10^3 kcal/t liquid steel	remarks
Coal	492	3 444	
Oil	56	560	
Various fuels	35 th	35	
Electrical energy	(165 kWh (	142 380	860 kcal/kWh 2 300 kcal/kWh
Total recovery of gases	(	4 181 4 419 1 078	860 kcal/kWh 2 300 kcal/kWh
Total net	((	3 103 3 341	860 kcal/kWh 2 300 kcal/kWh

Taken from J. Astier (5)

TABLE 4

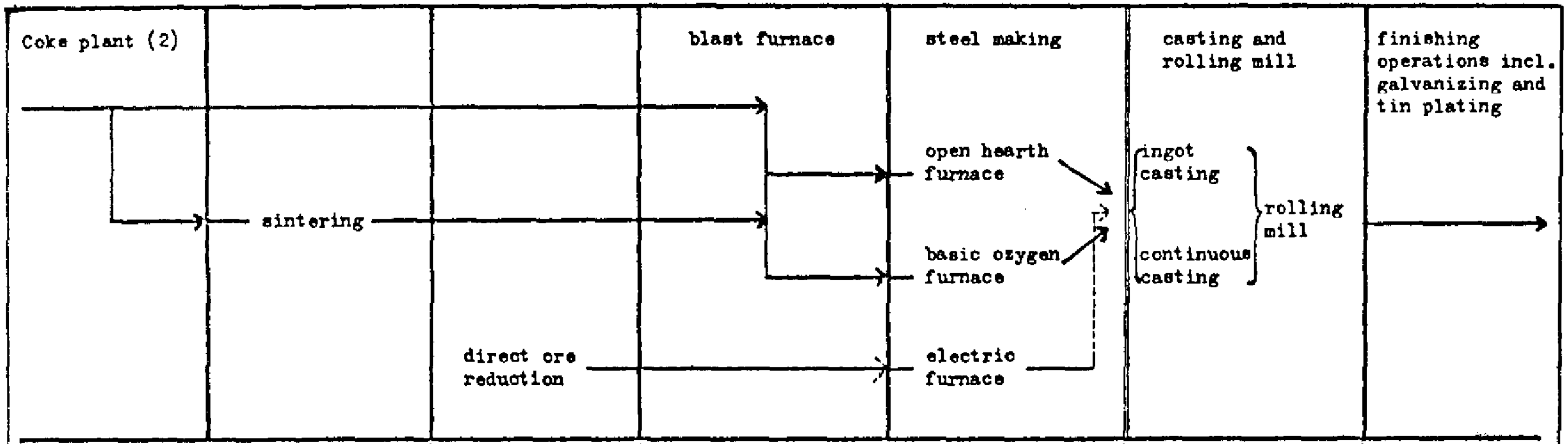
ENERGY CONSUMPTION IN BOTH ROUTES
FOR PRODUCTION OF 1 SHORT TON OF LIQUID STEEL

	Conventional route	Direct reduction and electric arc furnace (74 % reduced pellets + 26 % scrap without thermal value)
Energy without electricity		
Coking coal	17.55×10^6 BTU	
Carbon additions	-	0.18×10^6 BTU
Natural gas	-	8.5×10^6 BTU
Fuel credit	3.5×10^6 BTU	
Sub-total	14.05×10^6 BTU	8.68×10^6 BTU
Electricity	45 kWh	750 kWh
GROSS TOTAL		
1/ with 1 kWh = 3400 BTU	14.2×10^6 BTU	11.2×10^6 BTU
2/ with 1 kWh = 10000 BTU	14.5×10^6 BTU	16.1×10^6 BTU

Taken from L. Hütten-Czapski
and L. Rouillier (2)

FIGURE 4

MAJOR POLLUTION SOURCES AND TYPES IN THE IRON AND STEEL INDUSTRY



WASTES PRODUCED															
Air	Water	Air	Water	Air	Water	Air	Water	Solids	Air	Water	Solids	Water	Solids	Water	Solids
Dust (3) NH_3 Steam H_2S NO_x CO	NH_3 BOD Phenol Cyanide Acidity	Dust SO_x NO_x Fluorides	Susp. Solids (SS) BOD Phenols Cyanide Sulfides	Dust SO_x (4) NO_x	SS	NH_3 CO (5) SO_x	SS NH_3 Phenol Cyanide	Slag Spent refractories	Dust NO_x	SS	Sludge Slag	SS Oil + grease Chloride Sulfate Iron Acidity	Scale Sludge Spent refractories Spent oil + grease	SS BOD Cyanide Oil + grease Chromium Iron Tin	Scale

(1) Other sources of relatively minor contamination include the yards (ore, coal and scrap), power generation, lime kiln and cooling towers.
(2) By-product plants associated with coke plants produce benzol, tars, sulfuric acid and phenol, which are used by the chemical industry.
(3) Note: whenever dust is removed by means of a wet process, such as a scrubber, a water pollution problem in the form of suspended solids results. When removed by a dry process a solid waste results.
(4) Amount depends on sulfur content of fuel used.
(5) Waste gas containing CO is frequently collected and cleaned for use as a fuel.

Taken from UNIDO (6)

- emission of gaseous pollutants present with coke oven gas, blast furnace gas, converter gas and a wide variety of secondary fumes, which must be collected, cleaned and recovered if possible ;
- use of large quantities of water ;
- formation of polluted effluents which have to be cleaned ;
- emission of noise, which increases with the size of the plants ;
- thermal emission to air, water and even the sea.

(b) Scrap Melting Route

17. One important problem with this route is the tramp metal content in scrap. Indeed, heavy metals are concentrated in electric arc furnace dust and can pollute ambient air when emitted and also ground water, if dumped, by rainfall leaching.

(c) Direct Reduction Route

18. The environmental impact of the new scheme is less important than for the classical route since :

- The size of the plants is more often than not smaller and the discharge of pollutants to air or water is less.
- Coke ovens are not required in this approach which avoids the important internal and external pollution arising from coke preparation.
- The simplicity of the flowsheet decreases the amount per ton of final liquid steel of a number of by-products either solid (slag, dust, sludge) or liquid or gaseous.
- In direct reduction units, solid wastes are either iron ores and products, which can be easily recycled, or desulphurization products, which are inert and can be dumped without risk.

Social Considerations

19. The social benefits of industrialization and the ultimate resulting improvement in the standard of living are highly significant and whilst it is recognized that industrial development inevitably brings about changes, it need not be ecologically destructive and should be environmentally sustaining. There are patterns of development which can be achieved without environmental destruction, provided wise resource management is ensured. The undesirable negative social impacts may be mitigated if recognized early and appropriate protection measures taken into consideration from the beginning. The benefits from these measures may significantly outweigh the costs.

20. Each route to steel making has its social impacts, partly depending on the size of the operation and partly depending on the local conditions. Additionally mining, particularly opencast, may be of particular concern due to the extent of the operations. Iron and steel industry development, as well as mining, invariably means disturbance of the land, changes in land use, disruption of natural ecosystems, disruption of communities and changes in life-styles. Air and water pollution arising from these developments may also have social implications, particularly where the local resource base is affected. Where solid fuels are used in the steel industry, coal mining has its own set of social and physical considerations, and these are not dealt with in this review.

21. In general iron ore mines located in densely populated areas have already been exhausted and new mines are far from large population centres. Consequently, the social impact of a new mine affects fewer people than mining in the past. Likewise most new steel making facilities are constructed on greenfield sites some distance from urban populations or in specifically designated industrial areas separated from residential areas. However, the opening of a new mine or construction of a steelworks changes the way of living of local people. Frequently there is an influx of workers from outside with different social and cultural habits. Urban infrastructure has to be provided for the additional workforce and their families ; transportation infrastructure for the mining operations or steelworks is needed. Whilst there are positive benefits, the local people may be the losers. Not only may they lose the land from which they live, their hunting and fishing rights, but also the environmental changes may affect detrimentally their sources of livelihood. It is essential to assess the social and related aspects along with the physical environmental aspects of mining or steelworks operations before operations begin so that actions to prevent unnecessary deleterious impacts may be taken, before and as the operation is established. It is not intended to deal with the subject of environmental impact assessment in this report and attention is drawn to relevant UNEP experience elsewhere (7, 8).

22. The sequence of actions leading to the establishment and operation of a new iron ore mine and/or a new steelworks, which are rarely on the same site, include :

- (i) prospecting and valuation of the ore body economies ; or prospecting for the steelworks site ;
- (ii) construction of necessary infrastructure, e.g. roads, rail, port facilities, airports, power supply, etc. ;
- (iii) establishment of residential and other facilities for the construction personnel and industry workforce ;
- (iv) building of the mine and ore processing facilities, and of the steelworks ;
- (v) operation of the mine site and ore processing facilities, and of the steelworks ;

Also action to be taken on closing of the industrial operation has to be considered in conjunction with initial plans.

23. Prospecting involves relatively small numbers of people and the social impacts are usually negligible. However, depending on conditions, there may be an intermediate impact on the physical environment if precautions are not taken, particularly in fragile ecosystems. Environmental protection measures appropriate to local conditions should be ensured during prospecting.

24. Construction of the site and the associated transportation infrastructure and power supply, as well as the residential and other facilities for the workforce, involves large numbers of people and equipment. There is frequently an impact on air quality, through dust ; on water quality, through displacement of the water-table ; on existing vegetation and natural ecosystems. Noise can also be a source of nuisance. However, the social impacts on local populations can be most devastating. Changes may come very rapidly, without the necessary time for adaptation to changing conditions. Local communities are often displaced. There may be a large influx of construction workers during the construction period who leave when the industrial site opens. Social disruption sometimes manifests itself in conflicting interests in the community between local peoples and an imported workforce. Often there is an increase in crime, alcoholism and other manifestations of social disruption.

25. Industrial operation may change the environment through excavation, land removal and displacement, impacts on air quality, impacts on water quality and through noise. There may furthermore be important working environmental health and safety considerations, each of which have social implications.

26. When an ore body is exhausted beyond profitable economic operation, the mine site is closed. Similarly a steelworks may be closed when it is no longer profitable. There are both physical environmental and social aspects. Whilst it may not always be either feasible or desirable to restore a site to its original use, it is essential to foresee and plan from the conception stage the ultimate use of the site. Rehabilitation may take several years to accomplish and its cost in respect of specific sites should be foreseen, the most cost-effective rehabilitation techniques depending on local conditions and needs. As far as mining is concerned, rehabilitation can often be started before mining terminates. Gangue can often be used for back filling in open cast mines and the land rehabilitated for various purposes, e.g. agriculture, forestry, recreational use. In special cases there may be a need to restore a specific ecosystem and protect endangered species.

27. The social disturbance when an industrial operation terminates may also be significant. The workforce may be left without other employment possibilities. In these cases often young people move away, leaving an elderly community. Ghost towns may result. Governmental authorities and industry need to foresee ahead of industrial closure the possible mitigating social measures which may be taken.

PART II : MINING AND PROCESSING OF IRON ORE

PROCESS DESCRIPTION

28. Iron ore for the purpose of this review is considered as a naturally occurring, iron-bearing material that can be economically used at a particular place and time under current cost and market-price conditions. According to this definition, what is classed as ore in one place would not necessarily be classed as ore in another place, and what may not be classed as ore now could well be so fifty or a hundred years from now, depending on technological development and economic conditions.

Mining of Iron Ore

29. There are two methods of mining iron ore : the open pit method, and the underground method. The method chosen for mining depends primarily on (a) the depth of the ore body below the surface, and (b) the character of the rock surrounding the ore body. The open pit method is much preferred. In this method, the valueless overburden is removed leaving the bare ore body exposed. Recovery of the ore is thereby very much simplified and more rapid than by the underground method.

30. Compared to open pit mining, underground mining requires relatively complicated and expensive installations. Restricted movement, air supply and drainage difficulties, and relatively dangerous conditions are other factors which mitigate against the choice of the underground method. This method, nevertheless, is adopted whenever the economics of the method will dictate the choice.

31. Iron oxides in an ore are found mixed with varying amounts of gangue materials such as lime, silica, alumina, magnesia, etc. as well as with variations of these materials. Elements such as sulphur, phosphorus, arsenic, copper, tin and manganese may also be found mixed in. Furthermore, the raw ore straight from the mine generally has undesirable characteristics of size and shape for use in most processes. Putting these raw ores into the furnaces to extract the iron would require excessive amounts of expensive energy in the forms of coal, oil, natural gas and electricity. Most of this energy would be wasted melting out the gangue which is discarded for the most part anyways. It is for this reason that ores are "beneficiated", a process which involves such operations as crushing, screening, blending, grinding, concentrating, classifying and agglomerating.

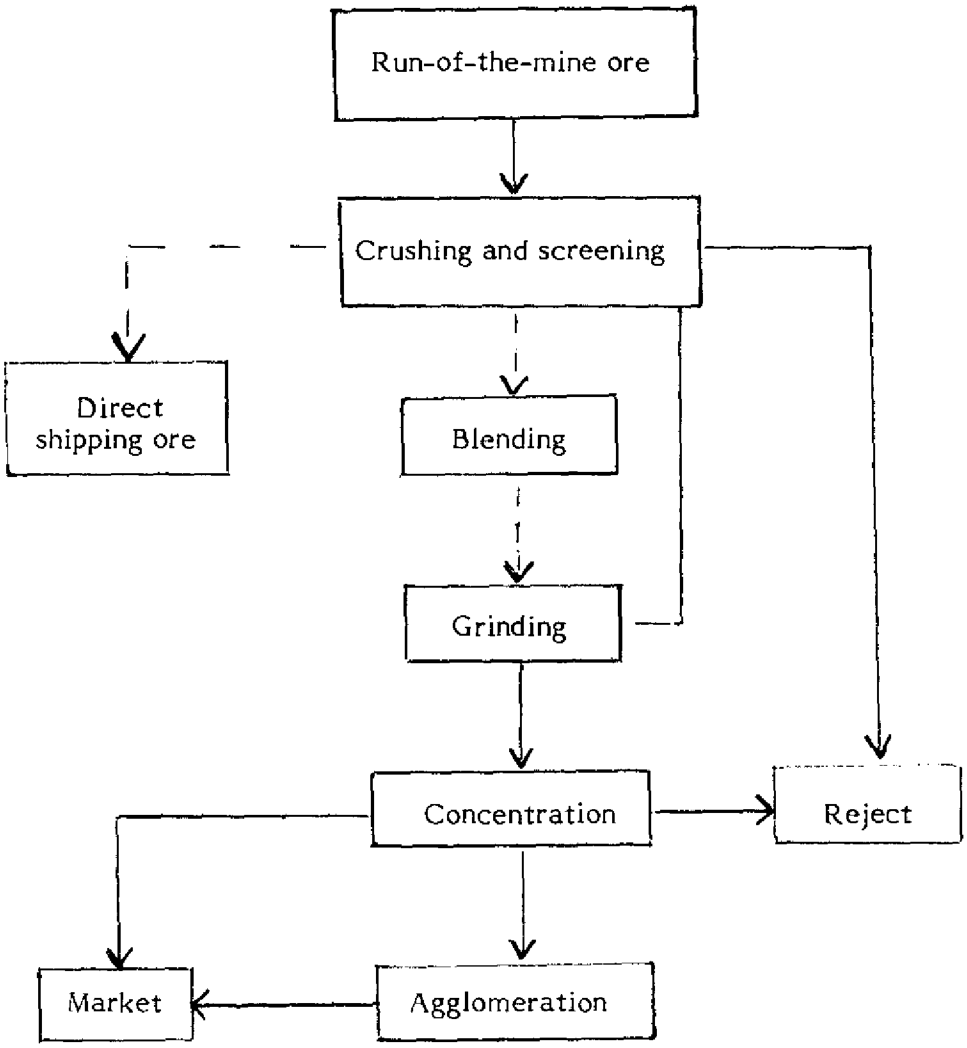
32. The choice of a particular process for beneficiation depends on two main factors :

(i) the differences in structure and mineral content of ores from different deposits ;

(ii) the metallurgical uses intended for the ore.

A generalized flow diagram of the beneficiation process is as follows :

A generalized flow diagram of the beneficiation process



Crushing and screening

33. There are two objectives in the primary operation of crushing and screening, namely : (i) to break down the "run-of-the-mine" ore containing large lumps to a manageable size ; and to effect a primary separation of the iron-rich materials from the gangue. The crushed ore can be screened several times with the different size fractions being directed to different outlets. There are generally three types of crushers used, namely the jaw crusher, the drum crusher and the gyratory crusher. Screening involves passing the crushed ore over several screens with different size openings to separate the ore into different sizes in order to make the most efficient use of the ore in subsequent stages.

Blending

34. The programme at any mine is designed to produce a uniform product. For example, a mine may produce more than one type of ore, or ore may be received from several sources. Variations in the characteristics of these ores can cause disruption in the processes of beneficiation or even in the furnaces for which they are destined. Thus, these ores are "blended". One method is to build up successive layers of different ores into huge piles by means of travelling conveyors. When several thousands of tons have been accumulated, the bedded ore is recovered by a travelling rake which removes the intimately mixed ore from the pile for further processing.

Grinding and Concentration

35. Ores may contain too much gangue material to be used directly, or they may exist in such crystal forms that their metallurgical use is difficult. These ores, after crushing and screening, require fine grinding and concentration.

36. The iron oxide in an ore may be intimately mixed with the gangue in such fashion that the only way to liberate the oxide is to grind it down to a size as fine as flour before being able to separate the materials. The three types of grinders in common use are the rod grinders, the ball grinders and the autogenous grinders. In these machines the crushed ore is fed in one end of the rotating drum and the ground ore comes out the other end. Either water or air may be used to help move the material through the drum.

Concentration

37. With the gradual disappearance of local high-grade, direct shipping ores, investigations began into the possibilities of using lower grade deposits not previously employed, with the adaptation of concentration techniques utilized for other metal ores. Only a few of the many concentration processes available are described below.

38. Heavy-media separation process : This process is known as the "sink float" process and is used for the large, roughly-crushed ore in order to effect a primary concentration. When a mixture of particles of two minerals with different specific gravities is placed in a liquid with a specific gravity intermediate between those of the two minerals, the lighter of the minerals will float while the other will sink.

39. Magnetic concentration : This process takes advantage of the ferromagnetic properties of magnetite and requires only a relatively low-intensity magnetic field. However, it is also applied to certain hematite ores displaying paramagnetic properties in which case a high-intensity magnetic field must be used.

40. Flotation processes : By passing a stream of finely divided bubbles of air in the suspension, chosen minerals can be selectively lifted out to the top of the vessel, where they can be swept off into another vessel.

41. Gravity separation : Humphrey's spiral is a commonly employed gravity separation technique. This device is a narrow trough wound in a helicoidal manner. A slurry is made of the ore and it runs down the spiral and is centrifuged. The heavier grains of iron oxide describe a less eccentric path than the lighter grains of gangue, and thus can be removed from the spiral circuit at any point along the path by appropriate traps.

Agglomeration

42. Powdery or granular iron-bearing material resulting from the ore preparation steps has to be agglomerated into larger sized material which can be used in furnaces. Either heat or pressure or both is used for agglomeration.

43. Pelletizing : Iron ore concentrate is made into roughly spherical shaped balls or "oxide pellets" using the "snowball effect". In this process, the concentrate has a tiny amount of binder, usually bentonite, added to it which acts somewhat like a glue, and just enough water to make a dry mud. At this point, there are two options for the choice of machine which will actually make the pellets : either a "balling drum" or a "disc pelletizer". In either case, some granular material is first added to the machine. This material acts as "seeds" for the balls. As the machine turns, the muddy concentrate is added at a fixed rate and gradually the balls grow in size as they roll about, with the sticky mud adhering to the balls in much the same fashion as building up a large ball of snow by rolling a small snowball in wet snow. When the "green" pellets reach about 1 cm. diameter in size, they are discharged for further processing. The soft "green" pellets are dried and hardened so that they can be shipped and otherwise handled. The resulting hard pellet is called an "indurated" pellet.

44. Induration : Induration is the mechanism whereby the application of heat to a loosely compacted material causes the individual grains to coalesce and grow together without having to be melted in whole or in part. In other agglomeration processes such as "sintering" or "nodulizing", the material is partially melted while in "briquetting" the material is subjected to enormous pressures for compaction. Induration can be carried out by three processes : the travelling-grate system, the shaft furnace system and the grate-kiln system.

45. In the travelling-grate system, the green pellets are coated with a thin layer of fuel (coal or coke) and are continuously fed to a travelling grate. This machine is much like a conveyor constructed of heat-resisting alloy frames on which the pellets are indurated. Under the grate are a series of wind boxes which either draw or blow air according to the required sequence. The pellets are first dried out and preheated, they are then ignited by a gas flame, and the burning or induration is then carried on by a powerful downdraft of air. Upon completion of induration, an updraft of air then cools the indurated pellets before discharge.

46. In the shaft-furnace system, the fuel is incorporated inside the pellet rather than applied as a coating by adding some coal or coke dust to the muddy concentrate. The green pellets are charged through the top of the furnace. As the pellets pass down, they are first dried, then indurated about a quarter of the way down the shaft, where the temperature rises to around 1320° C. From this point on, the indurated pellets are cooled before discharge.

47. In the grate-kiln system, no solid fuel is added to the pellets. The green pellets are dried and preheated on a travelling grate before being discharged into a rotary kiln where they are indurated by hot gases from burning fuel oil or gas. The indurated pellets are then cooled in separate facilities.

The Impact of Mining and Ore Processing on Water Quality

48. Most open pit and underground mines operate below ground water level ; there is a water flow from periphery to the mine site. In order to prevent flooding, a system of water pumps is in constant operation. The water pumped out from the mine site is usually contaminated by salts which were leached from the ground and from the ore body. The salt content may vary from insignificant up to brackish waters. With growing acidity of the rain-fall throughout the whole northern hemisphere, more and more metal salts are leached from the ground to streams and lakes. Most species of plankton and fish are sensitive to salts, especially to heavy metal salts, and cannot survive in higher than their natural threshold concentrations. This condition is often found in areas where there is little calcium in the ground soil. The cost of desalination or neutralization is very high if pre-treatment is needed before mine drainage is disposed of. There should be further appropriate monitoring of water bodies into which discharge is made.

49. Ore beneficiation and concentration require large amounts of water and it is essential to make a prior assessment of water resources and quality of the region in different seasons in relation to other needs as well as those for ore treatment. There may be considerable deleterious social environmental impacts of failure to give adequate consideration to the use of water resources and care should be taken to avoid problems of pollution and salinity as well as to protect the water table. Conservation and economy of water use appropriate to local conditions should be practised.

50. Normally for ore treatment a closed circuit can be operated encompassing the process, settling pond or filter plant back to the process. In order to prevent clogging of a system by gangue some part of the water is removed from the circuit to the mud ponds where the gangue particles settle on the bottom of the pond and the overflow is released to a stream or river. Depending on factors such as the gangue particle size and specific gravity, water salts content, temperature and viscosity, it may take hours, days or months to reduce particle content in the overflow to acceptable concentrations. Provision should also be made for storm water overflow. These factors have to be studied in designing the water circuit. Care must be taken to ensure that toxic reagents, surface activating agents, flotation depressants etc. are not discharged in harmful concentrations. Special precautions should be made in case of accidental spillage. Each mine site is different and environmental protection measures required will depend on physical and chemical properties of the ore body, the available water, the ore treatment processes employed and the specific water uses in the region.

The Impact of Mining and Ore Processing on Air Quality

51. Whilst mining, beneficiation, concentration and agglomeration may not be major sources of air pollution, dust and particulate matter are frequently a source of nuisance. There may also be the special problems of toxic dusts in case of certain ores, e.g. silica containing dusts. Strict attention to well known methods of dust containment should be given in mining, especially under dry and windy conditions. Crushing, milling of ores and concentrate drying may also be sources of dust which may be readily controlled using cyclones, fabric filters or electrostatic precipitators. The induration process may release significant amounts of particulate matter, which may also be controlled using fabric or electrostatic filters. Particulate air pollution could also be a problem with the use of coal as a fuel in pelletizing.

52. Gaseous emissions, particularly sulphur and nitrogen oxides, arise from fuel combustion in ore processing, drying and agglomeration. The amount of sulphur oxides depends on the sulphur content of the fuels. Techniques are available for reducing nitrogen oxide formation. In the specific cases of ores containing fluorine compounds, hydrogen fluoride emission may be a problem and cause damage to vegetation or grazing animals in the region. Wet or dry gas scrubbing techniques are available to control these emissions, if necessary.

Noise

53. Noise and vibration from equipment and use of explosives can be a nuisance to populations near mine sites. Techniques are available to minimize noise and vibration in mining. Noise also arises from ore crushing and grinding, as well as from materials handling and transport. Its impact on the surrounding community may be mitigated through equipment and building design. Plants housing crushing and grinding equipment can be acoustically insulated. There exist a number of passive noise abatement measures, including noise barriers, screens or mounds, which offer the additional possibilities of landscaping the area and planting it with trees and scrubs.

Solid Waste Arising from Mining and Ore Processing

54. Gangue has to be disposed of from mining operations. It is often used for back filling, but may have to be stockpiled initially. Tailings arising from concentration and superbeneficiation also have to be disposed of. Wise resource management calls for careful consideration to be given to tailings disposal management and site rehabilitation. Certain minerals are used for multi-extraction. In respect of others, the technical and economic conditions may not currently favour multi-extraction, but the possibility of further resource recovery should be kept open should circumstances change. These considerations, as well as possible toxic materials within the tailings, have an important bearing on techniques for tailings storage and disposal.

55. Tailings are most commonly disposed of on land. Disposal in rivers and lakes is also practised in some countries, usually by pipelining. Sea disposal is also a possibility, although not practised in relation to iron ore. Before ore treatment begins it is essential to assess the environmental impact of the chosen tailings disposal procedure and foresee not only the resource recovery possibilities, but also the rehabilitation and ultimate use of the site in accordance with local conditions and needs.

56. For disposal on land, tailings dams must be designed in consideration of the local physical conditions. Significant areas of land may be taken out of use (e.g. for agriculture) at least for a period of a number of years. During tailings disposal, protective measures against erosion and dust should be taken (tailings are usually kept under water, then the dam revegetated when filled). Filled impoundment areas should be rehabilitated. Compacted surface on which equipment may be used may be needed and a soil cover and fertilization provided depending on use. Vegetation, initially adapted to local conditions and resistant to materials in the tailings, should be planted. The subsequent use of the land, e.g. for agriculture, forestry or grazing, should be carefully monitored and managed to avoid undesirable possible build-up of toxic materials. The rainwater run-off (surface water) and the water table should be monitored during use of the tailings dam and after rehabilitation. The run-off is often collected and recycled or appropriately treated before discharge so as to avoid pollution.

57. For disposal in water or at sea it is essential to undertake beforehand a comprehensive physical and ecological pre-audit to assess, amongst others, the sedimentation and dispersion characteristics *in situ* and the possible effects on bottom life and the aquatic ecosystem.

Ore Mining and Processing : Worker Health and Safety

58. Health and safety are very important aspects to be considered in mining and reference is made to ILO Tripartite activities in this field(+). Areas of particular concern are dust and possible problems of toxic dusts from certain ores ; noise and vibration from equipment, maintenance shops and use of explosives ; air pollution from diesel motors and ancillary equipment ; accidents.

59. In relation to ore processing, there are within the working environment problems of noise which can be mitigated by equipment and process design ; of dust where standard techniques for dust suppression and control are available ; and of accidents. Particular care is needed in handling toxic reagents. Adequate ventilation should be provided and clean up procedures in case of spillage.

Ore Transportation and Storage

60. Consideration must be given to the environmental aspects of transportation of ore from the mine to the mill and of ore concentrate to the ore facilities and reduction plant. Conveyor belts, pumping, road, rail and shipping, etc. are often used. Due to the volume of material transported, it will be necessary to provide specific transportation infrastructure, which has its own environmental impact (both physical and social). Dust is usually the main problem, which calls for hooding of transfer and trans-shipment points with dust arrestment, covered containers, washing of roads and loading areas, etc. Consideration must also be given to the transport of reagents, such as depressants, flocculants,etc. and explosives, into the mine area, especially in mountainous and poorly accessible regions. There are also the health and safety aspects of transportation.

61. Large volumes of material are involved in storage and handling. Stocks may either be kept in covered constructions or left open with temporary covers. The main problems arise from dust and water pollution. Dust can be controlled by dampening and/or covering stockpiles. There may be need for storm water run-off control and water treatment. Materials may become entrained in the air during transportation and handling. Conveyor belts may need to be covered and transfer points hooded. Dust arrestment equipment (cyclones, fabric filters or electrostatic precipitators) may be needed at transfer points.

(+) See Report of Third Tripartite Technical Meeting for Mines other than Coal Mines, ILO, Geneva 1975.

PART III : REDUCTION

DESCRIPTION OF THE MAIN PROCESSES+

62. A list of the different direct reduction installations throughout the world is given in Table 5, which is taken from Metal Bulletin Monthly (December 1981) and which was brought up to date during the UNEP/UNIDO meeting of experts held in Puerto Ordaz, Venezuela (April 1982)(9). 41 plants are operational, 2 have an intermittent production and 1 is being modified. 7 plants are under construction or being commissioned. 6 plants have been ordered and 17 are planned. Moreover a few other direct reduction plants have been established, particularly in Japan, for treating iron waste dust containing high Zn and Pb.

63. Direct reduction units can be classified in two groups, depending on the nature of the reductant : (i) gaseous ; (ii) solid. For the gaseous reduction, three technologies can be distinguished : (a) shaft furnace ; (b) fixed bed ; (c) fluidized bed. By contrast, one technology is preferentially applied with the reduction by solid fuel ; that is the rotary kiln. Incidentally, however, one solid reductant process uses a shaft furnace.

64. Figures 5 to 14 give the flowsheets of the better known processes, namely :

(a) MIDREX, HyL III, NSC-DR, ARMCO and KINGLOR METOR for the shaft furnace ;

(b) HyL I and II for the fixed bed ;

(c) FIOR for the fluidized bed ;

(d) SL/RN, CODIR and DRC for the rotary kiln.

(a) Shaft Furnace Processes

(i) Midrex Process *

65. Developed in the mid-1960s at Toledo, Ohio, by Midland-Ross Corporation's Surface Combustion Division, the Midrex process has experienced rapid rates of development and commercial introduction over the past 15 years. In December 1973, ownership of the process was acquired by Midrex Corporation of Charlotte, North Carolina, a subsidiary of Korf Industries Inc. The first commercial installation incorporating the Midrex process and the first commercial direct-reduction plant in the United States was constructed at Oregon Steel Mills in Portland, Oregon, and was placed in operation in 1969. Over the past decade, the Midrex process has become established as the world's leading producer of steelmaking-grade DRI, its 1980 output amounting to 4.4 million tons or 55.5% of the world's total.

66. In the Midrex process (see Figures 5 and 6), a top-charged burden of continuously descending iron oxides is heated and reduced in the top portion or reduction zone of a vertical-shaft furnace by means of countercurrent interaction with an ascending stream of hot reducing gas (at a temperature of 850 to 900°C), which is introduced toward the bottom of the reduction zone and withdrawn at the top for cleaning and recirculation. The resulting DRI is cooled by a recirculated, non-oxidizing gas mixture in the shaft's lower, conical portion or cooling zone. The required reducing gas is produced in a multiple-tube, catalytic reformer from a mixture of natural gas and cleaned off-gas from the reduction process.

[+] In this section, descriptions of processes marked with an asterisk * are taken from (10) in which, unless otherwise stated, 1 ton represents 2,000 pounds.

TABLE 5

WORLD DIRECT REDUCTION FIGURES

Country, company	Location	Process	Reductant	Capacity	Start-up	Status
ARGENTINA						
Acindar	Villa Constitucion	Midrex	Gas	420,000	1978	Operational
Dalmine Siderca	Campana	Midrex	Gas	330,000	1976	Operational
Sidersur	San Antonio Est	-	Gas	550,000	1983	Planned
AUSTRALIA						
Hamersley	Dampier	-	Gas	1,000,000	-	Tendering
BRAZIL						
Aços Finos Piratini	Charqueadas	SLRN	Coal	65,000	1972	Operational
Cosigua	Santa Cruz	Purofer	Gasified Oil	330,000	1976	Dismantled
Usiba	Bahia	HYL	Gas	225,000	1974	Operational
BURMA						
Government	Mandalay	Kinglor Metor	Coal	20,000	1981	Operational
Government	Mandalay	Kinglor Metor	Coal	20,000	-	Planned
CANADA						
Niagara Metals	Niagara	Accar	Gas + oil	30,000	1973	Pilot plant
Sidbec-Dosco	Contrecoeur	Midrex	Gas	400,000	1973	Operational
Sidbec-Dosco	Contrecoeur	Midrex	Gas	625,000	1977	Operational
Stelco	Bruce Lake	SLRN	Coal	360,000	1975	Shut down
Sudbury Metals	Sudbury	Accar	Gas + oil	240,000	1976	Shut down
EGYPT						
National Iron & Steel Co.	El Dikheia	-	Gas	800,000	1985	Planned
ECUADOR						
Ecuasider	Machala	-	Gas	200,000	1983	Planned
FEDERAL REPUBLIC OF GERMANY						
Hamburger Stahlwerke	Hamburg	Midrex	Gas	400,000	1972	Shutting down
Nordferro	Emden	Midrex	Gas	880,000	1981	Operational
Thyssen Niederrhein	Oberhausen	Purofer	Gasified-oil	150,000	1971	Dismantled
INDIA						
Bihar State	Ranchi	SLRN	Coal	120,000	1983	Planned
Orissa State	Orissa	Accar	Gas + coal	150,000	1982	In construction
Sponge Iron India Ltd	Paloncha	SLRN	Coal	31,000	1980	Operational
Sponge Iron India Ltd	Paloncha	SLRN	Coal	31,000	-	Planned
Tata Iron & Steel	Jamshedpur	Tata	Coal	5,000	1979	Pilot Plant
HEC	Ranchi	SLRN	Coal	120,000	1984	Planned
INDONESIA						
PT Krakatau Steel	Kota Baja	HYL	Gas	560,000	1978	Operational
PT Krakatau Steel	Kota Baja	HYL	Gas	560,000	1980	Operational
PT Krakatau Steel	Kota Baja	HYL	Gas	1,120,000	1982	
IRAN						
Nisic	Ahwaz	Purofer	Gasified-oil	330,000	1977	Not operational
Nisic	Ahwaz	HYL	Gas	1,030,000	1982	Not completed
Nisic	Ahwaz	Midrex	Gas	1,000,000	1982	Not completed

TABLE 5 (cont...)

Country, company	Location	Process	Reductant	Capacity	Start-up	Status
IRAQ						
Soidac	Khor Al Zubair	HYL	Gas	543,000	1980	On hold
Soidac	Khor Al Zubair	HYL	Gas	925,000	-	No progress
ITALY						
Danieli & C	Buttrio	Kinglor Metor	Coal	10,000	1973	Pilot plant
Arvedi	Cremona	Kinglor Metor	Coal	40,000	1976	Shut down
Finsider	Piombino	Flufer	Gas	130,000	1981	Pilot plant
JAPAN						
Hitachi Metals	Yasuki	Wiberg	Coke breeze	10,000	1964	Operational
Kawasaki Steel	Chiba	Kawasaki	Coke breeze	60,000	1968	Operational
Kawasaki Steel	Mizushima	Kawasaki	Coke breeze	180,000	1974	Operational
Kawasaki Steel	Chiba	Kawasaki	Coke breeze	180,000	1977	Operational
Nippon Steel	Muroran	Koho	Coke breeze	36,000	1971	Operational
Nippon Steel	Hirohata	NSC	Coal + gas	150,000	1977	Intermittent
NKK	Fukuyama	SLRN	Coal	350,000	1974	Operational
Sumitomo Metal	Wakayama	Kubota	Coal	350,000	1975	Operational
Sumitomo Metal	Kashima	Kubota	Coal	100,000	1975	Operational
Sumitomo Metal-CE Lummus	Niihama	LS-Rior	Coke	3,000	1979	Pilot plant
Tohoku Satetsu	Ominato	Kawasaki	Coal	24,000	1957	Operational
REPUBLIC OF KOREA						
Inchon Iron & Steel	Inchon	SLRN	Coal	150,000	1970	Shut down
LIBYA						
Government	Misurata	Midrex	Gas	1,100,000	1983	Under contract
MALAYSIA						
Government + partners	Labuan	Midrex	Gas	650,000	1984	Under contract
Government + partners	Terengganu	Nippon Steel	Gas	600,000	1984-5	Under contract
MEXICO						
Hylsa	Monterrey	HYL	Gas	105,000	1957	Operational
Hylsa	Monterrey	HYL III	Gas	250,000	1970	Operational
Hylsa	Monterrey	HYL	Gas	420,000	1974	Being modified
Hylsa	Monterrey	HYL	Gas	750,000	1984-5	Under contract
Hylsa	Puebla	HYL	Gas	250,000	1969	Operational
Hylsa	Puebla	HYL	Gas	639,000	1977	Operational
Premexsa	Altamira	HYL	Gas	1,000,000	1983-4	Under contract
Sicartsa	L. Cardenas	HYL III	Gas	2,000,000	1983-4	Under construction
Tamsa	Vera Cruz	HYL	Gas	235,000	1967	Operational
NEW ZEALAND						
NZ Steel	Glenbrook	SLRN	Coal	160,000	1970	Operational
NZ Steel	Glenbrook	SLRN	Coal	96,000	1987	Planned
NIGERIA						
Delta Steel	Warri	Midrex	Gas	1,000,000	1982	Commissioning
PERU						
Siderperu	Chimbote	SLRN	Anthracite/ coke breeze	120,000	1980	Operational
Siderperu	Chimbote	Krupp-Codir	Oil	200,000	1983	Contract on hold

TABLE 5 (cont...)

Country, company	Location	Process	Reductant	Capacity	Start-up	Status
PHILIPPINES						
Government	Cagayan del Oro	-	Coal	1,200,000	1985	Planned
National Steel Corp	Iligan City	-	-	400,000	-	Planned
QATAR						
Qatar Steel Co	Umm Said	Midrex	Gas	400,000	1978	Operational
SAUDI ARABIA						
Sabic	Al Jubail	Midrex	Gas	800,000	1983	Under construction
SOUTH AFRICA						
Dunswart Iron & Steel	Benoni	Codir	Coal	120,000	1973	Operational
Dunswart Iron & Steel	Benoni	Codir	Coal	180,000	1983	Planned
Highveld Steel & Vanadium	Witbank	SLRN	Coal	320,000	1968	Operational
Highveld Steel & Vanadium	Witbank	SLRN	Coal	300,000	1977	Operational
Highveld Steel & Vanadium	Witbank	SLRN	Coal	60,000	1981	Under construction
Scaw Metals	Germiston	DRC	Coal	75-100,000	1983	Under construction
Iscor	Vanderbijilpark	SLRN	Coal	600,000	-	Planned
SPAIN						
Presursa	Huelva	Midrex	Gas	750,000	1985	Under letter of intent
SWEDEN						
Granges	Oxelosund	Hoganas	Coke breeze	35,000	1954	Operational
Sandvik AB	Sandviken	Wiberg	Coke breeze	24,000	1952	Operational
SKF Stahl	Uddelholm	Wiberg	Coke breeze	40,000	1954	Dismantled
SKF Stahl	Hofors	Wiberg	Coke breeze	30,000	1960	Dismantled
SKF Stahl	Hofors	Plasmared	Plasma	70,000	1981	Pilot plant
TRINIDAD						
Iscott	Point Lisas	Midrex	Gas	400,000	1981	Operational
Iscott	Point Lisas	Midrex	Gas	400,000	1982	Under construction
UNITED KINGDOM						
British Steel Corp	Hunterston	Midrex	Gas	800,000	1979	Never commissioned
UNITED STATES OF AMERICA						
Armco	Houston	Armco	Gas	330,000	1972	Intermittent
Direct Reduction Corp	Rockwood	DRC	Coal	50,000	1978	Pilot Plant
Georgetown Ferreduction	Georgetown	Midrex	Gas	400,000	1971	Operational
Gilmore Steel Corp	Portland	Midrex	Gas	300,000	1969	Shut down
Hecla Mining	Casa Grande	SLRN	Coal	60,000	1975	Shut down & for sale
Texas Ferreduction	Beaumont	Midrex	Gas	400,000	1980	Postponed
St. Joe Minerals	Pea Ridge	-	Coal	-	1984	Planned
Midrex	Charlotte	Midrex EDR	Coal	2,000	1977	Pilot planned
Midrex	Charlotte	Midrex EDR	Coal	200,000	-	Planned
USSR						
OEMK	Kursk	Midrex	Gas	4,800,000	1983-5	Under construction

TABLE 5 (cont...)

Country, company	Location	Process	Reductant	Capacity	Start-up	Status
VENEZUELA						
Fior de Venezuela	Matanzas	Fior	Gas	300,000	1976	Operational
Minorca	Puerto Ordaz	HIB	Gas	650,000	1973	Shut down
Sidor	Matanzas	Midrex	Gas	355,000	1977	Operational
Sidor	Matanzas	HYL	Gas	360,000	1977	Operational
Sidor	Matanzas	Midrex	Gas	1,200,000	1979	Operational
Sidor	Matanzas	HYL	Gas	2,100,000	1980	Operational
YUGOSLAVIA						
Rudnici-Zelezara	Skopje	SLRN	Lignite char	-	1968	Shut down &
Zambia						
Tika	Solwezi	HYL	Gas naphtha	250,000	-	Abandoned

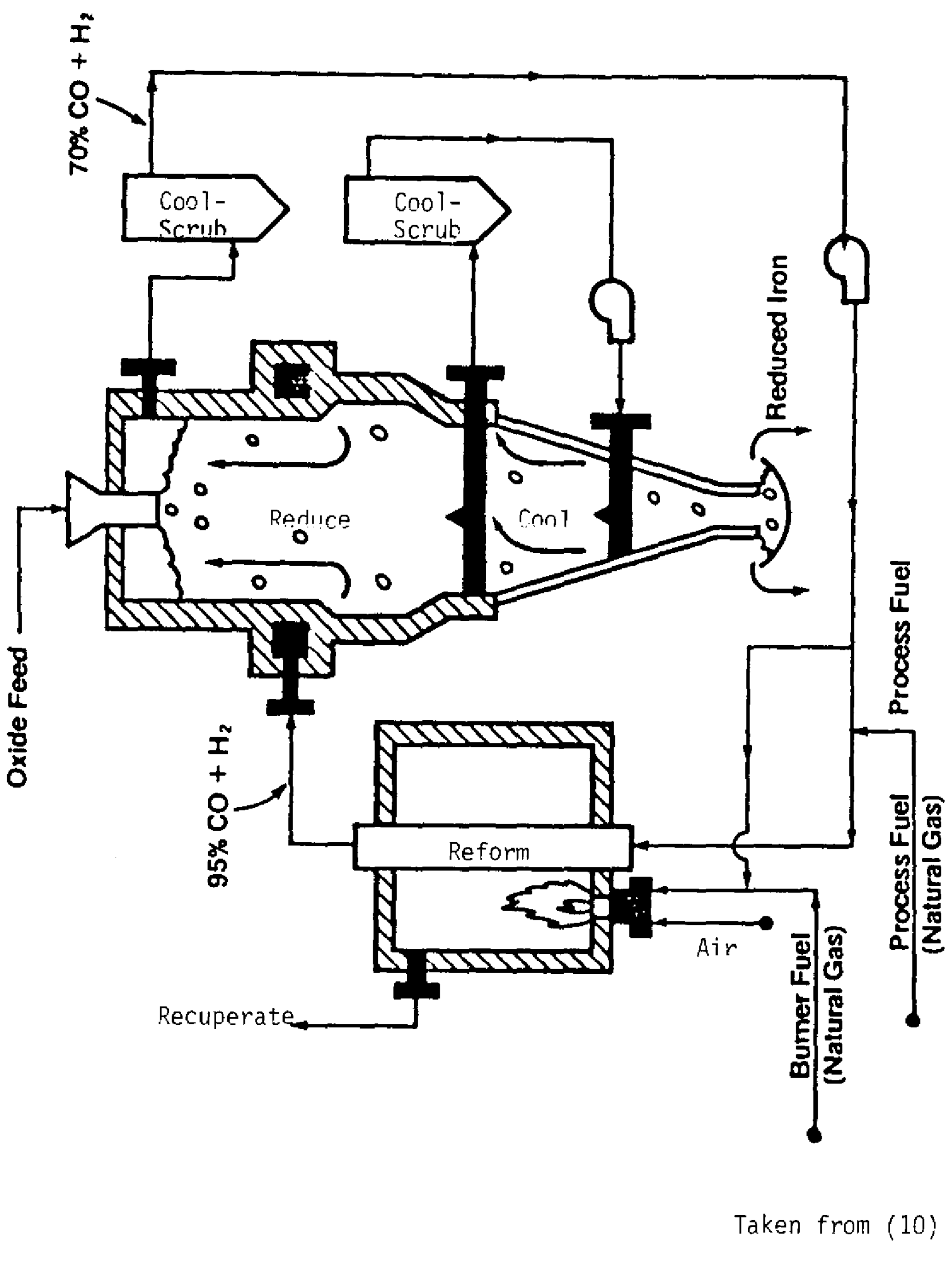
67. As shown in Figure 5, in the standard flowsheet for the Midrex process the upper reduction zone of the shaft furnace, which is circular in cross section and lined with refractories, accounts for somewhat more than one-half of the shaft's total height, the balance comprising the unlined cooling zone. Uniform distribution of the iron-oxide burden within the shaft is accomplished by a system of feeding tubes supplied by a conical hopper. The required reducing gas is introduced through a series of entry ports situated around the reduction zone's circumference and, having been spent, is withdrawn through an exit port situated near its top. A similar system of gas ports is incorporated into the cooling zone, with high-efficiency scrubbers and cooling towers employed to reprocess the off-gas prior to its being recirculated. In charging the iron-oxide burden and discharging the finished DRI (at a temperature of approximately 50°C), inert gas is used to seal the shaft, circumventing the need for valves or locks. To insure uniform descent of the burden, cluster breakers are situated beneath the reduction zone, while a discharge feeder beneath the cooling zone determines the burden's retention time in the shaft and the rate of product removal.

68. The alternate Midrex flowsheet in Figure 6 is employed with iron ores having higher sulphur contents of up to 0.02%, the modifications of the standard flowsheet being designed to prevent the resultant sulphur in the off-gas from poisoning the gas reformer's catalyst. In the alternate flowsheet, off-gas from the reduction zone is circulated through the cooling zone prior to being used in the reformer, its sulphur content being absorbed by the DRI rather than the catalyst. For situations where coke-oven gas can be made available for direct-reduction purposes, Midrex has developed further process modifications to accommodate coke-oven gas containing up to 200 ppm by volume of sulphur.

69. Because of its efficient gas-reforming system and the inherent advantages of its continuous operation, the Midrex process results in low rates of energy consumption and labour utilization. The gas reformer, developed by Midrex to convert natural gas to reducing gas, uses oxygen from the reduction shaft's iron-oxide burden to continuously crack the natural gas and since no additional oxygen carriers are needed, investment and operating costs have been favourable. Top-gas from the reduction shaft is completely utilized, approximately two-thirds by recycling through the reforming process, with the remaining one-third used to heat the reformer. The reformed reducing gas has a low water-vapour content and does not require quenching before introduction into the reduction shaft, resulting in additional energy efficiencies.

70. Although the process can reduce both iron-oxide pellets and lump ore, the latter can result in a higher incidence of fines and a consequent decrease in throughput. The final DRI output generally exhibits a high and uniform degree of metallization at or above the desired 92% level. Variations in its carbon content can be obtained, and sulphur levels can be effectively controlled. If the DRI is to be stockpiled in the open or transported over long distances, it should receive passivation treatment, which Midrex has commercialized as the Chemaire oxidation-inhibiting process. Since the first commercial Midrex unit was placed in operation in 1969, process refinements have regularly evolved, affording reductions in energy requirements and permitting the scale-up of individual production modules.

FIGURE 5

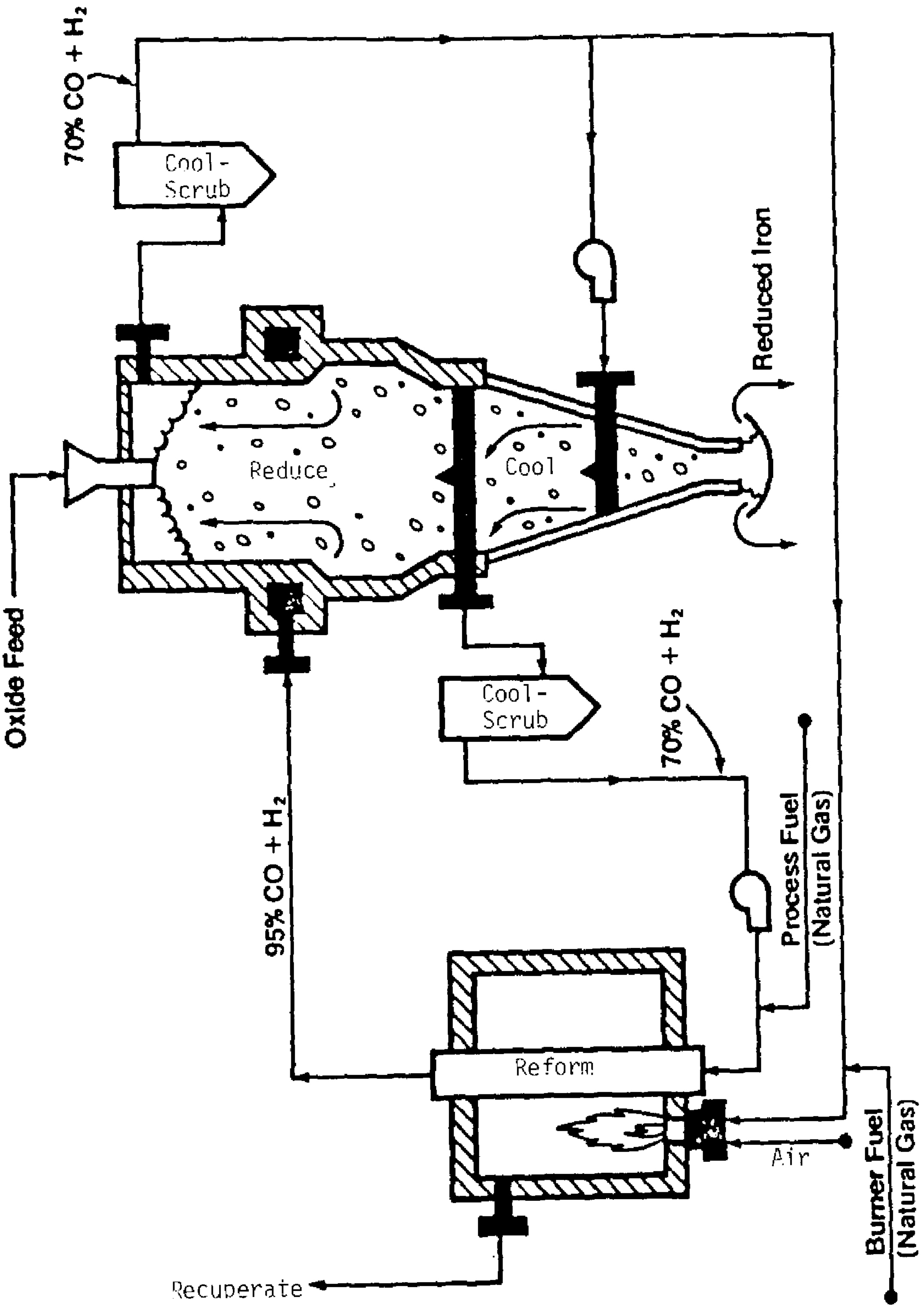


Standard Flowsheet for the Midrex Process

Taken from (10)

FIGURE 6

Alternate Flowsheet for the Midrex Process



Taken from (10)

(ii) HyL III Process*

71. In 1967, Hojalata y Lamina SA of Mexico (HyL) initiated a research and development programme in the field of continuous rather than fixed-bed direct reduction. The eventual result, a new-generation process named HyL III, is currently in its initial marketing phase, following five years of pilot-plant experience starting in 1975 and a year of successful trials at a full-scale plant retrofitted to the commercial HyL unit that was placed in operation at Monterrey in 1960. A number of unique design features incorporated into the process permit high-temperature, high-pressure reaction, the use of hydrogen-rich reducing gas, and independent control of product metallization and carburization. Their combined purpose is to accelerate reduction time, permit the use of smaller equipment units, maximize energy efficiency, and ensure finished-product uniformity and stability. Compared to the conventional HyL plant below, the new process effects major changes in the reduction stage by employing one moving-bed reactor instead of four fixed-bed retorts, and one gas preheater and scrubber operating continuously instead of four operating intermittently. The use of air preheaters or combustion chambers is likewise eliminated.

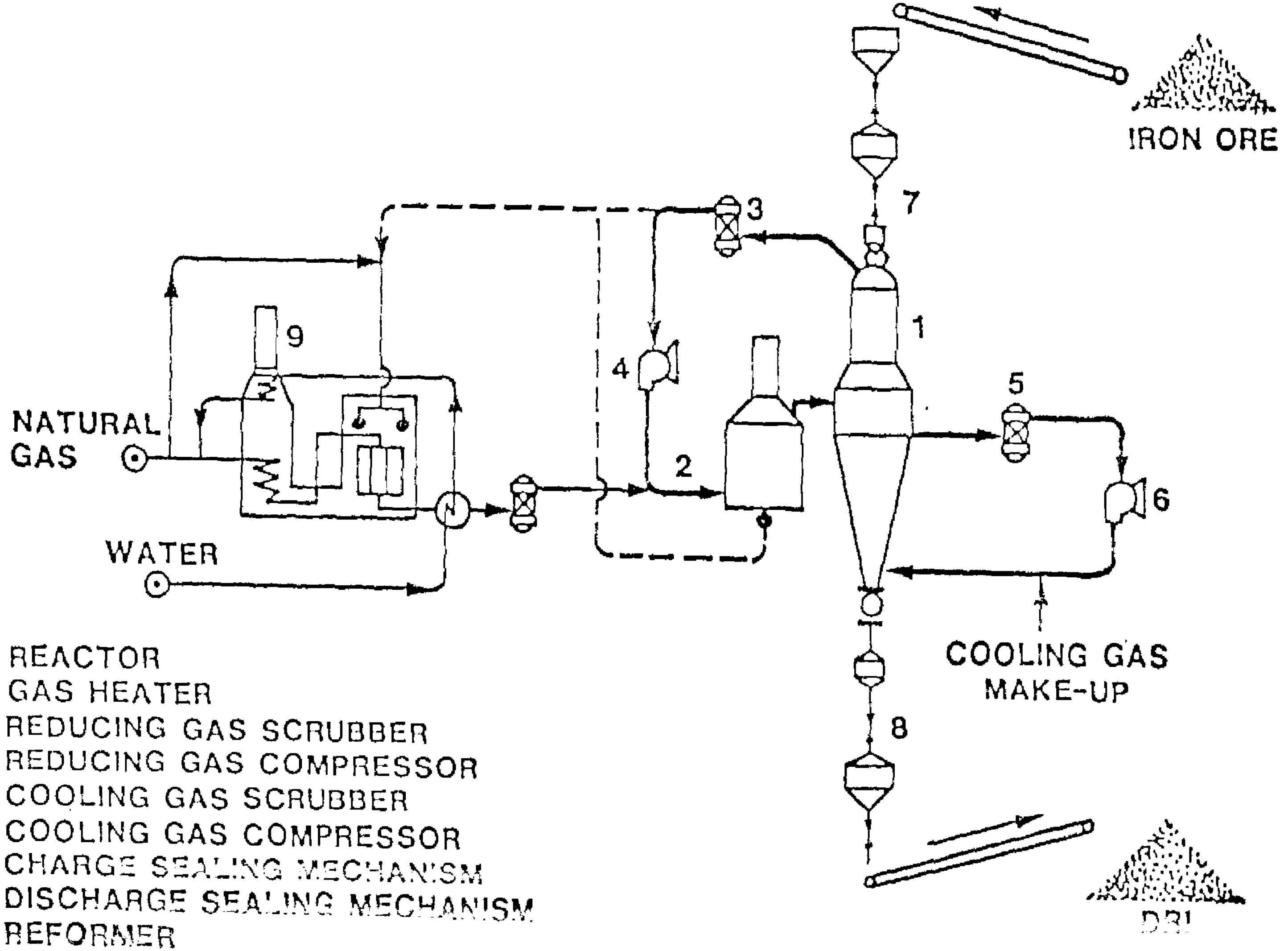
72. The flow sheet in Figure 7 indicates the major elements and operating stages of the HyL III process. An automated pressure-lock system of sealing mechanisms is used to introduce the iron-ore charge into the reactor vessel, which operates at a high gas pressure of four or more atmospheres. Because of the reactor's high pressure, the locks in the charging-bin system operate intermittently, permitting ore to be fed into its upper bins at atmospheric pressure for subsequent pressurization and discharge into a distributing bin, which continuously charges the reactor by means of feeding tubes. A rotary valve regulates the continuous gravity flow of the charge downward through the reactor's reduction and cooling zones, and finished DRI is removed from its bottom by means of sealing mechanisms similar to those employed in the charging operation. Upon removal, the DRI has a uniform temperature below 50°C and as in the conventional HyL process, it has a carbon coating and can be stored and shipped without additional treatment.

73. In the upper part of the reactor or its reduction zone, the descending iron-ore charge meets an upward flow of hot reducing gas from a gas heater, which receives top-gas from the reactor, after it has been cooled, scrubbed and compressed, as well as make-up gas from a natural-gas reformer. Top-gas not recycled back to the gas heater is used as fuel for the heater and reformer, together with any additional natural gas required to meet the thermal requirements of the process. The cooling zone in the lower part of the reactor is supplied with cooling gas that is essentialy recycled through a scrubber and compressor, with suitable make-up gas fed as needed into the recycled stream. Cooling gas can also be removed from the circuit to adjust the gas composition and obtain the atmosphere required to produce a desired degree of cooling and carbon content (within an approximate range of 1.0% to 4.0%) in the final DRI product.

74. The gas reformer used in conjunction with the HyL III process is essentially the same as that designed for fixed-bed HyL plants and operates independently of the reduction section. In the reduction reactor, an isobaric zone prevents the mixing of gases in the upper reduction and lower cooling loops. The reactor's interior is unique in that it has no moving parts or cluster breakers, so that the generation of fines is minimized. While ore reduction occurs essentially in the reduction zone, the carbon content of the DRI is adjusted in the cooling zone, thereby permitting the independent control of product metallization and carbon content.

FIGURE 7

HYL III - SHAFT FURNACE



1. REACTOR
2. GAS HEATER
3. REDUCING GAS SCRUBBER
4. REDUCING GAS COMPRESSOR
5. COOLING GAS SCRUBBER
6. COOLING GAS COMPRESSOR
7. CHARGE SEALING MECHANISM
8. DISCHARGE SEALING MECHANISM
9. REFORMER

75. The full-scale HyL III plant at Monterrey was built starting in April 1978, and went into operation in September 1979. Its original design capacity of approximately 615 tons per day was increased approximately 30% by a number of process modifications made in its initial operating stages. The gas-inlet temperatures employed have ranged from 800° to 940°C and product metallization rates of up to 93% have been realized using iron-ore pellets from a variety of sources, as well as lump-ore/pellet mixtures.

(iii) NSC-DR Process+

76. 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 has since been dismantled. Today there is no commercial NSC-DR plant. 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 desulphurized, is mixed with steam which is generated in the heat recovery section of the reformer. The mixture is then catalytically reformed in presence of a nickel based catalyst in the reformer tubes. It is reported that NSC-DR proposes to use the Topsoe reformer. It should be mentioned that in the demonstration plant at Hirohata works, reducing gas was generated by cracking heavy fuel oil in a Texaco gasification unit. The 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 a reductant is given in Figure 8. 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 has not been tried out at Hirohata.

77. The special features of the NSC-DR process are :

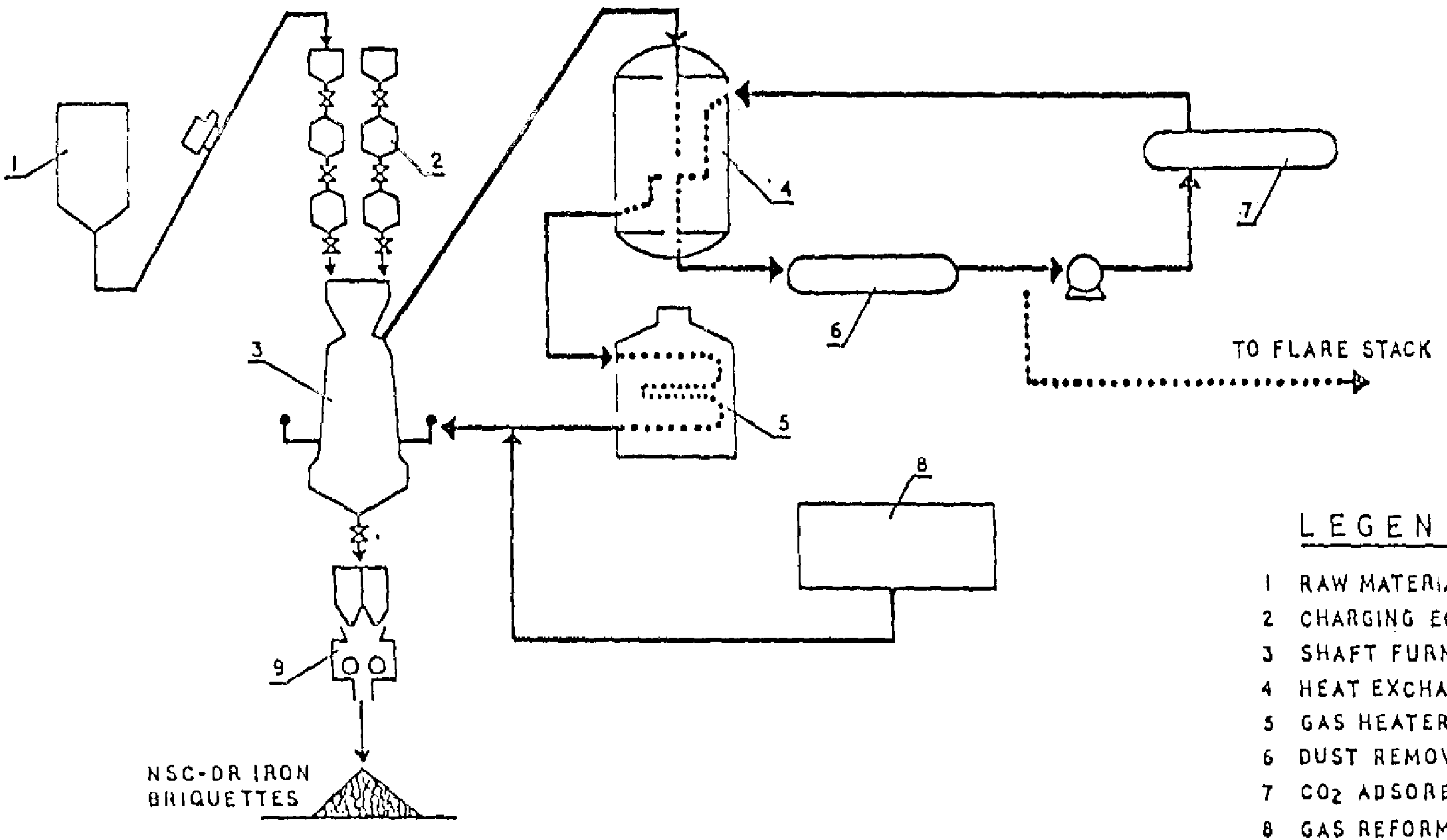
- Feed gas pressure of up to 6 atmospheres.
- Partial use of top gas as recirculated reducing gas in the shaft furnace.
- Addition of soot (unburned carbon) for preventing raw materials clustering.
- Double seal valve system for charging and discharging.
- Hot briquetting of sponge iron (which was not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

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 the Texaco reformer. There are no limitations in the sulphur content of the ore feed as the recycled top gas is desulphurized during carbon dioxide removal by the MEA process before being used in the shaft. The product quality achieved at the pilot plant generally had a degree of metallization of 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.

+ taken from (11).

FIGURE 8

FLOWSHEET FOR THE NSC - DR PROCESS



LEGEND

1 RAW MATERIAL STORAGE
2 CHARGING EQUIPMENT
3 SHAFT FURNACE
4 HEAT EXCHANGER
5 GAS HEATER
6 DUST REMOVER
7 CO_2 ADSORBER
8 GAS REFORMING FURNACE
9 BRIQUETTING MACHINE

(Taken from 10)

78. The material handling system is similar to other shaft furnace processes. For steam reforming the Topsoe reformer will be used, which is similar to the Pullman-Kellog reformer in principle. The cleaned off-gas is desulphurized, 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 pressurized 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, scrape 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.

(iv) ARMCO Process*

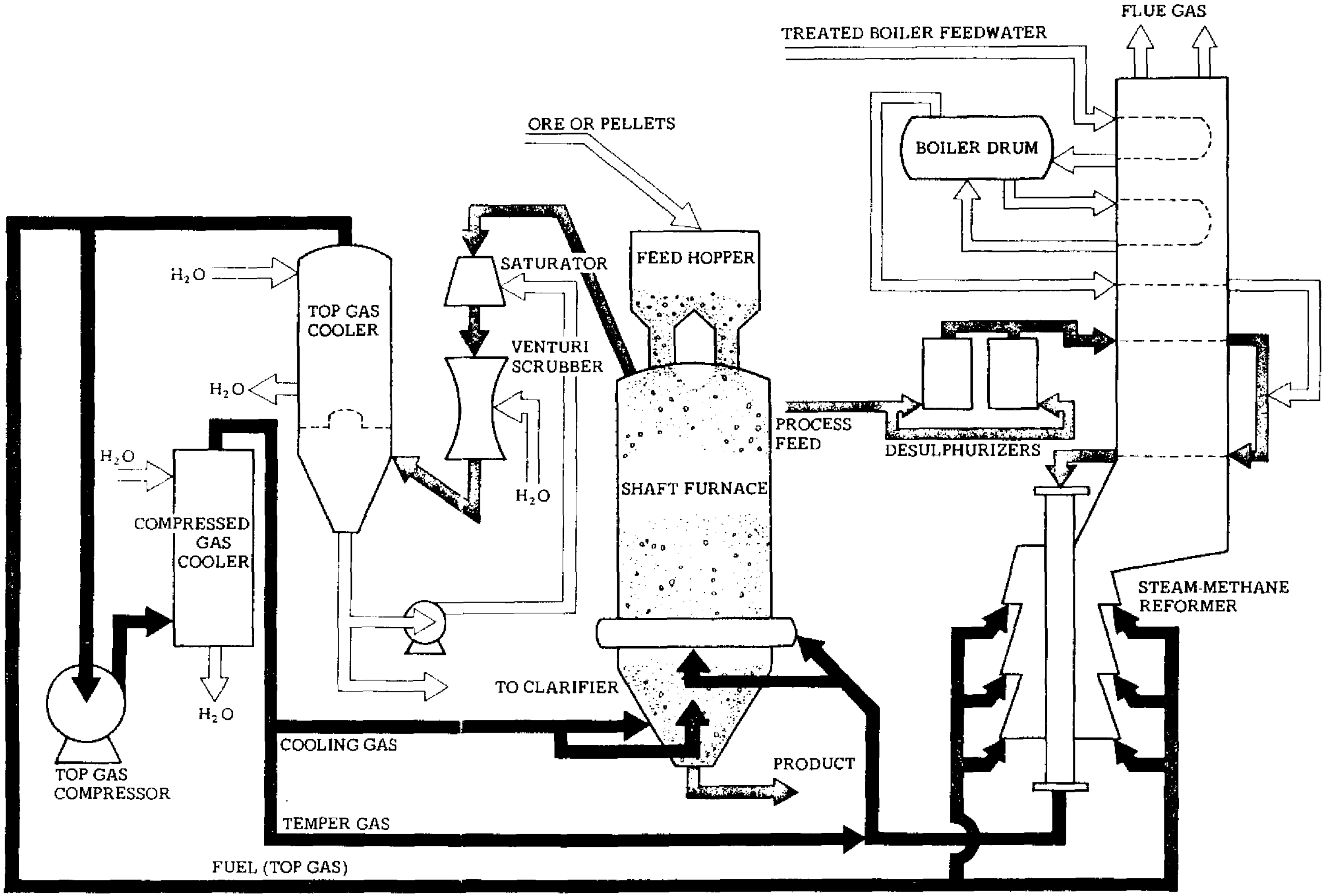
79. In 1962, direct reduction research at Armco Incorporated was accelerated in response to an increasing need for high-quality iron units at the company's Kansas City electric-furnace steel plant. A pilot facility was constructed at the plant in 1963, incorporating a vertical, moving-bed shaft furnace and reformed natural gas to produce 50 tons of DRI per day. The pilot unit's design was based on information gathered from bench tests on the gravity flow of pellets in a shaft with countercurrent gas flow and from operating experience on a laboratory pilot facility capable of producing one ton of DRI per day. In conjunction with this research, Armco experimented with alternate means of reducing-gas generation, including the partial oxidation of natural gas with oxygen, as well as pebble-stove reforming with carbon dioxide from spent reducing gas. The pebble-stove method was adopted for use on the Kansas City pilot unit.

80. The pilot unit's operation was terminated in 1966, and based on its successful performance and the desirability of providing DRI to Armco's steelmaking facilities at Kansas City, Sand Springs, and Houston, a decision was made in 1969 to build a commercial direct reduction unit based on the Armco process. Houston was selected as the plant site because it afforded advantages in terms of the cost and availability of natural gas and because of inadequate scrap supply in the general area. Subsequent to the shutdown of the Kansas City pilot unit, new gas-reforming technology evolved, leading to the selection of direct-fired, catalytic reforming furnaces in place of a pebble-stove reforming unit. The Houston plant, the only commercial Armco plant ever constructed, went into operation in 1972. It had a rated capacity of 365 thousand annual tons when it was shut down in May 1982 on expiration of its long-term contract for economically priced natural gas.

81. The Armco process (see Figure 9) employs a vertical-shaft furnace with countercurrent interaction between a top-charged, continuously descending burden of iron oxides and a rising volume of hot reducing gas, formed by the catalytic steam reforming of natural gas or other suitable hydrocarbons. Once gas from the reformer has been mixed with treated process off-gas to reduce its temperature to between 750 and 900°C, it is introduced into the shaft toward the bottom of its straight-sided portion by means of 12 refractory-lined tuyeres. After reducing and preheating the downward-moving burden, the gas exits by the top of the shaft for reconditioning and reuse in firing the reformer, adjusting the reducing-gas temperature, and cooling the hot DRI as it descends through the shaft's lower, conical portion. Gas from the lower cooling zone, together with heat removed from the DRI, rises through the shaft and contributes to the reduction reaction. The finished DRI discharges continuously from the furnace bottom.

FIGURE 9

FLOWSHEET FOR THE ARMCO PROCESS



(Taken from 10)

82. Following the plant's start up and break in, special problems with the shaft furnace, most notably channeling and uneven metallization, persisted and accordingly a major redesign effort was undertaken in 1974-75 to modify the shaft's internal configuration with the objective of producing uniformly reduced, non-pyrophoric DRI. The shaft redesign was completed in early 1975, and shortly thereafter all sales efforts related to the process were suspended. Actual rebuilding of the shaft was completed in late spring 1977, and after restarting, several trial runs were conducted, which proved positive in all respects. The trials established metallization rates as high as 94% and consumed natural gas at an average rate of 2.8 Gcal per ton. The DRI's ignition temperature in air, a measure of reoxidation stability, was greater than 230°C, and two 1000-ton trainloads of product were shipped to Kansas City in both covered and uncovered gondolas without any reoxidation or combustion problems.

83. At the end of 1977, the process was again placed on the market and is currently being offered for sale under a three-party agreement between Armco, Foster-Wheeler and IHI of Japan. Thus far, however, commercial implementation of the process has been limited to the Houston plant location, where operating results since the start of 1978 have closely paralleled those obtained in the 1977 trial runs. DRI with an average metallization of 93% and good reoxidation stability has been produced and is routinely shipped to Kansas City in open gondola cars. The stockpiling at Kansas City of more than 10 thousand tons of product resulted in insignificant metallization losses, despite weathering from heavy rainfall and hot summer conditions. This experience has confirmed that no passivation treatment is necessary, and to ensure the product's reoxidation stability and chemical analysis, automatic testing is performed on a regularly scheduled basis.

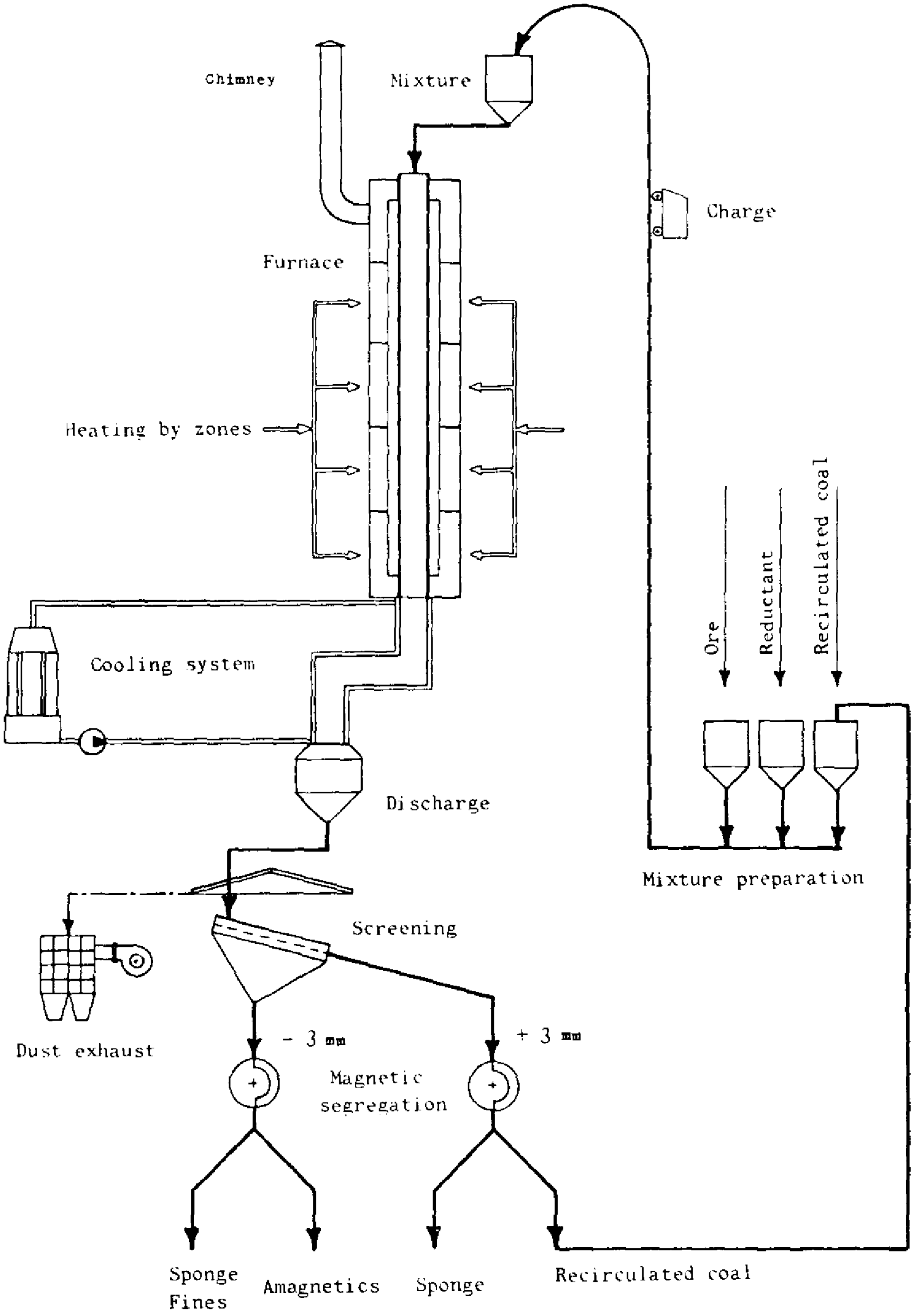
(v) KINGLOR-METOR Process*

84. The only commercially operated, coal-based technology using a shaft furnace, the Kinglor-Metor process for direct iron-ore reduction, was developed through the combined efforts of the Danieli Group of Italy and the Monteforno Group of Switzerland. After three years of preliminary investigation, the Kinglor Metor Company was formed in 1971, and a pilot plant incorporating the continuous, vertical-shaft process was constructed at Buttrio, near Udine, Italy. The pilot plant has operated on a semi-regular basis since early 1973, testing the basic concepts of the process and studying improvements and modifications to its equipment. A variety of iron ores and coals have likewise been tested. In March 1975, an order was received from Ferrieri Arvedi and Company S.p.a. for a commercial-scale plant to be installed at its steelworks located at Cremona, near Milan, Italy. The plant, with a production capability of 45 thousand annual tons, was put into operation in late 1976, but has subsequently been shut down and dismantled.

85. The Kinglor-Metor process uses a combination of solid reductant (principally coal) and hydrocarbon fuel (principally natural gas or fuel oil) to reduce a variety of iron ores to a high degree of metallization. As shown in Figure 10, the reduction reaction takes place in a vertical-shaft retort, encased in a furnace that burns the hydrocarbon fuel to provide the required process heat. A mixture of iron ore, solid fuel, recycled char, and limestone is charged into the top of the retort and progresses down through its length by gravity flow as reduced material is discharged at the bottom into an integrated water-cooling system. After screening and magnetic separation to remove non-metallic elements, the process yields finished, steel making grade DRI with an average metallization of 92% to 93%.

FIGURE 10

FLOWSHEET FOR THE KINGLOR-METOR PROCESS



(Taken from 10)

86. The cooling zone immediately beneath each furnace employs a water-cooling jacket through which treated water is circulated to and from a cooling tower. Movement of the burden through the cooling zone is controlled by a screw feeder in the lower portion of the zone. The cooled product is discharged at a temperature of 38°C through a series of two lock hoppers and is then magnetically separated to extract its DRI and remove its non-magnetic coal ash, spent limestone and residual char. The non-magnetic fractions are screened at six mesh to recover their recyclable char, which is then directed to the plant's feed-proportioning system.

87. Iron ore for the Kinglor-Metor process can be in coarse, lump or pelletized form, while its solid-fuel charge can include bituminous coal, anthracite, coke, charcoal, or lignite. Both the iron ore and solid fuel are prescreened at plus six mesh minus one inch to promote good mixing and free gas flow. With some coals, a small quantity of limestone is included in the burden for sulphur control in the end product. The hydrocarbon fuel for furnace combustion can include natural gas, methane, LPG, producer gas, or light fuel oil. Its sulphur content is of concern only in respect to the SO_2 content of the off-gas, since the fuel does not come in contact with the iron-ore charge.

88. The retort and furnace dimensions set forth above are maximums dictated primarily by heat-transfer requirements, which impose limits on the production capability and scale-up potential of the process. If a retort's rectangular cross section exceeds the maximum allowable dimensions, the heat generated in the furnace's combustion chamber cannot sufficiently penetrate into the burden, leading to incomplete reduction toward the retort's centre. Each six-retort furnace has a capacity to produce only 22.5 thousand annual tons of DRI and since the commercial plant at Cremona incorporates two furnaces, it has a rated capacity of 45 thousand tons. As presently designed, therefore, the Kinglor-Metor process entails strict plant-scale limitations and additionally, because about one-third of its energy input is derived from high-cost gas and/or oil, it involves definite drawbacks for widespread implementation.

(b) Fixed Bed Processes

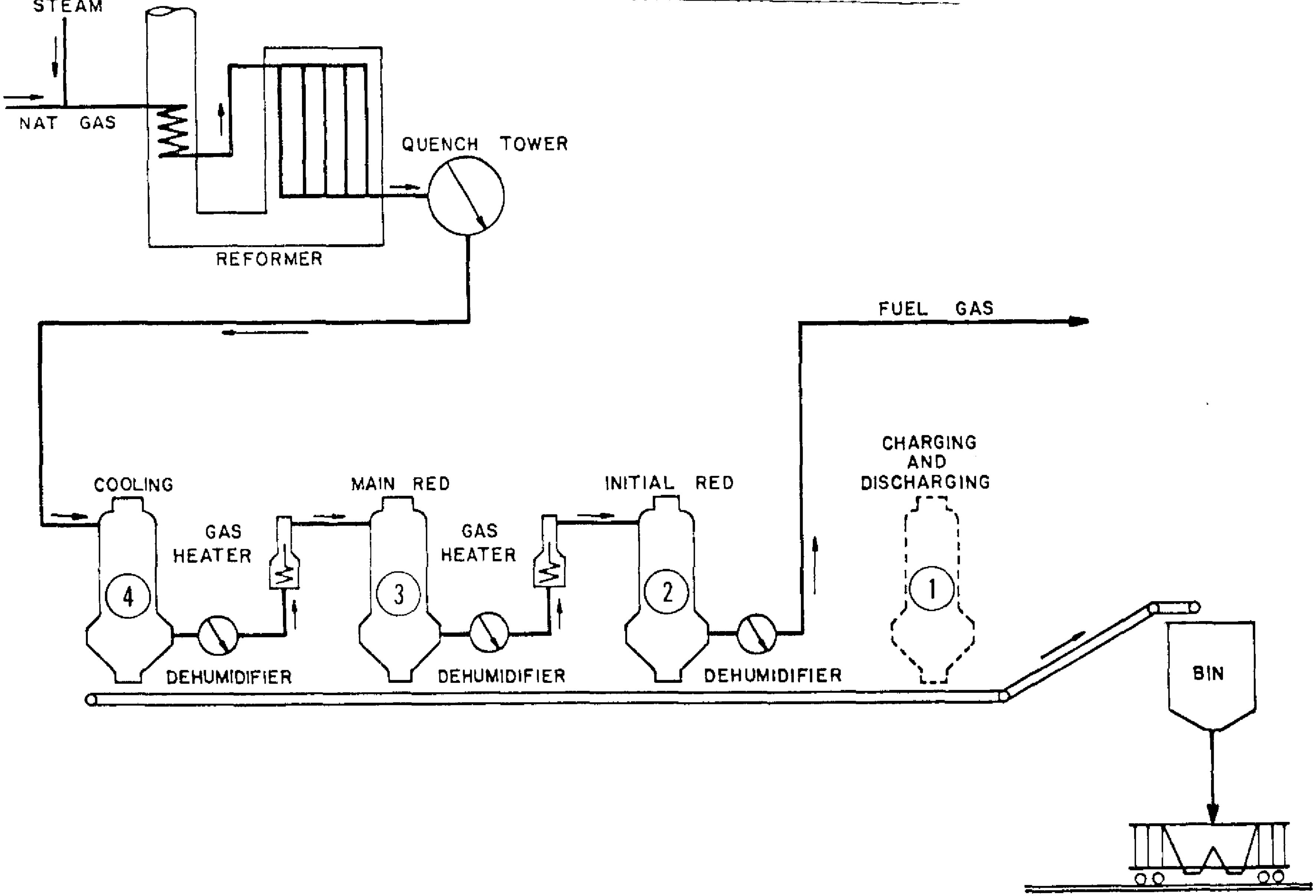
HyL I and II Processes *

89. The first direct reduction process employed on a full commercial scale was developed in Mexico during the early 1950's by Hojalata y Lamina SA and was placed in operation in Monterrey in 1957. Named for its developer, the HyL process evolved out of research performed in conjunction with M. W. Kellog Company into the use of steam-reformed natural gas in fixed-bed retorts. The historic 1957 facility supplanted a pilot unit installed in 1955 and was actually a prototype of the first commercial plant that was started up at Monterrey in 1960. The process is now administered by the HyL iron and steel technology subsidiary of Grupo Industrial Alfa. Over the past 24 years, HyL plants with an aggregate annual capacity of 8.4 million tons have been installed.

90. In the conventional HyL process (see Figure 11), reducing gas passes through and directly reduces iron oxides in a batch-type arrangement using a series of stationary-bed charges held in four vertical retorts, each of which is cycled through the following stages of operation : 1) a turn-around stage for unloading cooled DRI through the retort's bottom and reloading iron oxides (pellets and/or lump ore) through its top by means of an overhead hopper system ; 2) heating and initial reduction of the fixed iron-oxide bed by a

FIGURE 11

FLOWSHEET FOR THE FIXED BED HYL PROCESS



Taken from (10)

downward flow of regenerated reducing gas ; 3) main reduction of the charge, also using regenerated reducing gas ; and 4) cooling and carbonizing of the charge with fresh gas from a catalytic reformer, completing the reduction process and adding carbon to the finished DRI product. Each of these operating stages is about three hours in duration, so that completion of a single retort's full production cycle takes approximately 12 hours. The resulting DRI is protected from reoxidation by a carbon shell, which makes it adaptable to storage and transportation without additional treatment.

91. Reducing gas for the HyL process is usually produced by the catalytic reforming of natural gas and steam. It flows sequentially among the retorts in stages 2, 3 and 4 in reverse order, entering the top of each retort and exiting through a manifold above its conical bottom. All of the retorts are interconnected by valved manifolds incorporated into the reducing-gas system, and the gas can flow from one retort to another in any required order. Prior to entering the retorts in the initial and main reduction stages, the gas must be quenched and heated, so that each retort is preceded by a gas preheating furnace and followed by a dehumidifier, which removes water formed by the reduction reaction. Process tail gas is used for heating purposes at the reformer and preheating furnaces, and waste gas from the reformer is used for steam generation to help meet requirements throughout the plant.

92. Although the HyL process is one of the most successful and proven direct reduction methods, having been refined and optimized over many years, it entails certain drawbacks inherent in any batch-type operation employing multiple equipment units. Notably, instead of using multiple, fixed-bed retorts, the most recent direct reduction process introduced by HyL incorporates a continuous, moving-bed reduction system in a single reactor vessel (see HyL III, paragraphs 71 to 75). Its design, however, employs many components from the conventional process, including its reducing-gas reformer, and it produces DRI having comparable characteristics.

(c) Fluidized Bed Process

FIOR Process*

93. Designed to apply fluid-bed techniques common to the chemical and petroleum industries to the direct reduction of iron-ore fines, the FIOR (fluid iron-ore reduction) process dates back to the late 1950s when a development programme was initiated by Exxon Research and Engineering Company, an affiliate of Exxon Corporation. A pilot plant capable of producing five tons per day was started up in April 1962 at Exxon Research Laboratories, Baton Rouge, Louisiana. Incorporating facilities for ore preparation, reducing-gas generation, ore reduction and product briquetting, the plant was used to test equipment configurations and such processing variables as heat transfer, particle size, solids flow and gas-solids separation. Uniform, high-quality DRI with metallization rates of up to 93% was produced during 25 trial runs conducted over the period through March 1966, when pilot operations were terminated.

94. Based on the results obtained at Baton Rouge, a 300-ton per day demonstration plant was constructed at Dartmouth, Nova Scotia, adjacent to the refinery of Imperial Oil Limited. It went into operation in late 1965 and produced some 55 thousand tons of DRI briquettes over the succeeding four years. This provided adequate product quantities for steel making tests and generated engineering data required to further scale up the process for commercial application. During the demonstration period, it was proven that the product could be safely transported at sea without passivation and with a minimum of special handling

precautions. In November 1969, the Nova Scotia plant was shut down and has since been dismantled. To date, the FIOR process has been installed commercially at one location, the Fior de Venezuela plant at Matanzas, Venezuela, which started operations in 1976 and has an annual DRI production of 200,000 tons, a significant portion of which is shipped under long-term contracts to steel companies in the United States. Exxon has appointed Davy McKee Corporation of Cleveland, Ohio, exclusive licensing agent for the process, with rights to design and construct plants on a worldwide basis.

95. The FIOR process (see Figure 12) employs fluidized-bed techniques, whereby iron-oxide particles (high-grade natural ore fines) are suspended in a turbulent state by an ascending stream of hot reducing gas. A series of four refractory-lined, cylindrical reactors, one positioned above the other, permit the fluidized iron-oxide charge to flow by gravity from a preheat stage to a final-reduction stage. In the uppermost or preheat reactor, which is not operated in a reducing-gas atmosphere, the fluidized charge is preheated to reduction temperature (about $870^{\circ}C$) by hot combustion gases, which also purge much of its sulphur and any bound water. The preheated charge then flows downward into the first of three fluid-bed, reducing reactors and subsequently into each reducing reactor in series, interacting with a countercurrent or upward flow of reducing gas for conversion into DRI. Fresh reducing gas, which can be prepared by a number of methods (catalytic steam reforming, partial oxidation, etc.) from natural gas or other hydrocarbon feedstocks, is blended with process off-gas and preheated to more than $540^{\circ}C$ before introduction into the lower reducing reactor. Spent reducing gas exits the top of the initial reducing reactor and is cooled, scrubbed, and compressed for reuse, primarily by blending with gas from the reforming unit. DRI particles exit the lower reducing reactor and are passed through a double-roll briquetting unit to obtain a high-density finished product.

96. Although the FIOR plant at Matanzas, Venezuela attained regular operations in 1978, a number of technical and operating problems have persisted even to the present. As in all fluidized-bed systems, gas velocity is critical and must be closely controlled. Iron-oxide inputs to the system must be in the form of fines, and although this can provide cost advantages relative to the use of pelletized ores, uniformity of metallization and operating productivity are adversely affected unless high-grade fines of uniform grain size are employed. After several weeks of operation, the fines tend to produce clogging at certain points in the system, which must then be taken down for cleaning and may ultimately have to be redesigned to alleviate the problem.

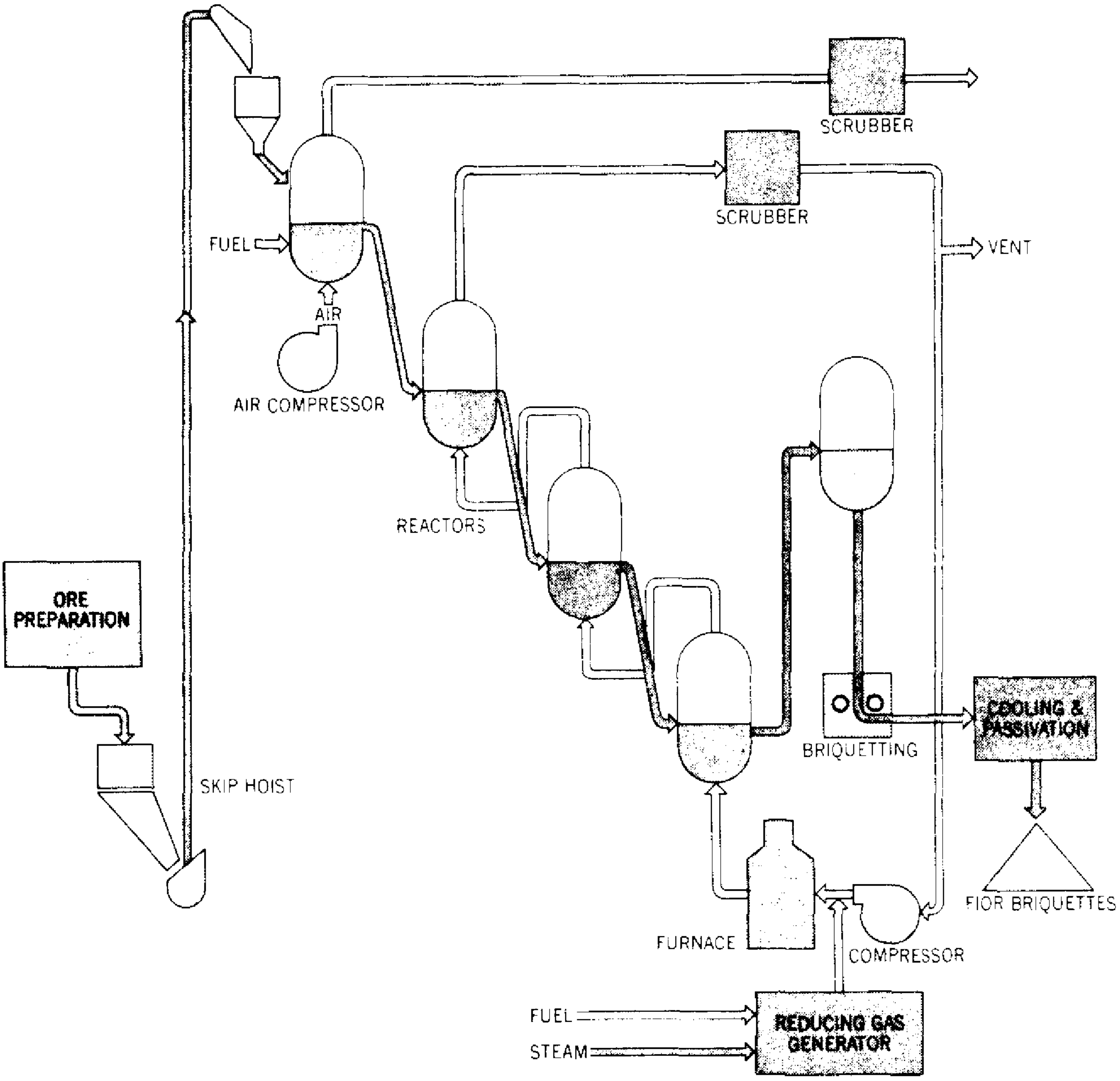
(d) Rotary Kiln Processes

(i) SL/RN Process*

97. The SL/RN process derives from development undertaken by two groups : the Steel Company of Canada, Stelco (S), working in conjunction with Lurgi Gesellschaft für Chemie und Hüttenwesen mbH (L) and the Republic Steel Corporation (R) working together with the National Lead Company, now NL Industries (N). In this process (see Figure 13), a blend of pelletized or lump iron ore, fresh reduction coal, recycled char, and limestone or dolomite are charged into a refractory-lined, rotary kiln, which slopes downward from its charging end. The kiln is fitted with a series of lengthwise and evenly spaced air ports to assist combustion and regulate process temperature. Commercial kilns are approximately 65 to 130 metres long, 4 to 6.5 metres in diameter and rotate at approximately

FIGURE 12

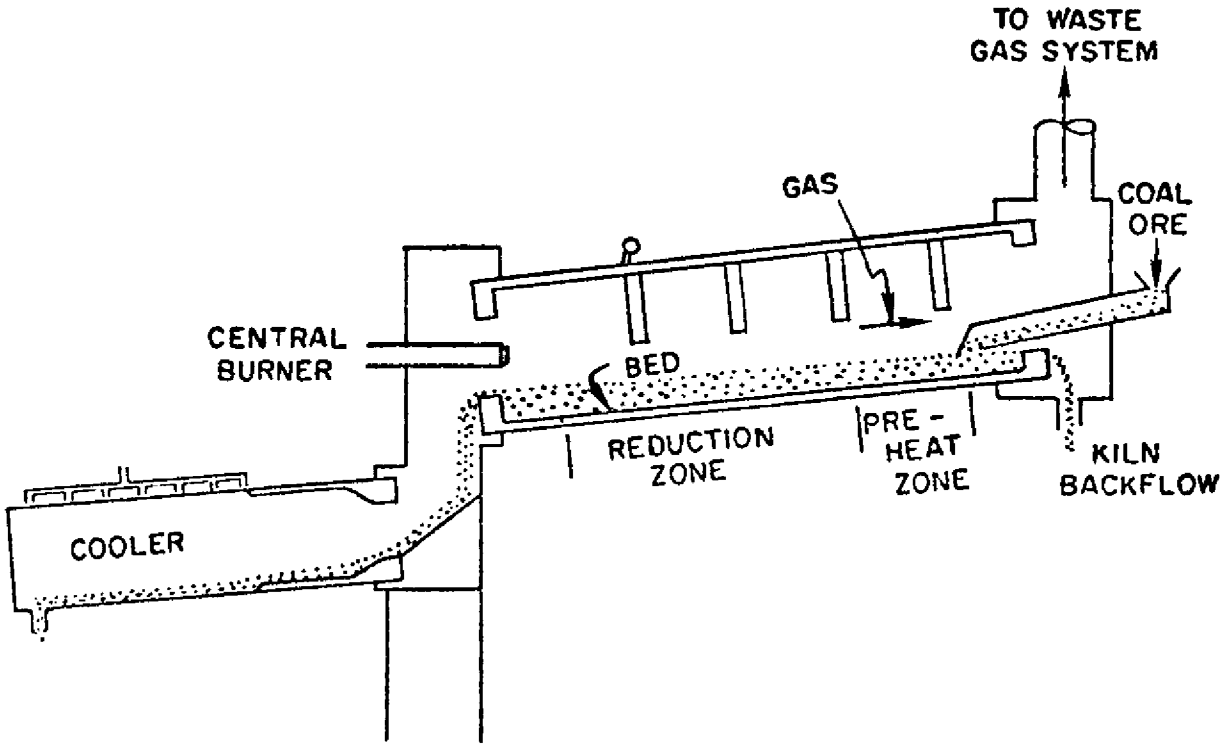
FLOWSHEET FOR THE FIOR PROCESS



Taken from (10)

FIGURE 13

FLOWSHEET FOR THE SL/RN PROCESS



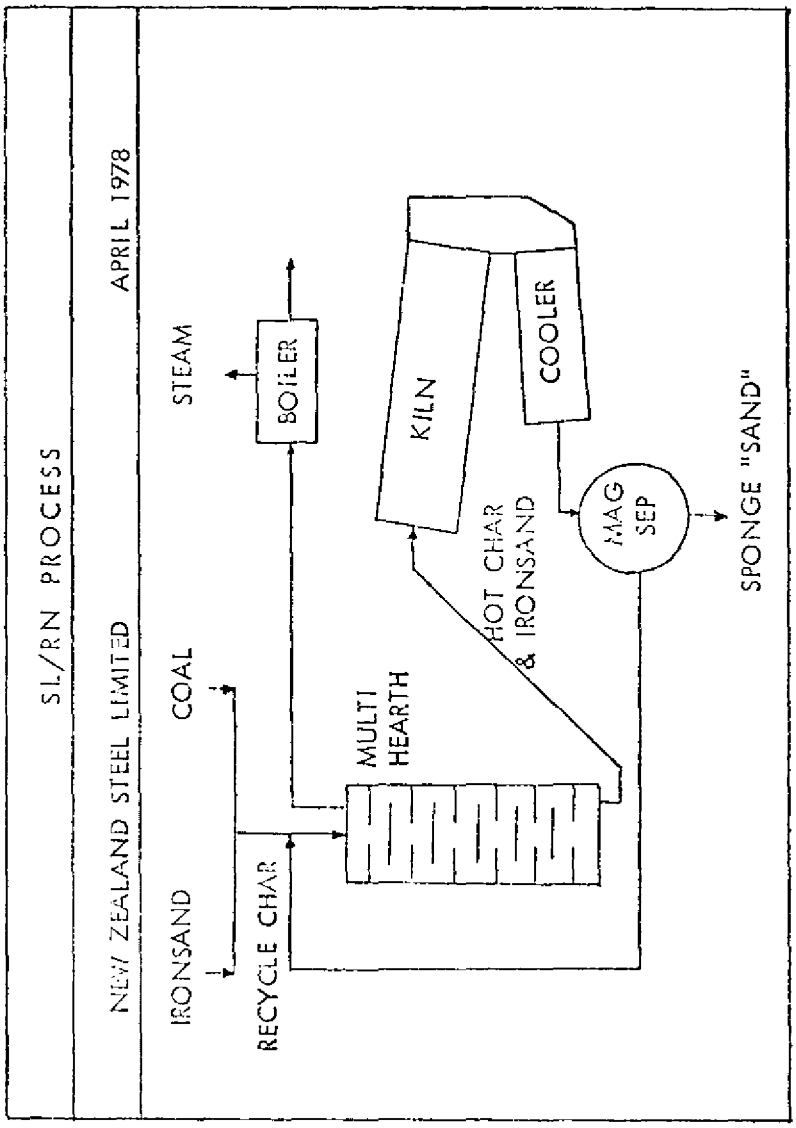
(Taken from (10)

1/4 rpm. At start up a central burner, introduced into the kiln's discharge end, is fed with light fuel for firing purposes. It brings the charge up to reduction temperature (1050 to 1100°C) and is subsequently fed with air. Retention time in the kiln depends on the desired degree of reduction, and thereafter, the charge passes through a gas-tight sluice at about 1000°C and enters a lower drum for water cooling to a temperature below 100°C. The reduced discharge from the cooling drum consists of coarse- and fine-grained DRI, return char ash, and the desulfurization agent, which are screened and magnetically separated. The optimum reduction temperature in terms of maximizing kiln throughput is just under the fusion temperature of the raw materials charged, so that close temperature control is essential. Although the process can reduce a wide variety of iron ores, the non-coking, reduction coals used should have a high reactivity, a low free-swelling index, and a low ash-fusion temperature. Notably, in the mid-1960s, following the merger of the SL and RN technologies, considerable worldwide attention was focused on the resulting direct reduction process, and for a time, it appeared to have potential to dominate the field. Numerous commercial-plant possibilities were announced, and by 1967-68, decisions were made to proceed with construction at Inchon Iron and Steel Co. Ltd., Inchon, Republic of Korea ; New Zealand Steel Ltd., Glenbrook, New Zealand ; and Falconbridge Nickel Mines Ltd., Sudbury, Canada. Started up in 1969-70, the three plants experienced protracted and difficult break-in periods, required a variety of equipment modifications, and were beset with serious technical and operating-cost problems, which ultimately resulted in the permanent shutdown of the Inchon and Falconbridge units. Given this performance, most of the commercial plants originally projected for installation failed to materialize, and since then, new-plant construction has been limited to four units, three of which have average capacities of only 70 thousand annual tons. The notable exception is the Stelco facility at Bruce Lake, which is capable of producing more than five times that amount ; however, because of cost considerations relating to the price of scrap, the plant has been shut down since August, 1976.

98. New Zealand Steel's Glenbrook SL/RN plant is a special case in the field of coal-based direct reduction which, following initial production problems of extremely serious proportions, has satisfied most, if not all, of its intended objectives and currently ranks as one of the most successful direct-reduction operations in the world. The modified SL/RN unit, rated at 125 thousand tons per annum which now operates at an annual capacity of 165 thousand tons, is used to directly reduce indigenous, titaniferous ironsand, a granular material with the consistency of beach sand and an iron content of about 58%. The resulting DRI has a metallization averaging about 85%, and a total Fe content of 71%. Called RPC or "reduced primary concentrate" in the company's terminology, it is unsuitable for merchant sale, particularly in view of its high gangue content (close to 30%) and consequent penalties in freight costs and electric-power consumption during electric-arc steelmaking (816 kWh per ton of raw steel using a 75/25 RPC to scrap blend). Despite these obvious disadvantages of RPC compared to low-residual scrap or high-grade DRI, the company is extremely satisfied with its direct-reduction facility and the resultant product as a source of iron units for its steelmaking operations. Originally employing a rotary kiln charged with ironsand and high-volatile, sub-bituminous coal, the plant was modified in April 1978 by the installation of a multiple-hearth furnace (MHF) in front of the rotary kiln (See Figure 14). The ironsand and raw coal are now fed into the MHF and preheated to 600°C by air injection to combust a portion of the released coal volatiles. The remaining volatiles are fully burned in an afterburner and the resulting heat captured in a waste-heat boiler. The preheated sand and char are then hot-charged in the

FIGURE 14

THE SL/RN PROCESS AT NEW ZEALAND STEEL



Taken from (10)

rotary kiln, which operates entirely as a reduction unit, using heat produced from the controlled combustion of air blown through the kiln's 11 burner tubes into the CO-rich atmosphere. No natural gas or oil is required, except for initial heating of the MHF and kiln to operating temperatures. The success of this integral ore-preheating, coal-charring and direct-reduction system has, in principle, demonstrated that a wide variety of high-volatile, carbonaceous materials can be directly charged for direct-reduction purposes. This includes sub-bituminous coal, lignites, and wood products, all of which can provide a reactive char for the reduction process and excess chemical heat, which can be converted to steam and then electricity for the subsequent melting stage. Development plans at New Zealand Steel call for the installation of four additional MHF/rotary-kiln modules, each with 220 thousand annual tons of capacity. To overcome the disadvantages imposed by its gangue content, the RPC and residual char from the kilns will be hot-charged at 900°C into two continuous-melting furnaces for the production of molten pig iron, which will then be treated in a conventional Q-BOP steelmaking furnace. This process route is designed to permit a more intensive use of New Zealand's contiguous, domestic deposits of lower-grade ores and high-volatile, non-coking reductants in supporting iron and steel production.

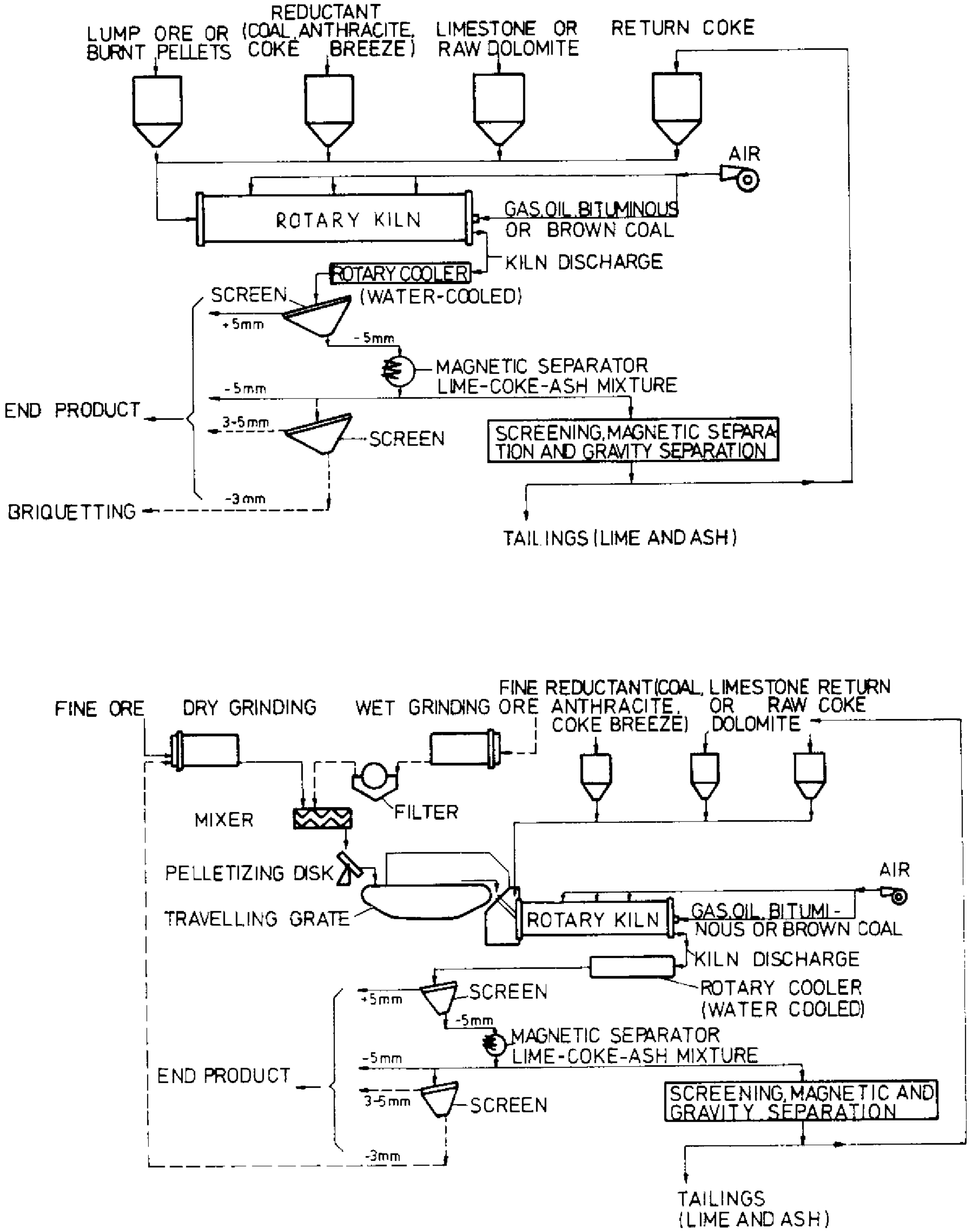
(ii) CODIR/KRUPP Process *

99. Based on extensive experience with rotary-kiln technology dating back to the mid-1920s, Krupp Industrie-und Stahlbau of the Federal Republic of Germany has developed the Codir process (derived from coal-ore-direct-iron-reduction). Krupp initially employed coal-based rotary kilns to reduce zinciferous raw materials in what became known as the Waelz process, which evolved into the Krupp-Renn process during the 1930s and, in turn, into the present Codir process. Krupp-Renn was developed to produce DRI called "luppen" from low-iron, high-silica ores and was installed at more than 40 plants, primarily in Germany where 38 kilns were in operation at the end of World War II. During the post-war years, however, low-cost, high-quality ores became available in increasing quantities, and given extremely high energy requirements for the process (between 30 and 35 million Btu's per ton of luppen), it was gradually phased out, the last kilns being closed down on August 1, 1963. A single Krupp-Renn unit was reserved for subsequent experimentation with a variety of ores and fuels, leading to the development of the Codir process, which has thus far been installed commercially at one plant, the Dunswart Iron and Steelworks Ltd., Benoni, South Africa.

100. Two variants of the Codir process are shown in Figure 14, one designed to use lump ore, which generally conforms to the process flow employed at the Dunswart commercial plant, and the other permitting the use of fine ores and/or concentrates. In both instances, the iron-oxide feed is charged together with an anthracite-coal reductant and a desulphurizing agent (limestone or dolomite) into a refractory-lined rotary kiln, where it is heated to a temperature of 950° to 1050°C by a countercurrent flow of hot gas and transformed into DRI. The fuel employed can be pulverized coal, gas, or oil, and depending on its volatile content, it is either blown into the kiln from the discharge end or introduced from the charging end together with the feed materials. The kiln discharge consists of a mixture of DRI (metallized to between 90% and 94%), surplus fuel, the desulphurizing agent, and ash. It passes into a rotary cooler that employs direct water spraying to reduce its temperature to about 150°C, and then it receives further treatment by a combination of screening and magnetic separation.

FIGURE 15

ALTERNATE FLOWSHEETS FOR THE CODIR PROCESS



(iii) DRC/HOCKIN Process*

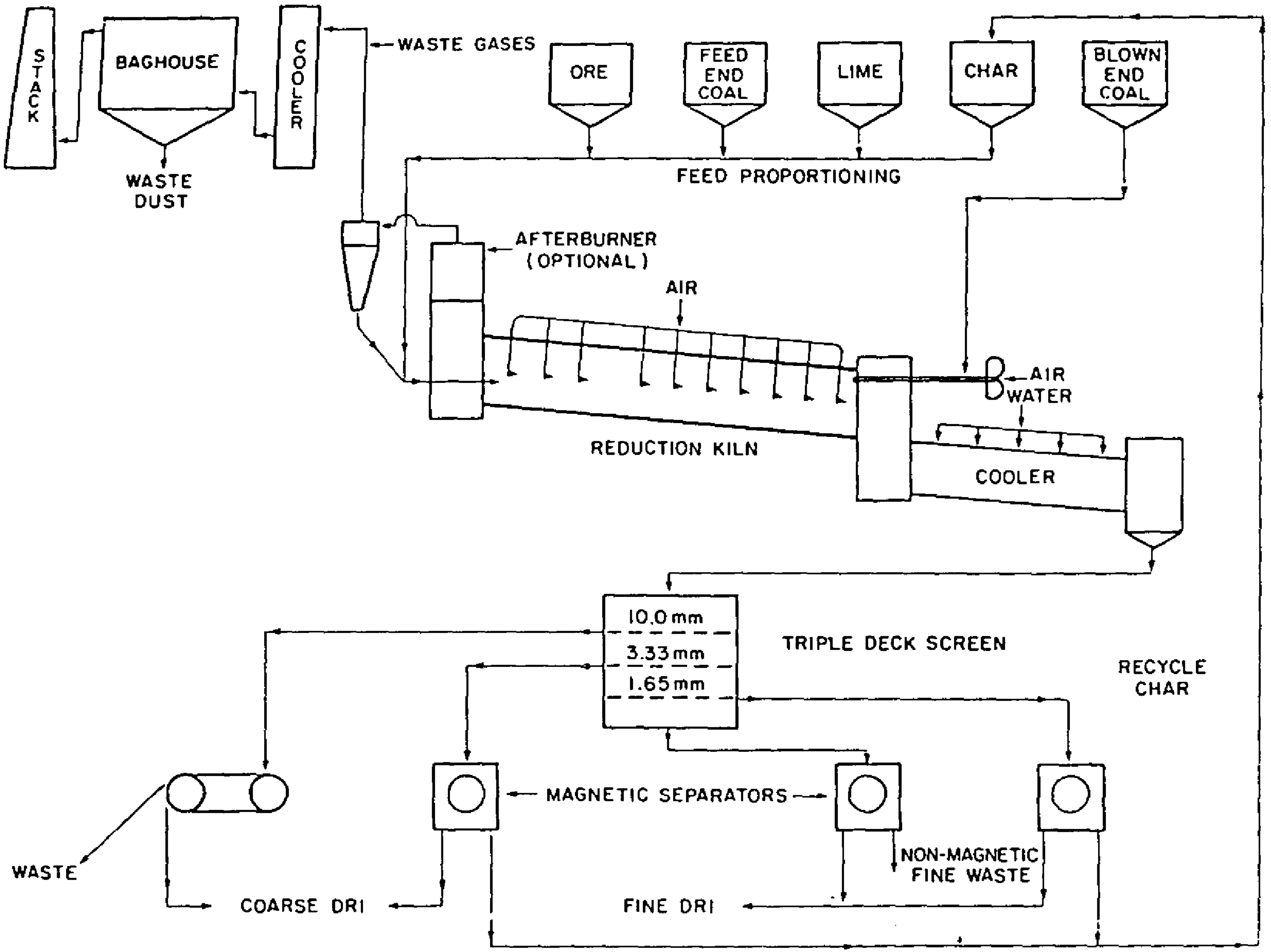
101. The DRC direct reduction process evolved out of the use of rotary kilns by companies affiliated with Consolidated Gold Fields Ltd., its origin dating back to 1969, when Western Titanium Ltd. of Australia applied the coal-based, rotary-kiln principles of the Hockin process to reduce the iron oxide in ilmenite and produce synthetic rutile. The technology developed in Australia was later adapted for direct iron ore reduction and called the Azcon process. In 1978, it was implemented at a demonstration plant in Rockwood, Tennessee, which has an annual design capacity of 65 thousand tons and has been used primarily to process test batches of various feedstocks. After the Rockwood plant's initial year of operation, the process was renamed DRC after Direct Reduction Corporation, an entity formed to manage the plant's operation and market its rotary-kiln technology.

102. In the DRC process (see figure 16), a proportioning-bin system continuously introduces charge materials (iron-ore pellets and lump ore, fresh reduction coal, recycled char, and limestone) into the feed end of a refractory-lined, rotary kiln, which incorporates shell mounted fans to supply combustion air through a lengthwise series of internal air tubes. Fuel oil or gas is used to fire the kiln from a cold, shut-down state, and a discharge-end burner injects coal into the kiln by means of low-pressure air. During reduction of the charge, the kiln rotates at less than one rpm, and air-input adjustments control the temperature profiles of the bed and reducing gases, which reach maximum levels of 1070° to 1170°C respectively. Reduced materials are discharged from the kiln through a sealed transfer chute into a rotary cooler, then to a treatment system for screening and magnetic separation. The resultant output consists of coarse- and fine-grained DRI, non-magnetic fine waste and char for recycling to the kiln. Process waste gases are cycloned to remove and recycle coarse dust, then cooled and passed to a bag-house, fan and stack. The final DRI has displayed metallization rates as high as 97% (the normal range is 90% to 92%), and owing principally to the kiln's high-temperature operation, it is passive in nature and has been held in covered barges for up to six weeks during shipment.

103. According to DRC, differences from other rotary-kiln systems that are characteristic of its process primarily involve its kiln design and methods of coal blowing and temperature control. With the exception of the firing fuel, the process makes exclusive use of coal for both reduction and operating purposes. As a general rule, it requires iron-ore feedstocks with greater than 66% total iron to produce steelmaking-grade DRI. However, good results have been obtained using a variety of pelletized and lump ores, as well as a wide range of sub-bituminous and semi-anthracite coals.

FIGURE 16

FLOWSHEET FOR THE DRC PROCESS



Taken from (10)

COMPARATIVE REVIEW OF ENVIRONMENTAL PROTECTION MEASURES

104. Figures 16 to 18, taken from a comparative study of the environmental impact of DR processes prepared by S. Das Gupta (11) for the UNEP/UNIDO meeting of experts give the principal sources of air and water pollution for the three most important processes in the world (Midrex, HyL and SL/RN processes). Table 6 lists for DR processes the environmental pollution problems and their treatment. Each country applies its own national regulations (see for example reference 12) and no attempt is made to review these comprehensively. For each section a few examples have been chosen for illustration. Environmental problems are considered under (i) air pollution ; (ii) water consumption ; (iii) water pollution ; (iv) solid waste ; (v) residue utilization ; (vi) noise ; and (vii) working environment.

(i) Air Pollution

105. The main air pollutants from DR processes are : (a) dust ; (b) sulphur oxides and (c) nitrogen oxides. Fluorides could possibly be a problem for DR using ores containing fluorine compounds.

Principal Sources of Emissions

(a) Dust

106. Direct reduction processes emit dust by two means : the charging and discharging of raw materials, and by the flue gases from heat recuperators. Up to 0.5% loss may occur in material handling at each transfer point, a figure that is frequently used in process and equipment design. From an economic point of view, as well as for environmental protection, it is important to minimize this loss. Particular care is needed in the handling of direct reduced iron due on the one hand to dust and air pollution and on the other hand to its potential for reoxidation and consequently fire and explosion risk.

(b) Sulphur oxides

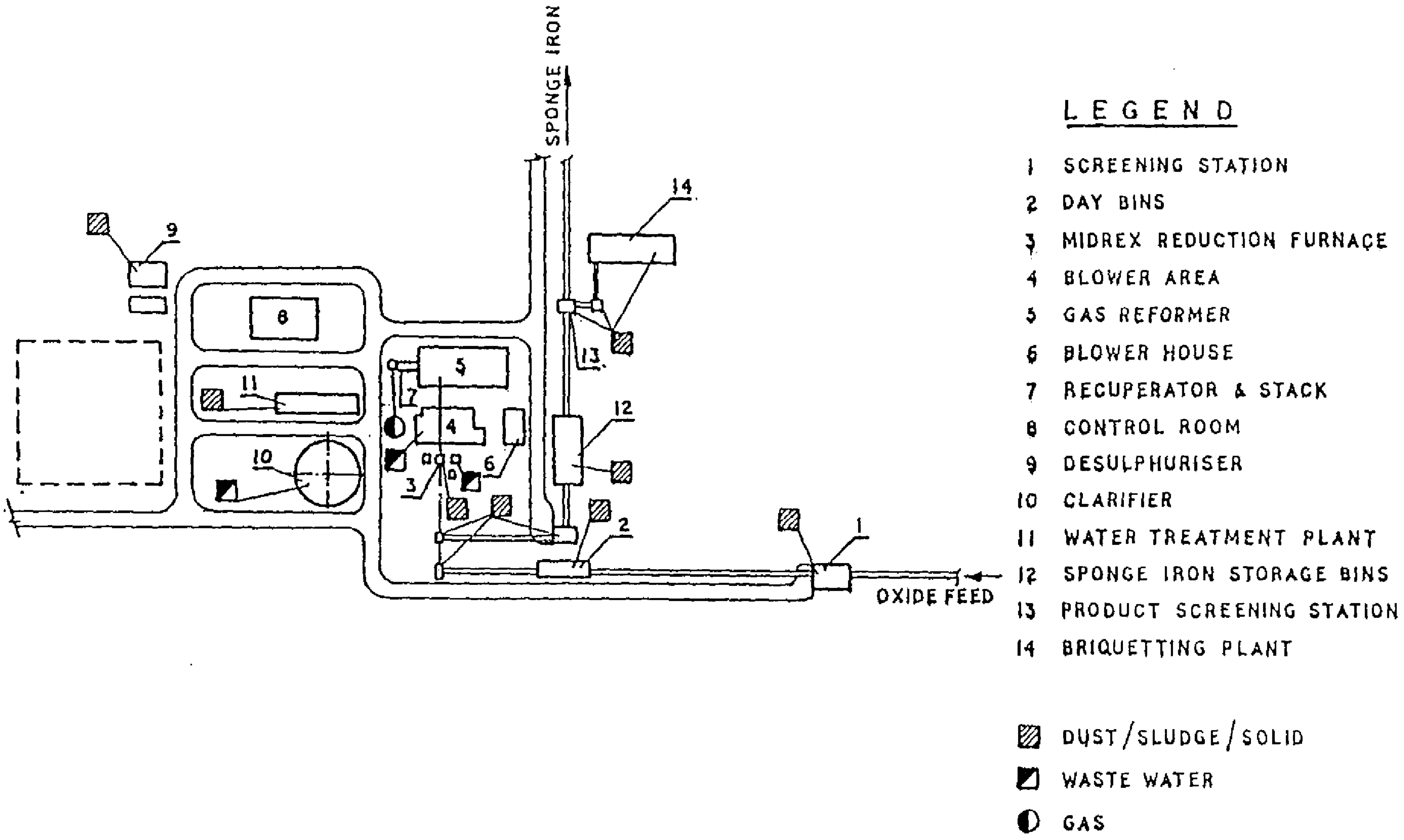
107. Sulphur is introduced in direct reduction processes by three means : by the iron ore to be reduced ; by the reducing agent, for instance natural gas in the Midrex or HyL processes, and solid carbon in the SL/RN process ; and by the heating agent, if it is different from the reducing agent. The level of introduced sulphur depends on the reducing agent. It is low with natural gas which is generally desulphurized before conversion. It is high with solid carbon which cannot be economically desulphurized.

108. A part of the introduced sulphur is fixed in the final charge, i.e. in the reduced pellets alone in the Midrex or HyL processes ; and in the reduced pellets and limestone or dolomite in the SL/RN process. The remaining part of the sulphur is released with the exhaust gases by stacks. For instance, according to D. Hankel (13), in a recent SL/RN unit, the SO_2 emission is approximately 1 g/Nm^3, corresponding to a flow of 750 mg SO_2/h/t sponge iron/y.

(c) Nitrogen oxides

109. All combustion processes emit nitrogen oxides : nitric oxide (NO), and in a lower proportion, nitrogen dioxide (NO_2). Direct reduction processes are consequently sources of some nitrogen oxides.

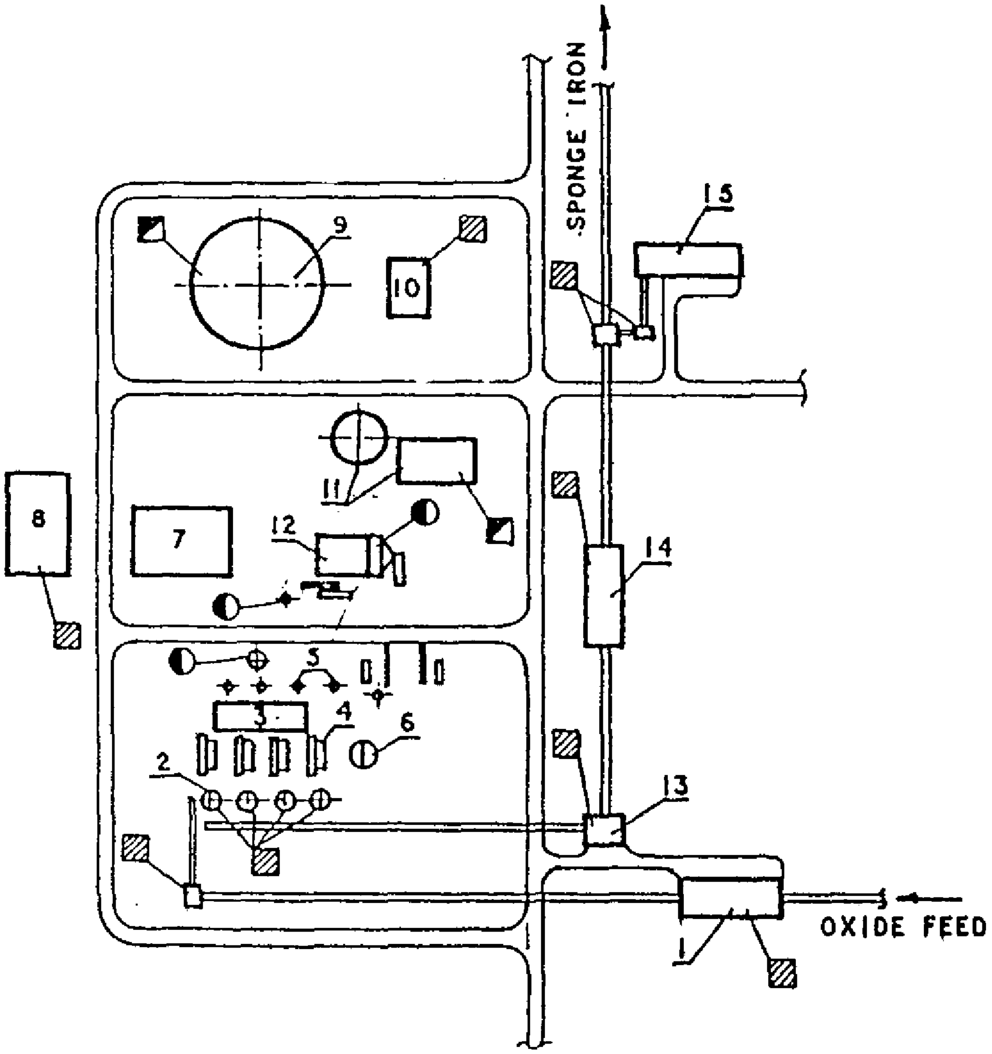
FIGURE 17



TYPICAL MIDREX PLANT – SOURCES OF POLLUTION

Taken from (11)

FIGURE 18



L E G E N D

1 PELLET SCREENING STATION
2 HyL REDUCTION UNIT
3 CONTROL ROOM
4 GAS PREHEATER
5 QUENCH TOWER
6 AIR PREHEATER
7 COMPRESSOR HOUSE
8 DESULPHURISER
9 CLARIFIER
10 FILTER UNIT
11 BOILER FEED WATER TREATMENT PLANT
12 GAS REFORMER
13 PRODUCT SCREENING STATION
14 PRODUCT STORAGE BINS
15 BRIQUETTING PLANT

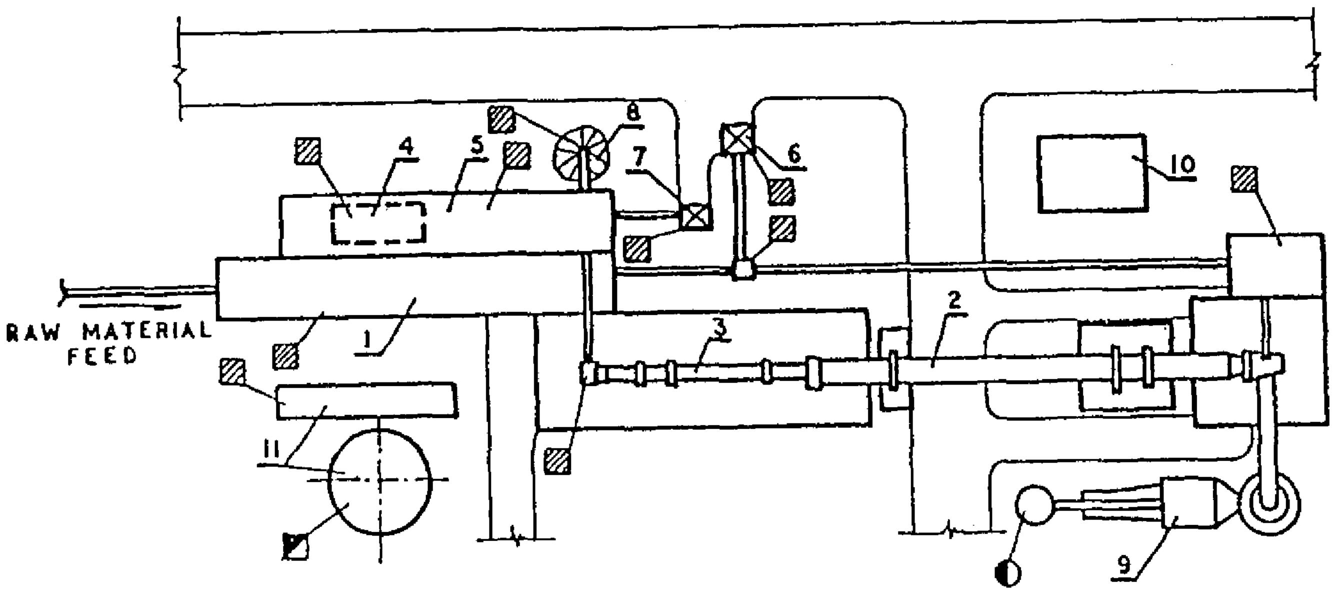
▨ DUST/SLUDGE/SOLID
◪ WASTE WATER
◐ GAS

TYPICAL HyL PLANT – SOURCES OF POLLUTION

Taken from (11)

FIGURE 19

TYPICAL SL/RN PLANT - SOURCES OF POLLUTION



TYPICAL SL/RN PLANT - SOURCES OF POLLUTION

▨ DUST / SLUDGE / SOLID
◩ WASTE WATER
◐ GAS

Taken from (11)

LEGEND

1 RAW MATERIALS BINS
2 REDUCTION KILN
3 ROTARY COOLER
4 PRODUCT SCREENING AND MAGNETIC SEPARATION
5 PRODUCT STOCK BINS
6 HOPPER FOR UNREDUCED SPONGE IRON
7 HOPPER FOR SPONGE IRON
8 PRODUCT BY-PASS STOCK PILE
9 WASTE GAS CLEANING SYSTEM
10 FUEL OIL STORAGE
11 WATER TREATMENT FACILITIES

TABLE 6

DIRECT REDUCTION PROCESSES ENVIRONMENTAL POLLUTION AND THEIR TREATMENT

Process	Type of pollutants	Source of generation	Details of pollutants	Method of treatment	Level prior to treatment	Level after treatment	Remarks
SHAFT FURNACE PROCESSES							
MIDREX	Exhaust **gases**	Shaft furnace, stack, screening station, silos, transfer points	About 3,000 Nm^3/ton of Fe at 400°C containing 12.9% CO_2, 4% O_2, 65.7% N_2, 17.4% H_2O (NO_x + S - nil). Dust content is about 4 mg/Nm^3 (12 g/ton of Fe)	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	**Dust g/Nm^3** Shaft furnace . . 100 Stack 15 Screening station 30 Silos 30 Transfer points 30	**Dust mg/Nm^3** Shaft furnace . . 50 Stack 15 Screening station 50 Silos 50 Transfer points 50	**Investment costs for** waste gas cleaning for a plant of 880,000 tons/yr is DM 3.32 million
	Particulate emission	Stack, dust collection systems, storage and load-out collection system, screening dust collection system	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) : Parti-culates / SO_2 / NO_x Material handling 0.001 0.001 0.002 Combustion system 0.012 0.035 0.172 Dust collection system 0.016 Trace 0.001	Dedusting systems		**kg/hr** Stack . . 0.5 Dust collection systems . . 2.5 Storage and load-out collection systems . . . 1.0 Screening dust collection systems . . 1.0	Dedusting systems are designed in order to limit dust emissions to atmosphere at 150 mg/Nm^3 under normal operating conditions
	Waste water	Surface water; sanitary water; industrial waste water	Depending on the cooling water arrangement: Avg. clarifier water 0.9 m^3/t of Fe Avg. suspended solids in effluent water 50-150mg eer litre Solids from clarifier 40-70 kg/t of Fe **Point source emissions to water;** **Suspended solids** mg/l / **Flow** m^3/t DRI Process blow down 60 0.15 Clarifier blow down 100x10^3 0.26 Effluent from plant 15 0.3-0.6	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	Surface water: Max. 400 mg/litre solids Sanitary water: Biological waste Industrial waste water: 50 mg/litre solids	Surface water: 5 mg/litre solids Sanitary water: BOD_5 : 25mg/litre Industrial water: 5 mg/litre solids	Investment costs for a plant of 880,000 tons/yr is DM 1.6 million Slurry of iron oxide collected in the dust collecting system is dewatered and then either sold or agglomerated and used as feehstock

Taken from (II)

(cont. . .)

TABLE 6

Process	Type of pollutant	Source of generation	Details of pollutants	Method of treatment	Level to treatment	Level after treatment	Remarks
MIDREX (cont. . .)	Noise	Conveyors, scrubbers, feeders, fans, compressors, reformer, screening station, pumps, air stations		Providing housing on conveyors; noise protection hoods, and buildings on machinery; insulation of pipework	**Without casing or housing** Belt conveyors 74 dB (A) Wet dedusting 97-99 dB (A) Vibrating feeders 100 dB (A) Waste gas fan 110 dB (A) Main air fan 133 dB (A) Process and cooling gas compressors 130 dB (A)	**Inside housing** Natural gas reducing station 104 dB (A) Briquetting plant 94 dB (A) Screening station 88-96 dB (A) Process gas and cooling gas section 106 dB (A) Pump station 98 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)	The noise levels outside the housing are approx. 20 dB (A) lower
NSC-DB	Solids	Top gas; pressure equalizing gas; raw materials screen		Wet scrubbers	g/Nm^3 Top gas . . 6 Pressure equalizing gas . . 5 Raw materials screen . . . 5	g/Nm^3 Top gas . . 0.01 Pressure equalizing gas . . 0.10 Raw materials screen . . 0.10	Main pollutants are the solids contained the top gas. This gas should inevitably be scrubbed basically for reuse/recirculation, and not for pollution control
	Water	Scrubbing water		Thickener	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
		Boiler water from the demineralizer and the boiler drum		Neutralization	pH 6-11	pH 7	
	Noise	Gas recirculation compressor		Installation of silencer and/or sound proof covers	100-106 dB (A)	85-95 dB (A)	

(cont. . .)

TABLE 6

Process	Type of pollutant	Source of generation	Details of pollutants	Method of treatment	Level prior to treatment	Level after treatment	Remarks
FIXED BED PROCESSES							
Hyl	Ore/pellet dust	Discharge to pellet silos Discharge to reactors Conveyors and junction houses for handling of ore/pellets	Dust particulate 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 m^3/hr	This water may be neutralized with HCl or other acids and then mixed with 3.7 m^3/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 pelletizing or sintering, or can be sold to the cement industries
	Zinc oxide and sulphur	Desulphurizers		Removed from the desulphurizers 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 hygienic 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 lowering the pH value to 3.5 from the normal level of 7
	Noise	All major equipment such as belt conveyors, scrubbers, reactors, reformers etc. and pipelines		Enclosing the noise generating equipment in housings and casings, and by insulation of pipelines		85 dB (A) maximum	

(cont. . .)

TABLE 6

Process	Type of pollutant	Source of generation	Details of pollutants	Particulate type	Method of treatment	Level prior to treatment	Level after treatment: Source	Particulate loading g/Nm^3	Remarks
FLUIDIZED BED PROCESSES									
FIOR	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	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		Ore drier . .	0.7068	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
							Ore crushing	0.28272	
							Ore storage and feed system . .	0.28272	
							Ore feed lock hopper	0.28272	
							Reheat reactor	0.7068	
			Let-down scrubber, quench-drum scrubber, briquetter ventilation and cooler	Reduced iron			Let-down scrubber	0.7068	
							Quench-drum scrubber	0.7068	
							Briquetter ventilation	0.7068	
							Briquetter cooler	0.7068	
								5.08896	

(cont. . .)

TABLE 6

Process	Type of pollutants	Source of generation	Details of pollutants	Method of treatment	Level prior to treatment	Level after treatment	Remarks
ROTARY KILN PROCESSES							
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/m^3. Operating data indicate generation of 0.03-0.06 ton of dust per ton of DRI produced	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		Sludge contains 0.07 to 0.11 g/litre of suspended solids at the kiln operating at SIIL (India). Under German conditions, limited to 8 mg/m^3	Separated dust is dumped either in the form of slurry or a paste, depending on the equipment chosen. The amount of waste material generated depends on type of plant and the reductant used. If the ash content in the coal is high, all the dust and non-magnetic products generated can be considered as waste materials
	Waste gases	Rotary kiln	Should be maximum 150 mg dust/m^3 at the stack. Temperature of flue gas about 70-300°C. Analysis of the flue gas CO_2-28%, O_2-2%, N_2-70%, dust 0.05-0.1 t/t DRI depending on raw materials	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	Analysis of sludge (%): Fe (t) .. 30-40 Fe_2O_3 .. 40-55 CaO ... 5-20 SiO_2 .. 15-30 Al_2O_3 .. 5-15	Accepted level is 150 mg/m^3. In ISCOR plant 50 mg/m^3 with electrostatic precipitation is guaranteed	Cost of operation of dedusting and waste gas systems at SIIL is about Rs30 per ton of DRI Sulphur is washed down by water to a certain extent using a scrubber system
	Waste water	Dedusting and waste gas systems; cooler	Dust and waste gases generated as above. About 2.25 m^3 of water per ton of DRI produced is consumed at SIIL	Thickener; neutralization in case of wet dedusting system; moistening of dust in case of dry dedusting	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** g/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
	Noise	All major equipment		Silencer and/or sound proof covers	100 dB (A)	85 dB (A)	

(cont. . .)

TABLE 6

Process	Type of pollutant	Source of generation	Details of pollutants	Method of treatment	Level prior to treatment	Level after treatment	Remarks
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 ingress-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 dustbearing 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 g/Nm^3 with a composition of: Pulverized coal — 24-30% Volative matter — 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/Nm^3 with the following size distribution (in microns): Less than 10 — 23% 10-30 — 58% 30-50 — 14% More than 50 — 5%	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 after-burnt for combusting the hydrocarbon compounds, carbon monoxide and coal dust. After cooling either in waste-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 Nm^3/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 Nm^3/ton Fe. Clean gas composition 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 — 0.08% 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 exists in the plant	Blow-down of open-cooling water circuit for indirectly cooled rotary coolers amounts to 1 m^3/ton of DRI containing about 60-80 mg/litre of suspended solids	Max. 50 mg/Nm^3 Slurry from indirectly cooled cooling drums is about 40 kg/ton of DRI with 1 kg of dry substance per ton of DRI	
	Noise	All major equipment		Silencer and/or soundproof covers		Noise levels at: 2 metres from kiln drive - 87 dB (A) Noise emission protected fans (waste gas - 85 dB (A) and shell fans)	

(cont. . .)

TABLE 6

Process	Type of pollutant	Source of generation	Details of pollutants	Method of treatment	Level prior to treatment	Level after treatment	Remarks
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	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
		Product handling, screening and separation	Fugitive emissions - coal ash, carbon and limestone fines; gas volume set depending on the equipment selected	Baghouses	About 100-200 kg/ton of DRI	No visible emission	
	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 condensible hydrocarbons	**Method I**: Complete after-burning of the unburnt hydrocarbons, direct gas quenching with water up to 250°C, and collection in insulated baghouse	Solids: 100-200 kg/ton of DRI Unburned hydrocarbons and condensible hydrocarbons up to 2,000 ppm	Solids: Less than 50 mg/m^3	Wet scrubbers of electrostatic precipitators could replace baghouses. These devices may, however, prove unreliable and uneconomical in the long-run
				Method II: Complete after-burning 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	Gas temperature — 150°C Volume — 5-82 Nm^3/kg coal feed	Gases (treatment by Method II): Less than 250 ppm SO_2 Less than 15 ppm SO_3	
	Noise	Kiln off-gas, fan, kiln product, general plant grounds		Fan discharge silencers on small baghouses		Kiln off-gas fan — 76 dB (A) Kiln product — 80-83 dB (A) General plant grounds — 60-80 dB (A) Average — 75 dB (A)	

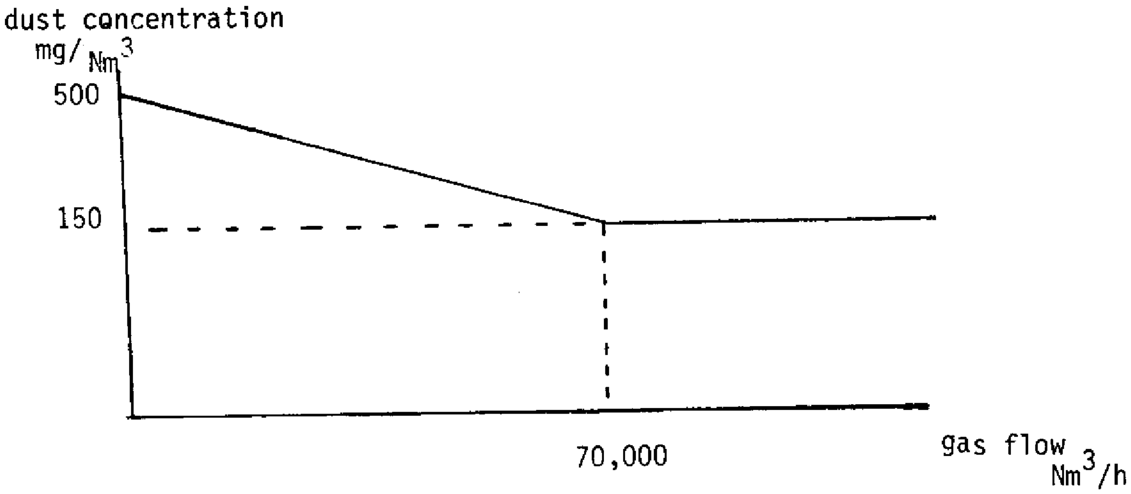
Emission Regulations

110. In the Federal Republic of Germany plants which may be expected to produce a certain amount of air pollution require prior approval before construction and operation. Technical instructions for air ("Technische Anleitung für Reinhaltung des Luft - T. A. Luft") lay down general restrictions on emissions as well as special emission standards and technical requirements for certain types of plants. The strictest restrictions are imposed on the emission of particulate matter (dust) :

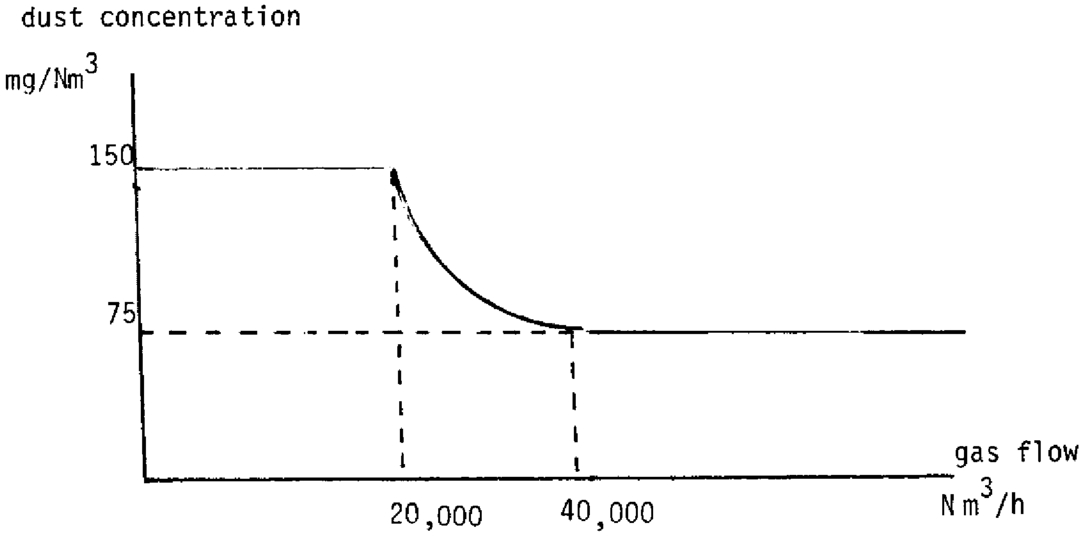
1) Guidelines for dust emissions :

Total dust	150 mg/Nm^3 max. for a gas flow of 70,000 Nm^3/h
Fine dust	10 mg/Nm^3 max.for a gas flow of 70,000 Nm^3/h

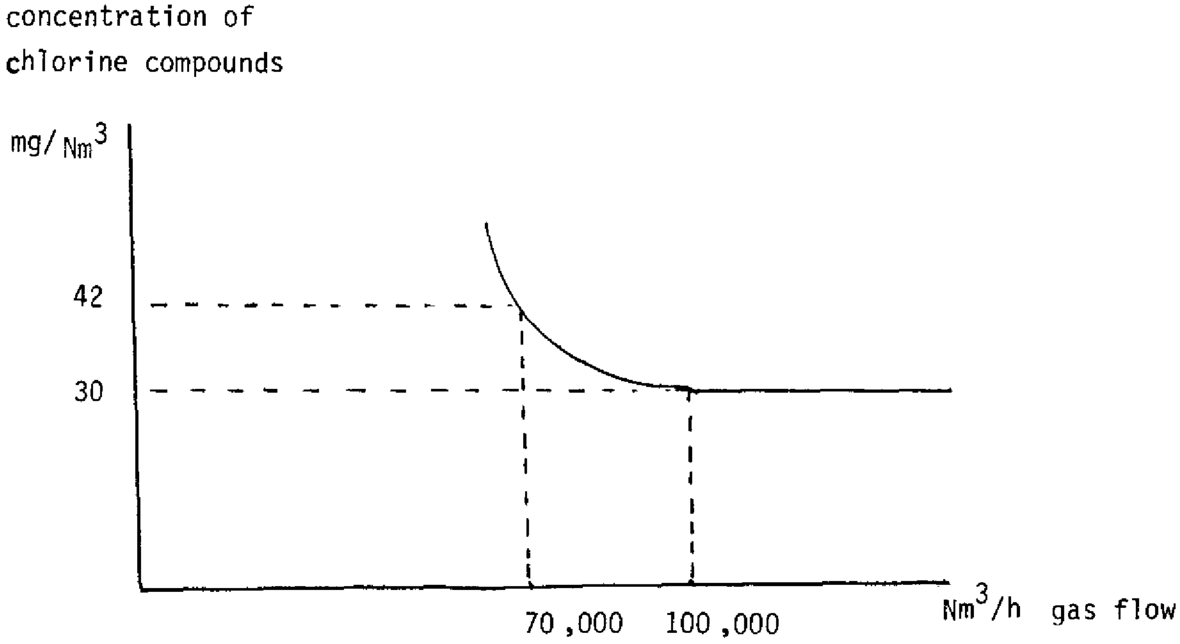
When the gas flow is less than 70,000 Nm^3/h, the dust concentration may be higher :

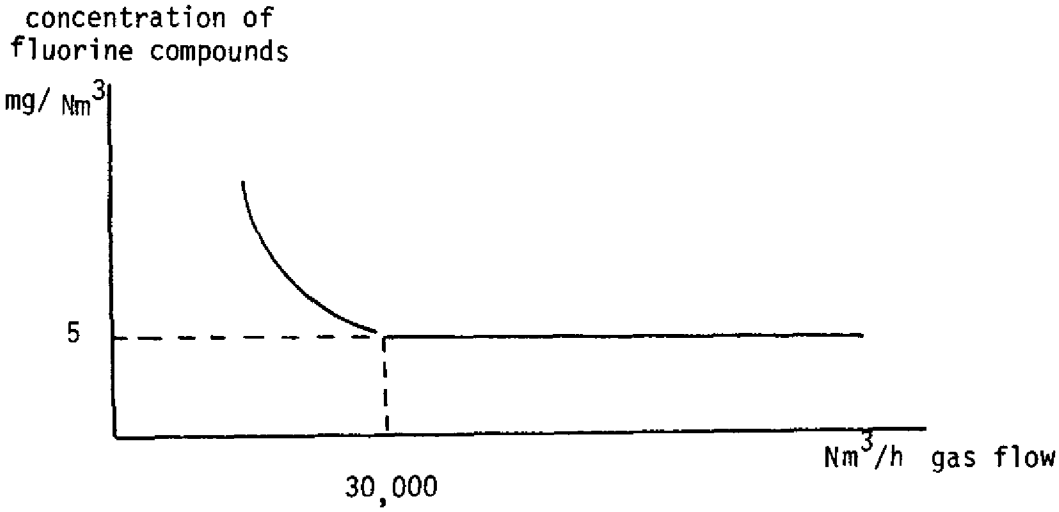


2) Guidelines for emissions arising from transport and handling of fine materials :



Similar curves are published for other pollutants, for instance for chlorine or fluorine compounds :





111. In Mexico (14) dust emission regulations depend on the hourly production capacity of the installation and on the gas flow rate. Regulations are different for new and existing installations.

1) Emission regulations in kg. dust/hour as a function of the hourly production for new and existing installations :

Process Production	Maximum Permitted Emission kg/h	
Ton/h	New Industry	Existing Industry
0.025	0.489	0.652
0.050	0.780	1.040
0.100	1.239	1.652
0.220	1.974	2.632
0.300	2.589	3.452
0.400	3.141	4.188
0.500	3.648	4.864
0.750	4.788	6.348
1.000	5.805	7.740
1.250	6.741	8.988
1.500	7.617	10.156
2.000	9.237	12.316
2.500	10.725	14.300
3.000	12.120	16.160
3.500	13.437	17.916
4.000	14.694	19.592
4.500	15.900	21.200
5.	17.064	22.752
6.	19.281	25.708
8.	23.382	31.176
10.	27.153	36.204
15.	35.625	47.500
20.	43.200	57.600
25.	50.166	66.888
30.	55.572	74.096
35.	57.462	76.616
40.	59.127	78.836
45.	60.564	80.752
50.	61.926	82.568
60.	64.269	85.693
70.	65.556	87.408
80.	68.052	90.736
100.	71.154	94.872
500.	95.436	127.248
1000.	107.813	143.084
3000.	130.080	172.650

2) Emission regulations for dust in mg/normal m^3 as a function of the gas flow for new and existing installations :

Volume of gas flow in normal cubic metres	Concentration of emissions from new installations	Concentration of emissions from existing installations
100	849.0	1,132.0
125	795.0	1,060.0
150	750.0	1,000.0
175	714.0	952.0
200	684.0	912.0
300	600.0	800.0
400	543.0	724.0
500	510.0	680.0
750	444.0	592.0
1,000	405.0	540.0
1,500	357.0	476.0
2,000	324.0	432.0
3,000	285.0	380.0
4,000	258.0	344.0
5,000	240.0	320.0
7,500	210.0	280.0
10,000	192.0	256.0
15,000	168.0	224.0
20,000	154.2	205.6
30,000	135.0	180.0
40,000	123.0	164.0
50,000	114.0	152.0

Ambient Air Quality Regulations

112. A number of countries also regulate air quality by setting limitations on local ambient concentrations of pollutants in an urban industrialized area. Plants are required to take measures so that these concentrations are not exceeded. The criteria for setting air quality standards are usually based on protection of health and welfare, but may also include avoidance of damage to vegetation and materials, as well as the minimization of nuisance. Table 7 gives examples of the air quality regulations for a number of countries.

Cleaning Systems

(a) Dust

113. Two kinds of dust are emitted, namely : oxidized dust of iron ore and other mineral products (for instance, limestone or dolomite in the SL/RN process) ; and metallized dust. For oxidized dust, conventional cleaning systems may be used : cyclones, wet venturi scrubbers, bag filters etc. For metallized dust, particular cleaning systems which take account of the pyrophorosity of the dust are needed and it is better to use wet filter systems.

(b) Sulphur Oxides

114. To reduce to an acceptable level the sulphur oxides concentrations around a direct reduction unit, four means are used :

TABLE 7

AIR QUALITY OBJECTIVES

	SO_2	NO_2	Suspended Particulate Matter	Dust Fall
CANADA *				
24 hr. average	300 $\mu g/m^3$	200 $\mu g/m^3$	120 $\mu g/m^3$	
Annual arithmetic mean	60 $\mu g/m^3$	100 $\mu g/m^3$	70 $\mu g/m^3$	
30 days arithmetic mean				7.5 t/km^2
JAPAN				
1 hr. average	226 $\mu g/m^3$	80 - 110 $\mu g/m^3$	200 $\mu g/m^3$	
24 hr. average	106 $\mu g/m^3$		100 $\mu g/m^3$	
USA				
24 hr. average	365 $\mu g/m^3$		150 $\mu g/m^3$	
Annual arithmetic mean	80 ug/m^3	100 ug/m^3	60 $\mu g/m^3$	

* Maximum acceptable concentrations

(i) Reduction gas (generally natural gas) is desulphurized before its conversion into CO and H_2. This is usually necessary since H_2S poisons the nickel catalyst used in the reforming process. The desulphurization process is the classical Claus process (see also paragraph 133 for a special case).

(ii) For solid fuel reduction processes, it is not possible to desulphurize carbon products before their use. Therefore limestone or dolomite are charged in the rotary kiln with iron ore and fix a part of sulphur introduced with carbon products. This fixed sulphur is eliminated from the process with used limestone or dolomite (dolochar).

(iii) Exhaust fumes can be desulphurized, for instance in a wet scrubbing system.

(iv) Residue exhaust fumes are discharged through relatively high chimneys.

(c) Nitrogen Oxides

115. No denitration process is currently economically practicable. The only means to reduce emission of NO_X into the atmosphere is to control combustion operations. For instance, the method used in rotary kilns resembles two-zone fuel burning in boilers. It prevents high temperatures and decreases the formation of nitrogen oxides. According to D. Hankel (13) a maximum of 40ppm NO_X, equivalent to 54 mg NO/m^3, were measured by means of a chemiluminescence analyzer in a SL/RN plant. High stacks also limit the ambient NO_X level around direct reduction plants, but may contribute to long range transmission of pollution and acid deposition.

Practical results

116. Each plant constitutes a particular case and it is impossible to generalize from local situations. Three examples are given. The first (see table 8) concerns a typical Midrex plant (15). The air pollution emissions are after treatment. The second (see table 9) refers to a HyL III plant.

117. The third (see table 10) refers to experience of the Midrex and HyL processes at SIDOR's plant at Puerto Ordaz (16) using air pollution control equipment designed on the basis of proven operations with other, non Venezuelan ores. Although research was done to anticipate the process reactions using natural Venezuelan ores, the results were not sufficiently in-depth to completely anticipate the erratic behaviour experienced with these ores. Problems arise from the greater than anticipated percentage of superfines and fines under 5 mm generated from the oxide pellets and from the further degradation of the pellets during the direct reduction process, screening and the delivery of the DRI to the EA Furnaces. The Venezuelan ores generate a considerably greater amount of superfines (dust) and fines, in some cases up to twice the anticipated amount, than that experienced with other ores. This means that on a unit-time basis the SIDOR dust removal system is underdesigned and cannot cope with the excessive dust loadings. In other instances and locations, dust collecting equipment was not installed, and now due to the high dust generation of the SIDOR DRI it presents serious ambient conditions and maintenance problems.

TABLE 8

ENVIRONMENTAL IMPACT OF A TYPICAL MIDREX DIRECT REDUCTION PLANT

POINT SOURCE EMISSIONS TO THE AIR	kg/t of product		
	Particulates	SO_2	NO_x
Materials handling (a)	< 0.001	< 0.001	< 0.002
Combustion system (c)	0.012	0.035	0.172
Dust collection system (d)	0.016	0.000 (b)	< 0.001

POINT SOURCE EMISSIONS OF WATER	Suspended solids (mg/l)	Flow (m^3/t of product)
Within plant boundaries :		
. process water blowdown	∿ 50	0.15
. clarifier blowdown (e)	∿ 100×10^3	0.26
Effluent from plant	15	0.3 - 0.6

NOISE	Noise level dB(A)
Inside the blower area	95 - 100
Immediately outside the blower area	∿ 85
Miscellaneous stations around the plant	80 - 88
At plant boundaries	70 - 80

(a) Day pile (oxide) through product silo including the shaft furnace

(c) Reformer stack

(e) This is a slurry of iron oxides which is dewatered and then either sold or agglomerated and used as feedstock

(b) Undetectable, less than trace

(d) Typically three independent dust collection systems are used in a MIDREX plant.
These emissions are for each of the three systems.

Taken from R.L. Hunter (15)

TABLE 9

ENVIRONMENTAL IMPACT OF A HYL 111 PROCESS PLANT

EMISSIONS TO THE AIR	KG/TON OF PRODUCT					
	PARTICULATES	SO_2	NO_x	CO	HC	OTHER
MATERIAL HANDLING	0.001					
COMBUSTION SYSTEMS	0.006	0.002	0.050	0.004	0.001	
DUST COLLECTION	0.032					
TOTAL	0.039	0.001	0.050	0.004	<0.001	

EMISSIONS TO THE WATER	SUSPENDED SOLIDS Mg/L	DISSOLVED SOLIDS Mg/L	FLOW M^3/TON
INSIDE THE PLANT :			
- TREATING PLANT BACKWASH	500	300	0.058
- BOILER BLOWDOWN	200	1500 - 2000	0.023
- CLARIFIER BLOWDOWN	100,000	300	0.001
EFFLUENT FROM PLANT	200	300	0.082

SOLID WASTES	KG/TON OF PRODUCT RECYCLED	DUMPED
GAS CLEANING SLUDGES	18.45	-
OXIDE PELLET FINES	18.20	-
METALLIZED DUST	-	
OTHER SOLID WASTES	0.25	0.35
TOTAL	26.90	0.65

NOISE	NOISE LEVEL (dBA)
COMPRESSOR ROOM	90 - 100
REFORMER FANS	95 - 110
MISCELLANEOUS STATIONS	80 - 90
AT PLANT BOUNDARIES	75 - 80

TABLE 10

QUANTITY AND TYPE OF DUST EMISSION CONTROL EQUIPMENT INSTALLED IN SIDOR'S PLAN IV DR FACILITIES

TYPE OF EQUIPMENT FACILITY	BAG HOUSE	WET SCRUBBER	DRY CYCLON
MATERIAL HANDLING (PELLETS)	6	-	-
HYL-II	-	5	3
MIDREX-II	-	5	-
BRIQUETTING PLANT	-	1	-
DRI HANDLING SYSTEM	-	1	-
TOTAL	6	12	3
%	28	58	14

118. The excessive formation and build-up of superfines and fines present also very serious ambient working conditions in closed areas and where constant daily cleaning is required and cannot be performed. The fine dust penetrates into the machinery moving parts and electrical controls and is responsible for premature mechanical and electrical failures. Dust collection and removal has been greatly hampered by the DRI dust characteristics which cause clogging of the air ducting, heavy accumulations in low air velocity sections and the excessive stickiness of the ore dust when wetted which clogs process equipment and discharge piping.

(ii) Water Consumption

119. An advantage of direct reduction technology is a lower water consumption than in the classical process (6). Table 11 presents comparative data on specific water consumption in both situations. Technically it is possible to operate on very low water requirements but the need for cooling water is an important factor in water use. The water use required depends on the local conditions, particularly ambient temperature and humidity as far as cooling is concerned. As the operating costs of recirculating and of once through water systems are similar, the choice of water system for a plant depends on local resource availability, as well as environmental and economic factors.

(iii) Water Pollution

Principal Sources of Discharge

120. It is necessary to consider two general cases, namely that where water is employed but without contact with the media being cooled, and the other case where water is used for cleaning gases and is polluted thereby.

Effluent Regulations

121. Effluent regulations are usually first aimed at reducing pollution arising from insoluble suspended matter including oil and tar and readily degradable substances, which, due to their drain on the oxygen content of the receiving water body, may be a threat to aquatic life. Furthermore, the pH is also usually controlled. Secondly, it is essential to have regulations limiting the discharge of hazardous substances, such as certain heavy metals and organic micro-pollutants, which may be resistant to degradation and persist in the environment, often accumulating in the aquatic ecosystems. Thirdly, it may be necessary to have regulations to control thermal discharge.

122. Table 12 shows the standards which the steel industry accepted in the Federal Republic of Germany for its water management (18). The first value quoted is based on a random test for "settleable matter", whilst the other values relate to 2-hourly mixed samples. The hydrocarbons referred to are mineral oils, which satisfy a pre-determined analysis regulation. The heavy metal levels relate to overall values which also include the level of "settleable matter". The minimum effluent standards must be met in the case of each individual inspection. The required standard is also considered to have been satisfied if the arithmetic mean of the results from the last five inspections carried out by the authorities does not exceed the quoted value. Results of inspections which took place more than three years ago, however, cannot be taken into consideration.

Table 11

SPECIFIC INDICES OF TOTAL WATER USE

CONSUMERS		SPECIFIC USE OF WATER m^3/t of :	
		Pig Iron	Prereduced Pellets
1.	Coke production	12	-
2.	Agglomerate production	10	-
3.	Pig iron production	25	-
4.	Slag processing	30	-
5.	Oxide pellets production	-	12
6.	Desulphurization of natural gas	-	1.5
7.	Prereduced pellets production	-	43.5
	TOTAL	77	57

Taken from V. V. Danshin (17)

TABLE 12

MINIMUM EFFLUENT STANDARDS IN THE FEDERAL REPUBLIC OF GERMANY (OCTOBER 1980)

	iron and steel-production	production of tubes	production of tinplate	cooling-water blowdowns	coking plants
settleable matter 1)	0,5 ml/l	0,5 ml/l	0,5 ml/l	–	0,8 ml/l
COD 2)	100 mg/l	200 mg/l	1,5 kg/t 2u.3)	50 mg/l	1 kg/t 4)
fish-toxicity 2)	2	2	2	–	64
hydrocarbons 2)	10 mg/l	10 mg/l	10 mg/l	–	–
ammonia, free 2)	–	–	–	–	60 g/t 4)
cyanide, uncomplexed (CN) 2)					1,2 g/t 4)
phenol, monohydric 2)	–	–	–	–	10 g/t 4)
residual chlorine 2)	–	–	–	0,2 mg/l	–
phosphate (P) 2)	–	–	–	3 mg/l	–
iron 2)	20 mg/l	20 mg/l	20 mg/l	–	–
zinc 2)	3 mg/l	3 mg/l	3 mg/l	4 mg/l	–
lead 2)	0,5 mg/l	0,5 mg/l	0,5 mg/l	–	–
tin 2)	–	–	3 mg/l	7	–

1) random test 2) 2-h-sample 3) related to 1 t tinplate 4) related to 1 t charged coal

123. No toxic contaminants find their way into effluents in direct reduction plants. The effluents can be polluted by certain chemical impurities or by a source of thermal pollution. Therefore cleaning of effluents involves no difficulty. Even if a completely closed water supply system has not been set up, it will always be possible to clean effluents. In this case, the main problem will be the salt content in effluents rather than the presence of toxic substances.

Practical Results

124. The impact on water of a typical Midrex plant in respect of suspended solids is shown in Table 8.

125. With reference to a typical HyL III plant, Figure 20 shows the flowsheet of water effluents. The effluents are basically from two different sources. One is the boiler blowdown with approximately the following characteristics :

Quantity	pH	Total Suspended Solids	Cl^-	PO_4^{---}	SiO_2
17-24 liters/ton DRI	10,5-11	1500-2000ppm	50-150ppm	30-40ppm	25-35ppm

The other source is the bleed-off from the BFW treatment plant, with an approximate flow between 50 to 60 liters per ton of DRI. The first type of effluents may be neutralized with HCl and/or other acid and then mixed with the second type of effluents which is considered neutral. After neutralization and mixing, the final effluent is not considered polluting and is discharged to the sewer without any additional treatment.

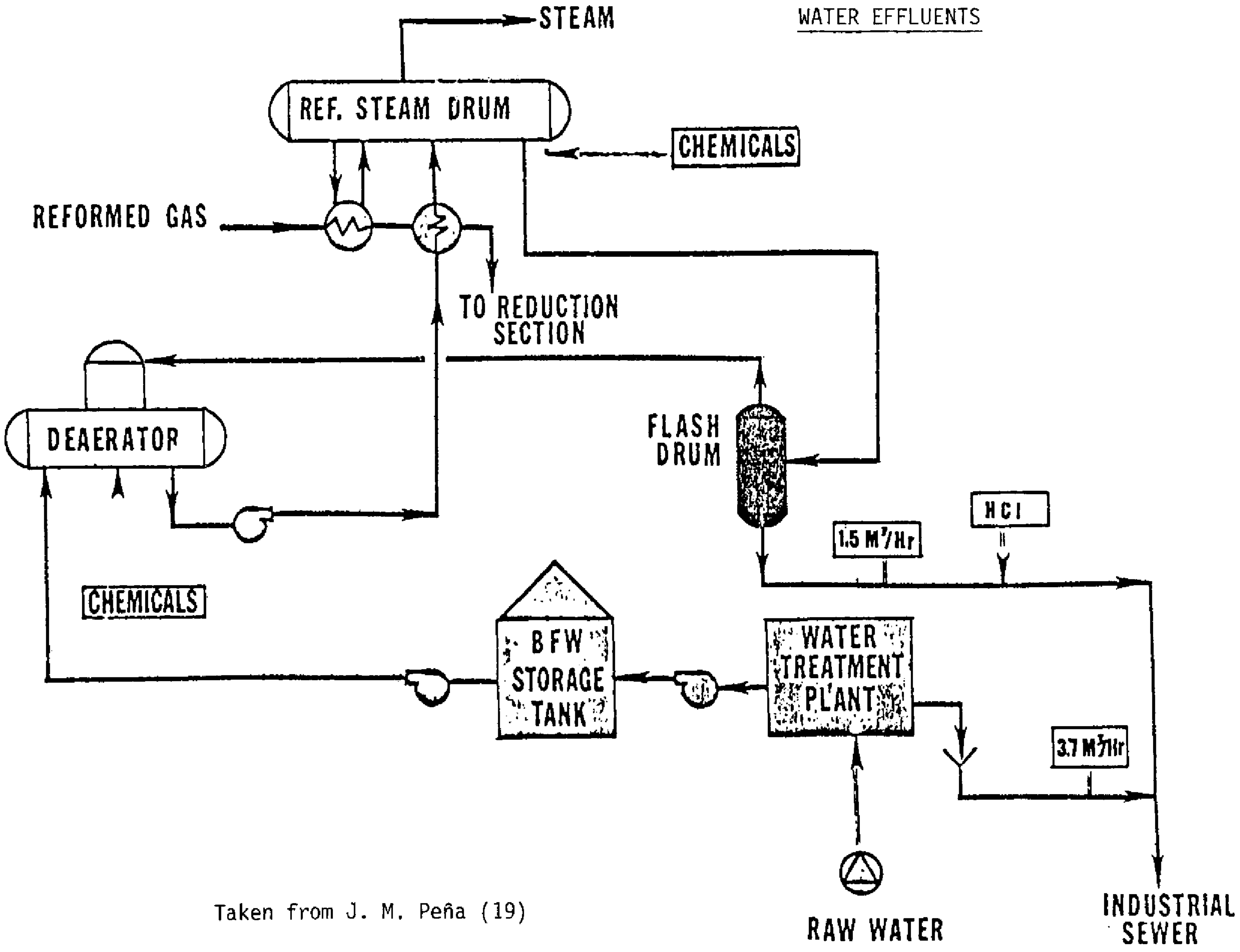
(iv) Solid Waste Pollution

Principal Sources of Discharge

126. First, solid wastes arise from the fume and water treatment systems. They contain dust, sludges, sulphates if the plant comprises a desulphurization unit, and mixtures of carbon and dolomite wastes for rotary kiln direct reduction processes. In the case of the latter these mixtures are called dolochar in the SL/RN process (13). The amount of dolochar depends on the ash content of the coal and is approximately 230 kg/t sponge iron, when a coal with 58%C fixed and 25% ash is used. Its composition is, for instance, as follows :

FIGURE 20

WATER EFFLUENTS



Taken from J. M. Peña (19)

C fixed : 30 - 65%

$SiO_2 + Al_2O_3$: 15 - 30%

$CaO + MgO$: 10 - 20%

S : 0,5 - 2% (95% as CaS)

Second, the operation of the unit gives rise to different solid wastes : iron ore dust, metallized pellets dust, molecular screens, catalyst, broken refractories etc.

Residue Utilization Systems

126. In principle residues can be recycled where the whole operation from raw materials processing to steel making is carried out on one site. In practice it depends on environmental and economic factors as there may be difficulties in residue use where a direct reduction plant is not integrated with other processes. Generally most solid wastes are recycled into the process, particularly gas cleaning sludges and oxide pellet fines. The non-utilizable wastes are dumped.

127. In the SL/RN process, since dolochar has a usable calorific value (approximately 14 GJ/t) as a result of its high C fixed content (30 - 65%), it is worthwhile to burn it and utilize the waste heat. Complete combustion in a circulating fluid bed permits oxidation of CaS into $CaSO_4$ suitable for landfill.

128. In the industrial countries, there are often limits or even bans on the disposal of the industrial solid wastes. Toxic wastes are of priority concern. Toxicity is controlled by a legal leaching test whose procedure is different for each country. However, most of the direct reduction solid wastes do not show toxicity with any of the tests.

Solid Waste Disposal Regulations

129. Waste management policy should encourage residue utilization. Wastes which cannot be recycled must be disposed of without risk to water quality. Particularly hazardous wastes should be dumped on specially controlled sites. In the case of wastes from DR operations special care must be taken with pyrophoric materials.

130. In most countries regulations cover the discharge of industrial waste (20). Measures are foreseen to ensure that waste is disposed of without endangering human health and without harming the environment, and in particular :

- without risk to water, air, soil, plants and animals.
- without causing a nuisance through noise or odours.
- without adversely affecting the countryside or places of special interest.

Special regulations concern toxic and dangerous waste, i.e. any waste containing or contaminated by substances or materials of such a nature, in such quantities or in such concentrations as to constitute a risk to health or the environment. For instance, table 13 gives a list of such materials according to an EEC directive of the Council of Ministers of March 20, 1978. In a few countries, the potential toxicity of waste can be assessed :

- by chemical analysis ;
- from the results of a leaching test.

TABLE 13

EEC List of Toxic and Dangerous Materials in Waste

arsenic, arsenic compounds

mercury, mercury compounds

cadmium, cadmium compounds

thallium, thallium compounds

beryllium, beryllium compounds

chromium 6 compounds

lead, lead compounds

antimony, antimony compounds

phenols, phenol compounds

cyanides, organic and inorganic

isocyanates

organo-halogen compounds, excluding inert polymeric materials and other substances referred to in this list or covered by other Directives concerning the disposal of toxic or dangerous waste

chlorinated solvents

organic solvents

biocides and phyto-pharmaceutical substances

tarry materials from refining and tar residues from distilling

pharmaceutical compounds

peroxides, chlorates, perchlorates and azides

ethers

chemical laboratory materials, not identifiable and/or new, whose effects on the environment are not known

asbestos (dust and fibres)

selenium, selenium compounds

tellurium, tellurium compounds

aromatic polycyclic compounds (with carcinogenic effects)

metal carbonyls

soluble copper compounds

acids and/or basic substances used in the surface treatment and finishing of metals

(i) Chemical Analysis

This procedure applies to the Netherlands, where limiting levels have been published for several elements or compounds (per kg of waste) :

- polycyclic aromatic hydrocarbons	50 mg/kg
- lead	5,000 mg/kg (0.5%)
- zinc	20,000 mg/kg (2%)
- oxides and hydroxides, except those of H_2, C, Si, Fe, Al, Ti, Mn, Mg	50,000 mg/kg (5%) (based on the element)
- aliphatic and naphthenic hydrocarbons	50,000 mg/kg (5%)

(ii) Leaching Test

In Italy, a waste product is considered toxic if its eluate, obtained by extraction with water in an acid medium, contains a quantity of pollutants higher than the quantity permitted by WHO for potable water multiplied by 10.

132. With reference to a typical HyL III plant, Figure 21 gives typical values of solid wastes for disposal.

133. In the particular case of using zinc oxide catalyst as the desulphurizing agent, the hydrogen sulphide in the gas stream reacts with Zn0 to form ZnS. The adsorptive capacity of the catalyst is exhausted after about 2 years and cannot be economically regenerated and so must be discharged. Depending upon the amount of S adsorbed on the zinc oxide, the catalyst may exhibit pyrophoric tendencies when it is exposed to air such as during unloading operations. Moderate care must be taken to prevent spontaneous oxidation. One means of doing this is to wet down the discharged catalyst with water.

Noise

Principal Sources of Noise

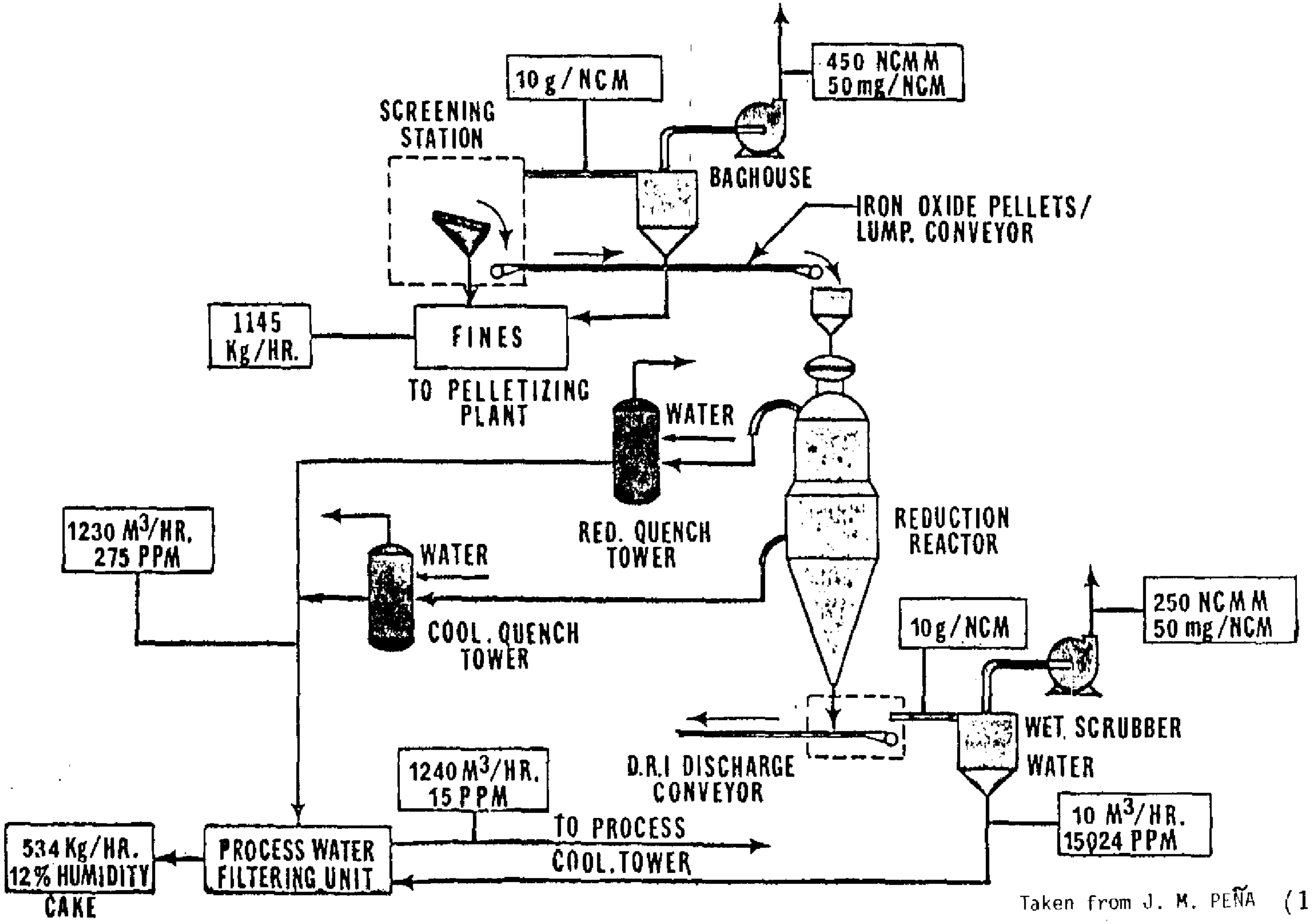
134. It is necessary to distinguish between protection of workers in a plant, which will be considered in paragraphs 142 - 145 below, and protection of the population, the latter being much more expensive to achieve. Direct reduction units have a number of noisy elements (e.g. fans, valves, compressers, burners, etc.) and noisy operations (e.g. charging and extraction of solid products, pressure blowing of gases etc.).

Noise Regulations

135. In the Federal Republic of Germany, the technical instructions for protection against noise (Technische Anleitung zum Schutz gegen Lärm = TA Lärm) contain standard noise limits according to the time of day and type of area in which the noise impact is made. For instance, the values for residential areas are more stringent than those for industrial areas. Particular protection is provided in order to prevent noise at night (21) :

FIGURE 21

HYL III PROCESS
TYPICAL VALUES FOR DISPOSAL OF SOLIDS
CAPACITY 500,000 MTPY D.R.I.



Taken from J. M. PEÑA (19)

Outside plant boundary :

- Noise impact of a plant onto a habitat :

  During night-time : max. 35 dB (A)

  During day-time : max. 45 dB(A)

- Noise impact of a plant onto an industrial area :

  During day- and night-time : max. 70 dB(A)

136. In France regulations, published in 1976, are similar :

Sites	dB (A)		
	Day-time	Intermediate time (+)	Night-time
Rural residential areas, hospitals and resorts	45	40	35
Low density residential areas with low road traffic density	50	45	40
Residential areas in towns	55	50	45
Residential areas with a few commercial or industrial activities or high traffic density	60	55	50
Areas with a predominance of commercial or industrial activities	65	60	55
Heavy industrial areas	70	65	60

(+) Intermediate : 6.00 to 7.00 ; 20.00 to 21.00

Practical Results

137. As an example, Table 8 gives the order of magnitude of the noise inside and around a typical Midrex plant. For instance, the Nordferro plant in Emden, Federal Republic of Germany, was designed so that the total noise of the whole facility would be less than 40 dB (A) at 1 km in any direction (Figure 22). Another example is given by Figure 23 for the SL/RN process. This figure shows the sound level to be expected with and without provision of noise abatement as a function of the distance from a SL/RN plant boundary.

(vi) Problems of Working Conditions

138. Five problems need to be considered in relation to the working environment :

(a) air pollution within plants and workshops ;

(b) noise exposure ;

(c) safety ;

(d) heat stress ;

(e) ergonomics.

This part of the overview deals briefly with these five main areas. For a more detailed consideration of the problems of working conditions and their solutions, reference should be made to the work of the ILO Steel Committee (22) and (23).

(a) Air Pollution

139. Direct reduction processes are usually operated in closed vessels and ambient air in the workplace is generally free from gaseous pollutants, except in the case of an accident by explosion (see (c) below) or an incident. An incident is always possible with a leak from ducts conveying gas or fumes, resulting in escape of CO into the working atmosphere. If the gases and fumes are well collected, cleaned and eventually desulphurized, the residual emissions are very low. It is technologically possible to obtain low levels of residual emissions all the time but there is an important investment and operating cost involved and it is essential to ensure proper maintenance.

Regulations for Air Pollutants in the Working Environment

140. Table 14 gives working environment standards for particulate matter and certain gaseous pollutants for the Federal Republic of Germany, USA and USSR. (It is important to bear in mind that standards are only meaningful in relation to a reliable measurement method. Consequently strict comparison of standards between countries is often not possible due to different measurement methods.)

(b) Noise Exposure

141. Direct reduction plants have the same noise problem as other industrial units. To protect the workforce, it is necessary to select low-noise equipment through the structural design of the plant and by some direct noise abatement, such as using silencers, noise enclosures, etc. Figure 24 shows the noise exposure contours inside and around an industrial SL/RN plant. This situation was determined by noise measurements made in 1979.

TABLE 14

Working Environment Standards for Particulate Matter and Certain Gaseous Pollutants

	GERMANY		USA		USSR	
	MAK *		TWA *		PDK *	
Compound	ppm	mg/m^3	ppm	mg/m^3	ppm	mg/m^3
Iron Oxide						
- dust	-	8	-	-	-	-
- fume	-	-	-	5	-	-
Hydrogen fluoride	3	2	3	2	0,6	0,5
Fluoride	-	2,5 (as F)	-	2,5 (as F)	-	1 (as F)
Nitrogen oxides						
- NO	-	-	25	30	-	-
- NO_2	5	9	5	9	2,6	5
Sulphur oxides						
- SO_2	5	13	2	5	3,8	10
- SO_3	-	-	-	-	1	-

*Definitions :

MAK	Maximale Arbeitsplatz Konzentrazion (Maximum Worksite Concentration) i.e. the concentration in the atmosphere of an industrial substance found at a worksite in the form of a gas or particulate matter which under normal circumstances does not affect the health of a person at this worksite on an 8 hr. working day or 45 hour working week.
TWA	Time Weighted Average Concentration, refers to the atmospheric concentration of a noxious substance to which a normal person may be exposed daily during 7 to 8 hours or 40 hours per week throughout an active working life.
PDK	Maximum Allowable Concentration refers to the maximum concentration at the work place which causes neither illness nor a change in the state of health of a worker.

NOISE EXPOSURE FORECAST CONTOURS FOR A TYPICAL TWO MODULAR MIDREX DR PLANT

Expected sound pressure level in dB(A) 1.5 m above ground level :

⑮ 95	▨	≥95 dB(A)
90	▧	90 – 94 dB(A)
85	───	85 – 89 dB(A)

Expected sound pressure level at a distance of 1000 m from battery limit ≅ 40 dB(A)

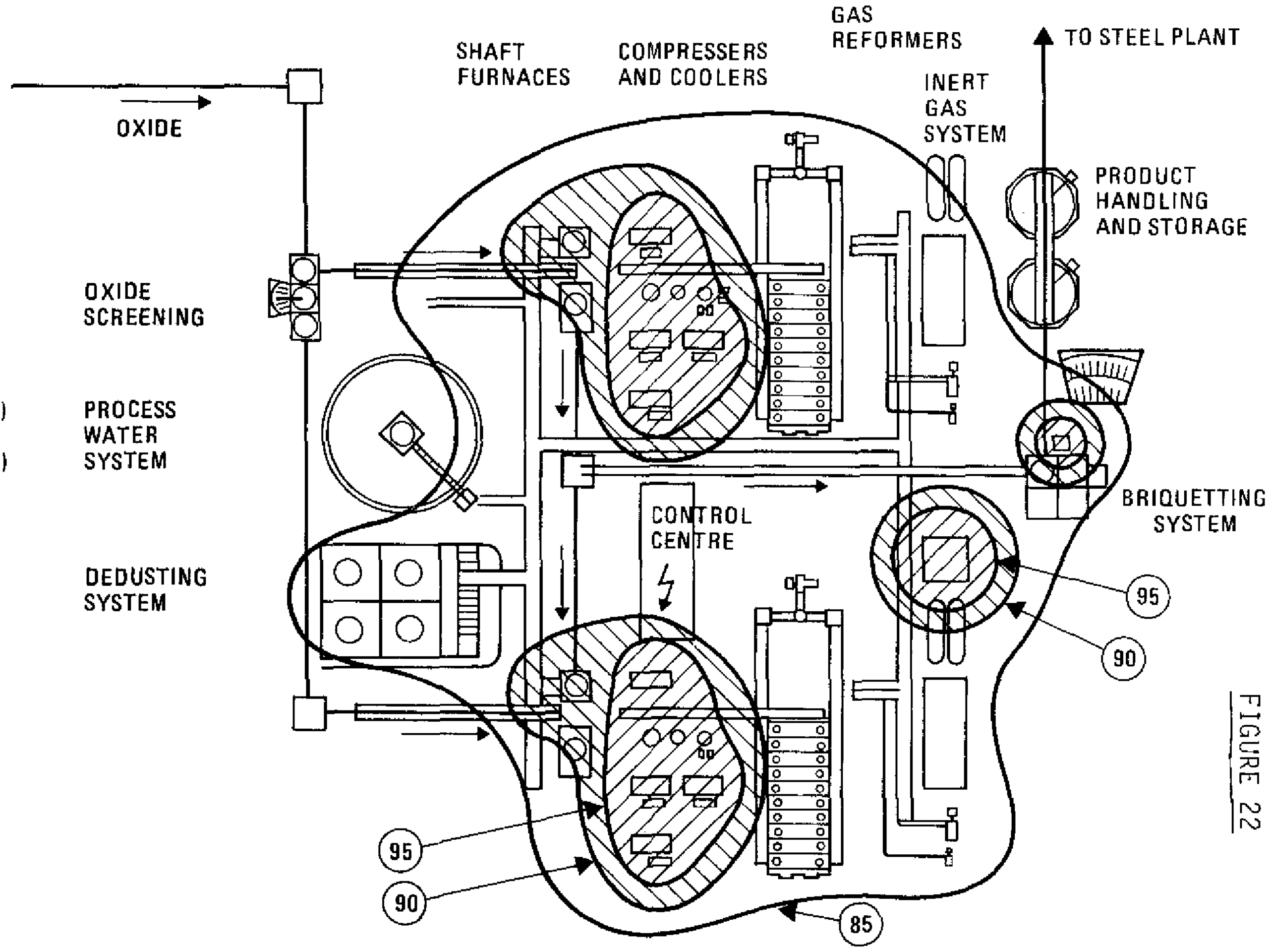
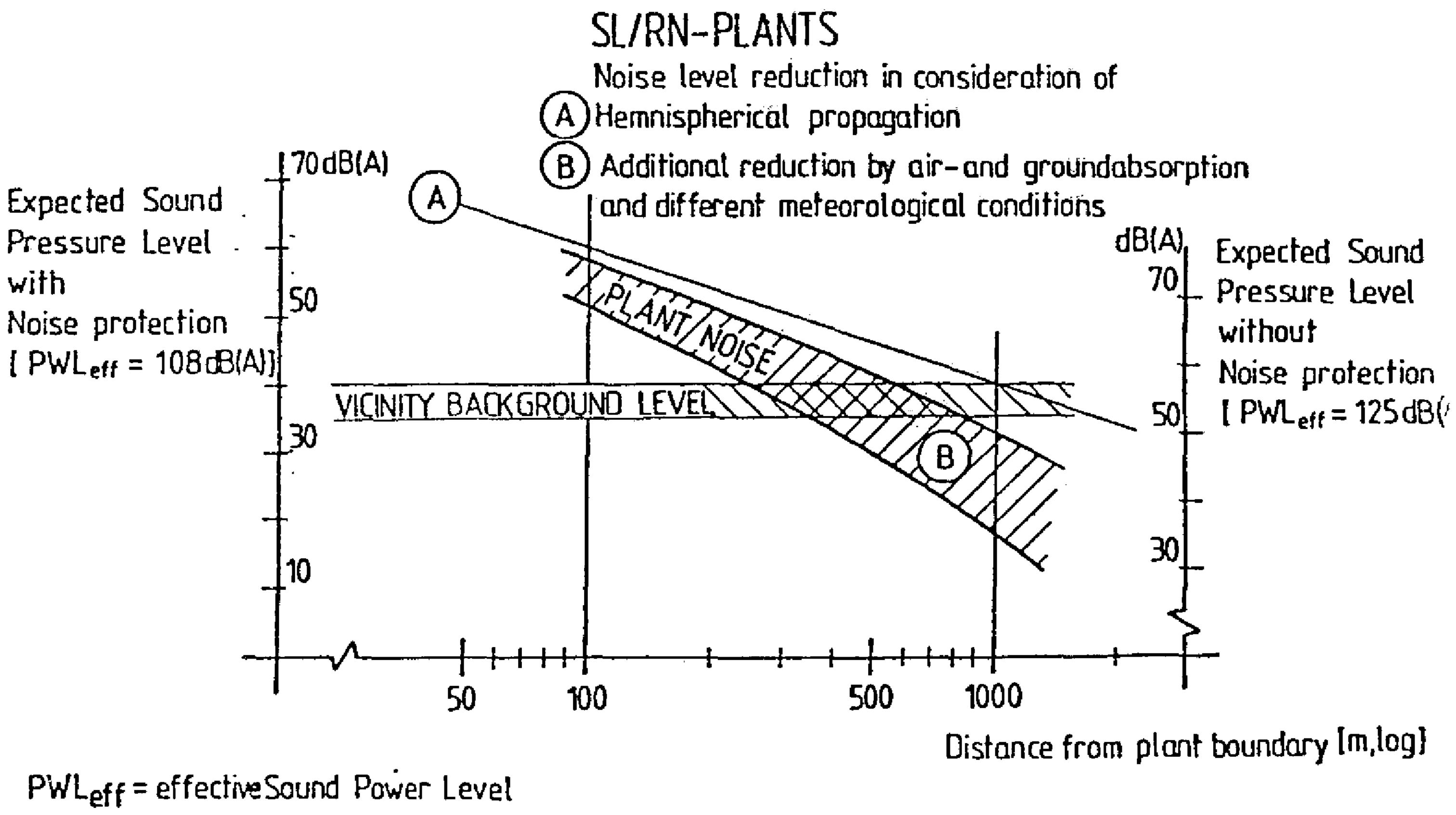


FIGURE 22

FIGURE 23

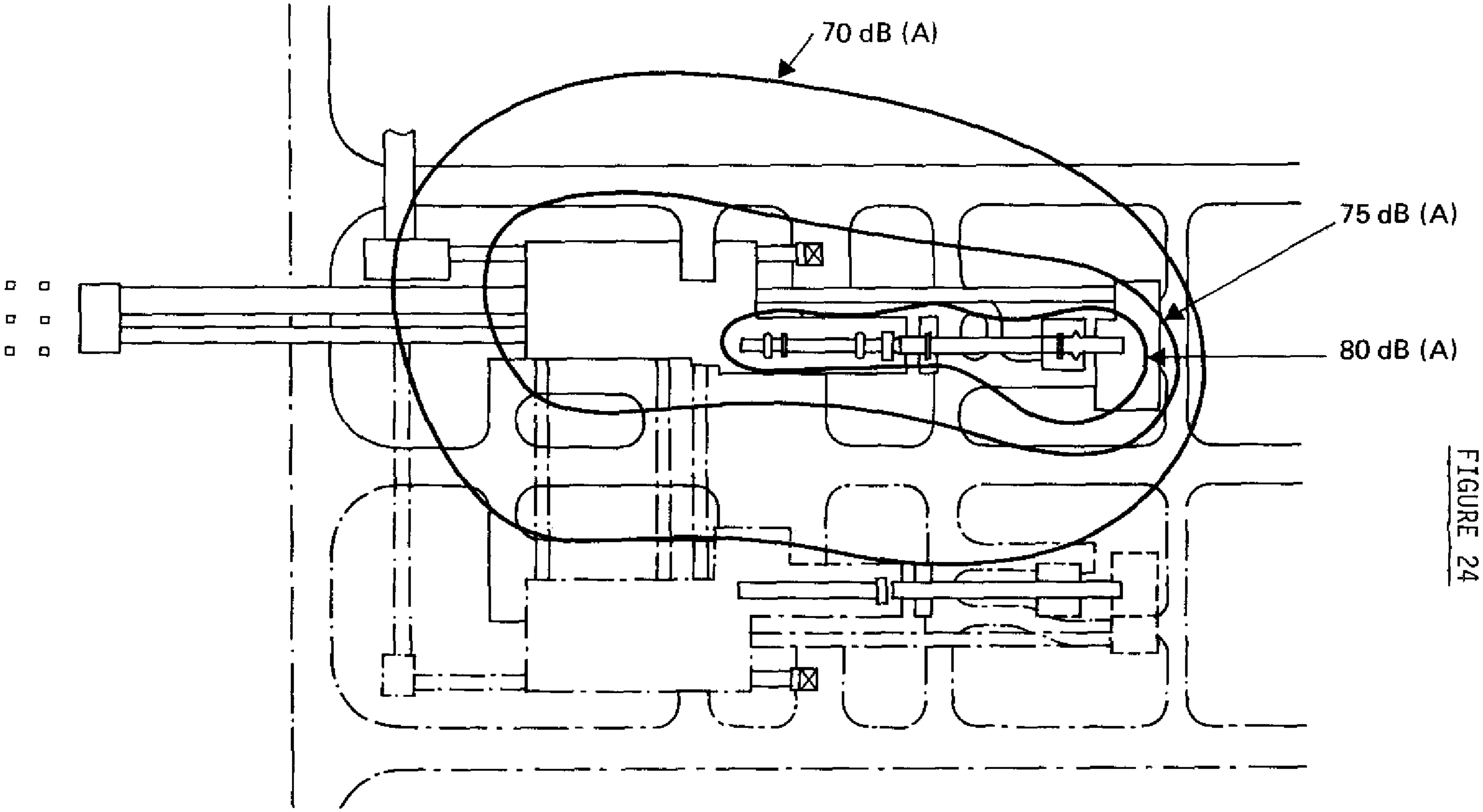


SOUND PROPAGATION AROUND SL/RN PLANTS

Taken from D. Hankel (13)

FIGURE 24

NOISE EXPOSURE CONTOURS IN A SL/RN UNIT



Sound pressure level in dB (A)

Taken from Hankel (13)

Noise Regulations for the Working Environment

142. Noise regulations are intended to control the risk of noise induced hearing loss by limiting the workforce's exposure to noise during the working period (25). Noise exposure can be controlled :

- by limiting the time of exposure to a noise level which exceeds the minimum below which hearing damage risk can be ignored ;
- by wearing ear protection devices ;
- by a combination of the two.

The risk of damage to hearing can be assumed to be proportional to the average noise energy or to the average noise pressure. Under the first hypothesis, the exposure time must be halved for every 3 dB (A) increase in noise level. Under the second hypothesis, the 3 dB (A) increase becomes 6 dB (A).

143. The ISO criteria which is prescribed in many European countries (Federal Republic of Germany, Sweden, United Kingdom) and in Australia is based on the first hypothesis. Its application, for instance in the Federal Republic of Germany, gives the following :

Permitted Noise Level Equivalent	With Ear Protection	Without Ear Protection
8 hours	90	85
4 hours	93	88
2 hours	96	91
1 hour	99	94

144. The OSHA criteria, which is applied in the USA and other countries (Belgium, Canada, Italy) constitutes a compromise between the two hypotheses with the exposure time halved for every 5 dB (A) increase :

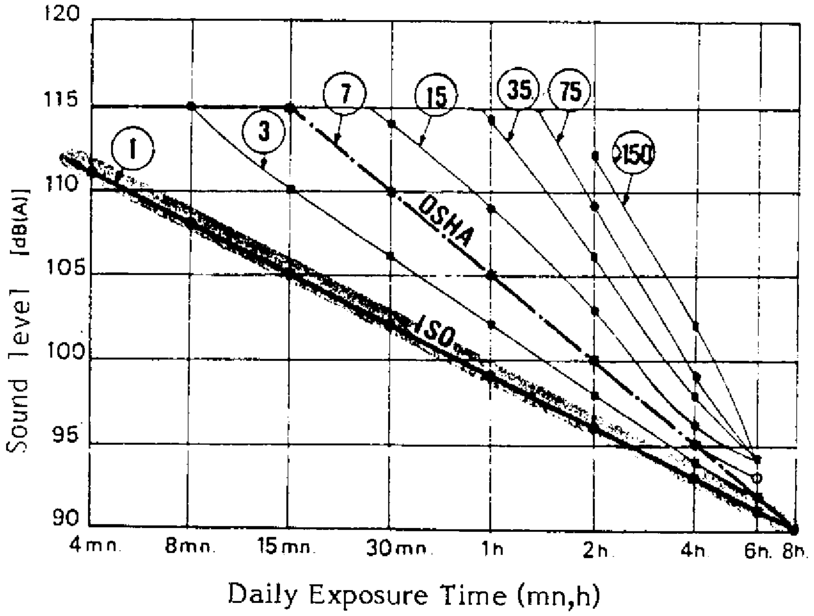
Sound level dB(A)	Maximum Exposure hours/day
90	8
92	6
95	4
97	3
100	2
102	1,5
105	1
110	0,5
115	0,25 or less

Exposure to sound level in excess of 115 dB (A) is not permitted.

145. It appears now well established (26) that the ISO criteria are more appropriate for a simple noise exposure a day, while the OSHA criteria apply better to about 5 to 7 exposures a day. This difference between the two criteria is explained in the Figure 25, which CHABA (Committee on Hearing, Bioacoustics and Biomechanics of the National Academy of Sciences/National Research Council) has published in the USA.

FIGURE 25

Criteria for Single and Multiple Exposures to Different Noise Levels



(c) Safety

146. For a "safe" working environment, consideration must be given to certain aspects of direct reduction facilities. Direct reduction iron dust can be a potential explosion and fire hazard. Therefore, in addition to an efficient dust collection system, good housekeeping is essential in a DR plant to prevent any dust accumulations. Enclosures should receive special attention.

147. DR processes use reducing gases at high temperature and it is necessary to prevent all risks of explosion, fire and asphyxiation. In the areas where such gases may escape, CO monitoring devices and portable CO monitors are recommended. Likewise gas masks and resuscitation equipment are necessary.

148. Appropriate training of the workforce is essential to maintain pollution control and housekeeping installations in order.

(d) Heat Stress

149. Heat stress, particularly in tropical climates, is a hazard in steel works. It is not a serious problem in relation to the direct reduction part of the plant, but may be much more significant in the electric arc furnace steel making part of the plant and is discussed below in paragraph 175.

(e) Ergonomics

150. Direct reduction processes, wherever they may be operated, are very sophisticated and call for a highly qualified workforce. Worker training in plant operation, in maintenance and in environmental and health and safety protection measures is essential in order to avoid serious perturbations in operation and unnecessary environmental discharges, as well as to protect the working environment.

PART IV : STEEL MAKING : ELECTRIC ARC FURNACE

DESCRIPTION OF THE PROCESS

151. Direct reduced iron from the DR process is melted in an electric arc furnace and converted into liquid steel by removing, or reducing, the content of various impurities. Further metallurgical processes may also be undertaken immediately after tapping the furnace in order to improve the quality of the liquid steel and obtain a precise required composition before it is cast, either directly into various semi-products, or into ingots for storage and later manufacture into products. This review only deals with the steel making process to the point of casting.

152. An electric arc furnace is a shallow depth, large diameter cylindrical refractory lined shell with a removable cover. Energy to melt the furnace charge is provided by an electric arc. Three electrodes are inserted through holes in the cover. There is usually a fourth hole for direct evacuation of emissions and/or emission collection system (see paragraph 162. below). Furnace openings are provided for tapping the finished steel and two doors, one for removing the slag and another for making additions to the bath. Arrangements may also be made for an oxygen lance, either through the slag door or a special hole in the furnace side wall ; for oxy-fuel burners, usually three around the furnace at appropriate positions ; and for a possible continuous feeding tube, usually located as far as possible away from the extraction fourth hole. The furnace may also be fitted with other devices for controlling noise and emissions which are discussed below. The furnace shell can be tilted forward about 45^{o} for tapping and about 15^{o} backwards for removing slag. Electrodes are made of graphite (approx. 30-60cm diameter) which are consumed at a rate of about 5-7 kg/t steel product. Furnace design will to a large extent be determined by the raw material input and the type of steel to be produced, although the metallurgical possibilities of secondary steel making have dramatically changed the role of the furnace. For a comprehensive description of the electric arc furnace design and operation reference is made to the recent study made by the International Iron and Steel Institute (27).

153. Most early attempts at melting direct reduced iron in the electric arc furnace were handicapped by the use of furnace units and equipment designed for conventional scrap-based practice, such as that employed in most mini-steel mills. Actually, the direct-reduction/electric-furnace process route is a distinct and new approach to steel production that requires specialized furnace practices and process modifications to achieve maximum operating effectiveness. Although electric arc furnaces may be operated with 100% direct reduced iron, it is usual to have a mixed scrap/direct reduced iron charge, the latter ranging from 20% to 80%. The initial charge, usually of scrap, often is melted using supplementary heat input from oxy-fuel firing to promote uniform melting, after which the direct reduced iron is added. As mentioned in the previous paragraph, it can be continuously fed through a 5th hole, which reduces charging-time requirements and permits the charging rate to be adjusted to an established power input in order to arrive at a desired temperature level once the furnace has been fully charged.

154. The objective of the metallurgical refining process is to adjust the composition of the steel and control the impurities. Gangue from the direct reduced iron is removed by addition of lime and other fluxing agents. Decarburization is accomplished with the assistance of oxygen lancing, which furthermore reduces the tap-to-tap time and the power consumption. Dephosphorization and desulphurization may also be needed and, depending on the specifications for the steel,

the composition, for example of carbon, chromium, manganese, molybdenum, nickel and silicon adjusted. Ferro-alloy addition is the usual means of achieving the latter. Dissolved gases such as oxygen, hydrogen and nitrogen may also need to be removed. Furthermore, it is necessary to control the composition in the charge of certain residual elements, such as copper and tin, whose concentration does not significantly change through the refining process, but the presence of which may significantly affect the quality of steel.

155. Whilst the electric arc furnace suitable for both oxidizing and reducing metallurgy is highly versatile, allowing the use of a wide range of raw materials for producing a variety of steels, it may be also necessary to employ secondary metallurgical processes in the ladle immediately after tapping. These processes allow a further range of chemical composition adjustment and include : decarburization ; refining and deoxidation ; desulphurization ; addition of alloys ; removal of deoxidation products, as well as homogenization and temperature adjustment.

Material Inputs

(i) Pre-reduced Iron

156. The quality of the input materials and the steel quality product requirements have an important influence both on the processing and potential environmental impacts of the operation. Impurities in the sponge iron have an impact on emissions and the nature of the slag for subsequent disposal, as well as on the process itself. Table 15 shows the composition of direct reduced iron available on the international market (27). The lower the ratio of metallic iron to the total iron, i.e. the higher the proportion of remaining iron oxide, the more energy and carbon is required and the larger the volume of emissions. The larger the amounts of gangue, the more flux required and the larger the volumes of slag formed which subsequently need disposal. Furthermore, in order to protect the refractories and ensure desulphurization, a basicity ratio of between 2 and 3 is required, which means that acidic components of the gangue, such as silica, must be neutralized by sufficient addition of lime and magnesia. The presence of sulphur and phosphorus in the sponge iron require refining operations in the furnace, which also have potential environmental impacts. The initial use of high grade ores, free of injurious residual elements, and the avoidance of addition of other elements during the reduction process, have an enormous advantage at the electric arc furnace steel making stage. In any case, direct reduced iron usually gives rise to fewer problems than use of scrap. The physical properties of the sponge iron employed also affects the furnace operation and could have environmental implications. Charging of very small material should be avoided as it tends to float on the slag and may be carried with emissions into the fume extraction system. Whilst newly manufactured sponge iron has good resistance to abrasion, the mechanical properties deteriorate with storage and fine material is produced in handling. Also where lump ore is used as feed material in the DR process, there is a tendency to increased proportion of fines.

(ii) Scrap

157. The nature and quality of the scrap used is also of particular significance (27, 28). Tramp elements (such as cadmium, copper, lead, tin, zinc, etc.) may not only interfere with the desired quality of the product, but also impact on air quality and subsequently on the disposal of sludge and dust from gas cleaning operations. Oils and combustible materials, as well as non-metalic

TABLE 15

PRE-REDUCED IRON ANALYSIS (percentage weight)

Type	SL/RN Dunswart (RSA) Lumps	FIOR Venezuela Briquettes	HYL Venezuela	MIDREX Emden (FRG)	MIDREX Korf, Hamburg (FRG) Pellets	ARMCO (USA)	MIDREX Georgetown (USA)	PUROFER Thyssen (FRG) Briquettes	SL/RN Dunswart (RSA) Briquettes
Fe total	90.0	90.0	> 87.5	92.5	94.0	91.0	87.0	93.8	83.2
Fe metal	82.5	82.0	> 76.0	85.5	89.0	82.0	80.0	88.1	75.6
% metal	91.6	91.0	> 86.0	93.5	94.0	91.0	92.0	94.0	91.0
C	0.2	0.6	2.1	1.5	1.0	2.4	2.0	1.0	0.11
S	0.03	0.3	< 0.015	0.007	-	0.01	0.01	0.01	0.02
P	0.05	0.01	< 0.05	0.02	0.025	0.03	0.05	0.06	0.04
Mn	0.08	-	-	0.15	0.010	0.03	0.03	0.064	0.04
SiO_2	3.6	3.5	1.0	3.0	2.0	3.2	2.5	1.7	4.0
Al_2O_3	1.5	2.1		1.0	0.7	0.6	1.0	1.0	2.79
TiO_2	0.1	-		0.01	-	-	-	0.057	-
CaO + MgO	0.06	-	-	0.7	0.25	0.44	1.8	0.5	1.05
Cu				Extra	Low				
Ni									
Cr									
Mo									
Sn									
As									

Taken from (27)

material in the scrap, may aggravate the problems of emission control during charging. Likewise the physical characteristics of the scrap also influence the economics and efficiency of furnace operation, as well as the potential environmental problems. It is essential for the metallurgical, economic and other constraints in using scrap to be optimized. Table 16 gives an example of guidelines for scrap type and quality to allow such optimization.

(iii) Lime and Fluxes

158. Metallurgical refining is undertaken with the help of fluxes which remove impurities as slags, which can be separated from the liquid steel. The usual flux employed is lime, which also provides basicity to react with acidic components, such as silica. The physical characteristics of the lime affects its efficacity in the refining process and it is desirable to use lime with a small grain size, high specific surface area and high porosity. Experience of pneumatic addition of lime to the furnace is not considered a technique conducive to dust control. Impurities in the lime, such as silica, sulphur and magnesium carbonates, both influence the furnace metallurgy and have environmental implications. Lime production by burning limestone (calcium carbonate) may also introduce impurities, such as sulphur. Furthermore, moisture content in the lime may increase the hydrogen content in the steel and care must be taken in ensuring good lime storage conditions, particularly in humid climates.

159. Fluidizing agents are also added to assist formation of a liquid slag and to help maintain slag fluidity throughout the refining operation. However, these agents should not introduce impurities, e.g. sulphur, into the steel, nor have a detrimental effect on necessary refining processes such as desulphurization and dephosphorization. The most common fluidizing agents employed are ferrite (Fe_2O_3) and alumina (Al_2O_3) for oxidizing slags and fluorspar (CaF_2) for reducing slags. Colemanite (B_2O_3), whilst being a good fluidizing agent, can introduce boron into the steel under reducing conditions. Finally, fluidizing agents may also influence environmental conditions within and outside the plant. For example, fluorine compounds may be produced with the use of fluorspar.

(iv) Carbon

160. It is sometimes necessary to add carbon either for the product specifications or as a deoxidizing agent in reducing slags. The carbon content is usually adjusted by means of the input raw materials. Alternatively coke, anthracite, or other carbon containing materials may be charged to the furnace. Care must be taken not to add unwanted impurities.

(v) Alloying Elements

161. Specific steels may require the addition of other elements such as chromium, manganese, molybdenum, nickel and silicon, which is usually done by adding a ferro-alloy. Pure metals and oxide can also be added under certain circumstances. Care must again be taken to avoid thereby adding tramp metals or unwanted residual elements, such as phosphorus. The physical and chemical nature of the alloying element additions may affect furnace operation and environmental conditions.

Pollution Control and Abatement Technology

162. It is now commonly accepted that adequate environmental protection measures should be taken in relation to steel making operations. This involves

TABLE 16

EXAMPLE OF GUIDELINES FOR SCRAP TYPE AND QUALITY

GENERAL CONDITIONS

A. Safety
All grades to be free from pressurised gas, fuel and other sealed containers, explosives, shells, bombs and dangerously inflammable material. Any material which is potentially re-sealable must be sheared or cut prior to delivery. All deliveries must comply with the statutory requirements of the Health and Safety at Work Act.

B Cleanness
All grades shall be free of dirt, non-ferrous metals or foreign materials of any kind, excessive rust and corrosion. However, the term "free of dirt, non-ferrous metals or foreign materials of any kind" is not intended to preclude the accidental and unavoidable inclusion of any negligible amounts.

C. Residual and Other Alloys
All grades must be free from alloys. However, the term "free from alloys" is not intended to preclude the accidental and unavoidable inclusion of any negligible amounts or to preclude proportions permitted by joint agreement.

D. Grading
No delivery shall contain a mixture of grades. However, this is not intended to preclude the accidental and unavoidable inclusion of negligible amounts of other than the advised grade.

No.	Specification
OA	**Old Heavy Steel Scrap**, consisting of cut structural and plate scrap not less than 6mm thick, in sizes not exceeding 1.50 metres x 0.60 metres, prepared in a manner to ensure compact charging. May include properly prepared wagon scrap.
OB	**Old Heavy Steel Scrap**, consisting of cut structural and plate scrap not less than 6mm thick, in sizes not exceeding 0.60 metres x 0.60 metres, prepared in a manner to ensure compact charging. May include properly prepared wagon scrap.
1	**Old Steel Scrap**, not less than 6mm thick, in sizes not exceeding 1.50 metres x 0.60 metres, prepared in a manner to ensure compact charging. May include properly prepared scrap from dismantled vehicles but must exclude domestic appliance and vehicle body scrap.
2	**Old Steel Scrap**, not less than 3mm thick, in sizes not exceeding 0.60 metres x 0.60 metres, prepared in a manner to ensure compact charging. May include properly prepared scrap from dismantled vehicles but must exclude domestic appliance and vehicle body scrap.
3A	**Fragmentised Scrap**—old light iron and steel scrap fragmentised into pieces not exceeding 150mm in any direction. Must be commercially free from dirt, non-ferrous metals and foreign material, and exclude grindings, swarf, turnings and borings. Must conform to the following specifications: Density—0.80 tonne per m³ minimum. Tin (Sn) content—0.03% maximum. Copper (Cu) content—0.20% maximum.
3B	**Fragmentised Scrap**—old light iron and steel scrap fragmentised into pieces almost all not exceeding 200mm in any direction. Must be commercially free from dirt, non-ferrous metals and foreign material, and exclude grindings, swarf, turnings, and borings. Must conform to the following specifications: Density—0.80 tonne per m³ minimum. Tin (Sn) content—0.03% maximum. Copper (Cu) content—0.25% maximum.
3C	**Fragmentised Scrap**—old light iron and steel scrap fragmentised into pieces almost all not exceeding 200mm in any direction. Must be commercially free from dirt, non-ferrous metals and foreign material, and exclude grindings, swarf, turnings and borings. Must conform to the following specifications: Density—0.60 tonne per m³ minimum. Tin (Sn) content—0.04% maximum. Copper (Cu) content—0.30% maximum
4A	**New Production Compressed Steel Sheet Bales**, in works' furnace sizes, free from all coated, tinned, galvanised, enamelled and deleterious material.
4B	**New Production Compressed Steel Sheet Bales**, in sizes not exceeding 0.30 metres x 0.30 metres, free from all coated, tinned, galvanised, enamelled and deleterious material.
4C	**New Production Compressed Steel Sheet Bales**, in works' furnace sizes, including an agreed proportion of coated material but excluding tin-coated scrap
4D	**New Production Compressed Steel Sheet Bales**, in sizes not exceeding 0.30 metres x 0.30 metres. Including an agreed proportion of coated material, but excluding tin-coated scrap.
4E	**New Production Compressed Steel Bales**, including rods and wire, in works' furnace sizes, including an agreed proportion of coated material, but excluding tin-coated scrap.
4F	**New Production Steel Strip and/or Wire Bobbins**, in works' furnace sizes, including an agreed proportion of coated material, but excluding tin-coated scrap. Must be securely fastened.
5	**Compressed Old Light Steel Scrap**, in works' furnace sizes. Must be free from tin-coated and non-metallic material.
6	**Old Light Steel Scrap**, suitable for pressing. May include an agreed proportion of coated material other than tin-coated scrap.
7A	**Heavy Carbon Steel Turnings**, crushed or naturally short, shovellable, free from bushy, non-ferrous metals, scale, grinding dust, oxidised turnings or other materials from chemical industries, and free from excessive oil.
7B	**Heavy Carbon Steel Turnings**, mixed with bushy up to 20%, not shovellable, free from non-ferrous metals, scale, grinding dust, oxidised turnings or other materials from chemical industries, and free from excessive oil.
8A	**New Loose Light Steel Cuttings**, suitable for pressing, free from coated, tinned, galvanised, enamelled and all deleterious material.
8B	**New Loose Light Steel Cuttings**, suitable for pressing. May include an agreed proportion of coated material, but excluding tin-coated scrap.
9	**Heavy Cast Iron Scrap**, not less than 13mm thick. In works' furnace sizes, free from burnt metal.
10	**Light Cast Iron Scrap**, in works' furnace sizes, free from burnt metal.
11	**Cast Iron Borings**, free from corroded lumps and excessive cutting fluid.
12A	**New Production Heavy Steel Scrap**, consisting of cut structural and plate scrap, billet and bar ends, not less than 6mm thick. In sizes not exceeding 1.50 metres x 0.60 metres, prepared in a manner to ensure compact charging.
12B	**New Production Heavy Steel Scrap**, consisting of cut structural and plate scrap, billet and bar ends, not less than 6mm thick. In sizes not exceeding 0.60 metres x 0.60 metres, prepared in a manner to ensure compact charging.
12C	**New Production Heavy Steel Scrap**, consisting of cut structural and plate scrap, billet and bar ends, not less than 3mm thick. In sizes not exceeding 0.60 metres x 0.60 metres, prepared in a manner to ensure compact charging.
12D	**New Production Clean Shovellable Steel Scrap**. In sizes not exceeding 150mm in any direction, including new factory sheet clippings, punchings and stampings.

Taken from (27)

protection of air and water quality, as well as controlling noise both within and outside the plant. Additionally, in the working environment heat may be a problem. In the electric arc furnace melt-shop the principal emission is of fume and dust arising from the furnace (charging, melting, refining, deslagging and tapping), as well as from some auxiliary operations such as handling of direct reduced iron, fluxes and scrap. Approximately 90% of these emissions arise during the meltdown period and the remaining 10% during tapping (4%), charging (2%) and as fugitive emissions. Slag handling and furnace rebuilding are also important sources of dust. Noise arises mainly from the electric arc furnace and scrap handling. It is essential that the required pollution control techniques and equipment be integrated into the plant design if investment is to be optimized and effective discharge control achieved. For more detailed examination concerning pollution control and abatement technology, reference is made to the background paper (29) and the IISI publication (27).

Emissions to the Atmosphere

163. Built into the design of a modern electric arc furnace is the fume evacuation and collection system, consisting of direct evacuation through a fourth hole in the roof of the furnace and/or a roof hood above the furnace. The operation of the furnace, as well as the raw material input and product quality requirements, have a significant impact on emission collection and cleaning efficiency, currently almost exclusively directed towards control of particulate matter.

164. With the fourth hole system, emissions are evacuated directly to the gas cleaning equipment. Usually dilution air is added to reduce the gas temperature and provide excess oxygen for complete combustion of carbon monoxide. The typical capacity of such a system is about 1000 $Nm^3/h/t$ furnace capacity. Often surges in emission overload the system and give rise to secondary emissions. Furthermore, this system does not provide for emission capture during furnace charging or tapping.

165. The roof hood system provides a canopy above the furnace for evacuation of emissions and may be modified to ensure capture also during charging and tapping. Typical capacities of this system range from 340,000 to 850,000 Nm^3/h per furnace. Since the hood system is remote from the furnace, there are inevitably secondary emissions during operation. Increasing the system capacity increases considerably the investment and operating costs. A combination of the roof hood and fourth hole direct evacuation systems improves greatly the collection efficiency, enabling about 94% of dust emissions to be controlled. Canopy hoods may also be located over the ladle to capture dusts and fume during tapping and addition of alloys.

166. Control of secondary, or fugitive, emissions requires the evacuation of the air from the total furnace shop through a roof ventilation system which is cleaned before discharge. Capacities of 2.0 to 3.4 x 10^6 Nm^3/h are required. If capacities are not adequate, working environmental conditions are adversely affected. In hot climates the heat problem is accentuated. Furthermore, there is also the problem of large particle fall-out within the shop. Slag handling is also another source of fugitive dust. In most melt-shops the slag from the furnace is poured on the floor and its subsequent removal can create a major emission, often bigger than the quantities of fume generated during tapping and in ladle refining. A partial solution may be provided by pouring of the slag from the furnace into slag pots and removal by overhead crane, which adds a cost of approximately US $ 3 per ton of molten steel.

167. A number of these problems have been overcome recently by a system of furnace enclosure called a doghouse of which several different designs have been constructed. This approach reduces considerably the volume of air to be evacuated and cleaned, thus reducing operating as well as investment costs. This system combined with direct evacuation of emissions from the furnace is capable of controlling up to 98% of the total emissions generated during an operating cycle. It has the added benefit of reducing the noise problem (see paragraph 174 below). The approach calls for major design modifications in the electric arc furnace shop, particularly with regards to charging and tapping and to ensure good visibility for furnace operating personnel. These systems also need to be designed to meet sudden variations in emissions, as well as the risk of explosions.

168. The collected emissions from each of the evacuation systems need to be cleaned before being discharged to the atmosphere. Gas cleaning efficiency of 99% is practicable by means of a number of techniques. Bag filters are usually employed, but there is also extensive experience using electrostatic precipitators. Venturi scrubbers are usually considered to be uneconomical for use in steel making shops due to their high operating costs. Capital costs of bag filters are relatively low. Electrostatic precipitators have the advantage of low maintenance and operating costs, but are difficult to operate efficiently due to the variable load and dust resistivity conditions in steel making. However, they can operate at high temperatures whilst gas temperatures have to be reduced to below 130° for bag filters. At modern electric arc furnace installations, primary and secondary emissions streams are usually treated in the same gas cleaning system. It is important to bear in mind that efficient maintenance of gas cleaning systems is essential.

169. Care must be taken in handling dusts from gas cleaning equipment. Dusts collected by dry systems are very fine (90 - 95% below 0.5 micron in size) and often contain significant quantities of non-ferrous metals. Recycling and disposal of these dusts is discussed in paragraphs 184 - 186.

170. Existing emission collection and cleaning systems enable electric arc steel plants to meet air quality and emission standards for particulate matter currently in force in countries. Regulations vary amongst countries. Typical particulate emission standards for steel plants range from 0.2 to 0.4 g/Nm^3 or even lower, depending on furnace size and operating conditions. In general there is no attempt by steel plants to control non-particulate emissions, such as sulphur and nitrogen oxides. Other substances such as phosgene and nickel carbonyl may be found in electric arc furnace exhausts, but little is known about their formation. It is generally agreed that all plants should have a sampling and analysis schedule for emissions and ambient concentrations of particulate matter and other pollutants where significant. Examples of ambient air quality regulations in force in certain countries are given in Table 7.

Discharge to Water

171. Steel making in electric arc furnaces has a lower water requirement than in other processes. The main requirement is for cooling purposes. At modern plants water cooled furnace linings may also be employed which increase the requirement significantly. The IISI report (27) quotes an estimated water requirement of 1,100 m^3/hr for a 120 t electric arc furnace, which compares with 5,500 m^3/hr for a typical 210 t BOF furnace. Considerable amounts of water are also used in casting. The usual practice is to design a closed recirculating water system with chemical treatment. Several cooling heat exchange systems are available, including some which allow waste heat recovery.

172. A small proportion, usually less than 10%, from water recirculation systems may have to be discharged after treatment. The pH of the discharge has to be kept within the range 7.0 to 9.0. A pH below 6 might be corrosive and above 9 might be scale forming. There are usually regulations limiting total suspended solids and maximum permissible concentrations of various ferrous and non-ferrous metals (particularly hexavalent chromium, cadmium, lead and zinc) as well as other toxic substances, such as cyanides and organo-phosphorus compounds, plus substances such as oils and greases. The temperature of the discharge is often controlled to reduce risk of thermal pollution. Statutory discharge limits vary from country to country and in some cases depend on the receiving waters.

Noise Control

173. There has been in recent years a growing appreciation of the need to control noise at electric arc furnace plants and considerable technical progress has been achieved. The furnace itself is a major source of noise, particularly also of low frequency. The highest intensity occurs during early melt down with scrap and peaks approaching 125 dB (A) near the furnace are frequent. The noise level for continuous sponge iron pellet feeding is about 90 to 100 dB (A). Materials handling, scrap charging and ventilation equipment are other important noise sources, particularly of concern in the working environment. In the past, ear protective equipment was the main approach to protection of personnel within the plant and, whilst these types of devices are still used, plant and equipment design is now considered a more effective means of protection ; particularly as ear muffs are not pleasant to wear in hot climates and their use is difficult to enforce. Certain process operation techniques, such as proper sequencing of scrap charging, continuous feeding of pellets, fragmented scrap and early slag formation, may also be employed to reduce noise. DC arc furnaces as well as plasma arc operations generate less noise than the normal AC direct arc operation.

174. Acoustic installation can be built into electric arc furnace plant design, which helps to contain or deflect noise. Construction of adsorptive sound barriers directly over the furnace contribute to noise control. The IISI report (27) quotes a 5 dB (A) reduction in shop floor noise level by this technique. However, these types of barriers may interfere with the operation of fume collection. Recently the design of doghouse type enclosures has enabled very satisfactory noise protection both within the plant and of the surroundings. Retrofitting of existing installations with this technique has a lot of problems but for new installations it offers considerable benefits. These systems if properly designed may enable highly satisfactory noise and air pollution control, provided there is adequate protection for any personnel who may need to enter the doghouse during operation. Most plants are equipped with the sound proofed control rooms for furnace operation personnel. Techniques now available enable even night time protection of residential areas close to EAF plants of 35 dB (A) maximum. Consideration is being given by the USA/OSHA for an occupational health exposure standard of 85 dB (A) for 8 hours per day.

Exposure to Heat, Ionizing Radiation and Vibration

175. Heat exposure is a hazard for furnace operators and personnel involved in casting operations. Work may be strenuous in the hot environment and heat stress may be accentuated in hot and humid climates. Protective measures, such as shielding, adequate job placement, medical surveillance, rest periods,

protective clothing and correct body salt balance and water intake are essential. Protective measures developed for temperate climates may not necessarily be the most appropriate for conditions in the tropics and further study on this subject is required.

176. Ionizing radiation arises from electric arc furnace operation and appropriate protective measures are required.

177. Vibration is another possible problem area for the working environment. It calls for careful design of observation platforms, seats and operation of vibrating equipment, as well as for controlled duration of exposure. Hand tools can also be a source of vibration.

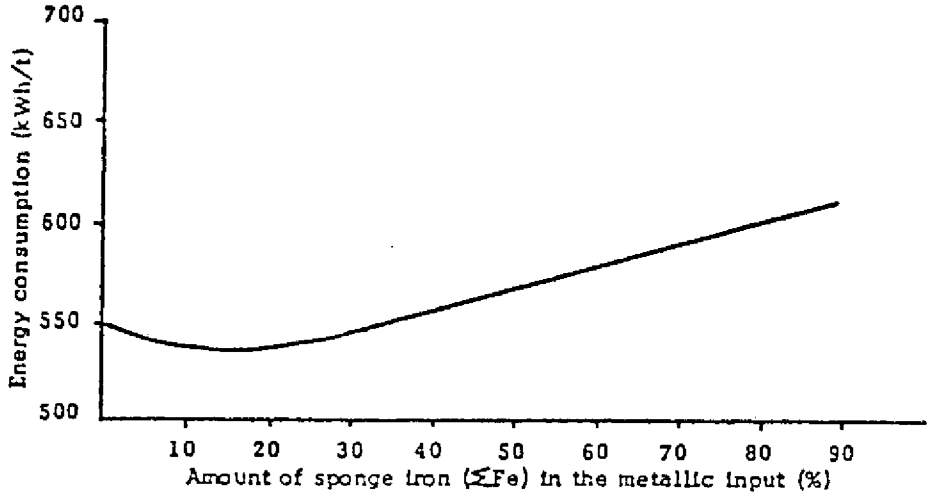
Energy Considerations and Their Environmental Implications

178. Production of 1 ton of liquid steel at 1550° C from direct reduced iron requires more power than from pure scrap (theoretically 391 kWh) due to the need to reduce iron oxide and neutralize gangue. There is also a small decrease (approximately 6%) in thermal efficiency of the furnace using sponge iron compared with melting scrap and melting times are consequently longer. The electrical requirements of the electric arc furnace process are about 640 kWh/ton molten steel when using 100% pre-reduced iron. The use of scrap reduces this requirement and 20% pre-reduced iron and 80% scrap requires about 540 kWh/ton. Figure 26 gives the energy consumption as a function of the percentage of sponge iron in the charge. The total iron content from pre-reduced iron also affects the electrical energy consumption. Figure 27 is a theoretical curve giving the electrical energy consumption in relation to the degree of metallization. According to the experience of some operators, depending on local conditions, this curve may level out at some optimum point or might even increase slightly. The larger the gangue content in the sponge iron, the more energy required, the acidic components (silica) being particularly important in this respect. Moisture in the lime can also adversely affect the energy consumption.

179. Up to about 10% of the electrical energy consumption (i.e. 50 kWh/t) in the steel making process may be required to operate pollution control equipment. This is predominantly for control of emissions to the atmosphere including both direct collection of furnace emissions and the secondary or fugitive emissions which may arise during charging. As has been seen above the quality of raw materials affects the quantity of emissions, as also does operating practice, particularly in relation to secondary emissions. Energy requirements for pollution control may consequently be optimized by careful choice and preparation of raw materials, as well as by good operating practice.

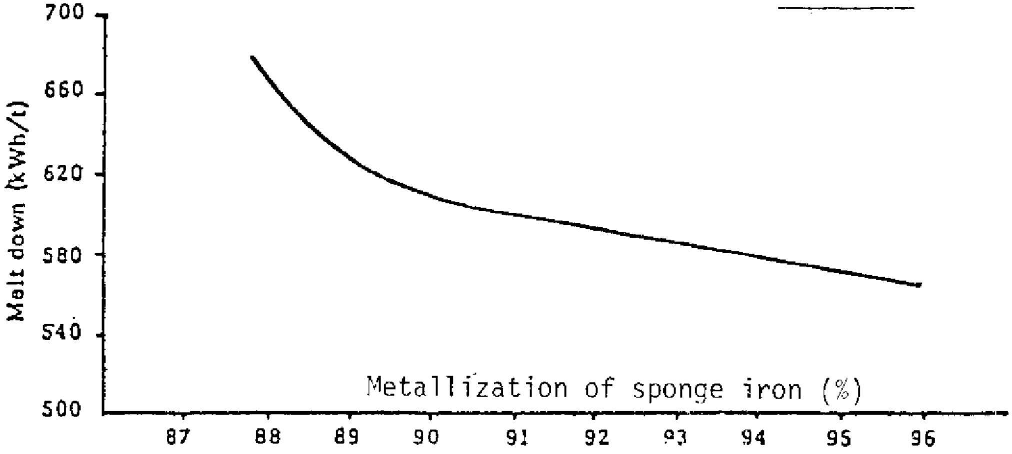
180. A considerable amount of heat loss occurs in steel making and there is a growing trend to endeavour to partially recover energy that would otherwise go to waste. This may have the added benefit of reducing thermal discharge to the environment. Continuous casting is the obvious widely practised technique which reduces energy consumption. A valuable means of energy recovery is to use the furnace emission gases. This may be done in a number of ways. The hot gases after combustion may be passed through heat exchangers to raise steam or employed to pre-heat scrap before charging. Part of the energy value of the gas may also be realized by using the carbon monoxide content as a fuel in raising steam. These various techniques are employed at some plants. Another important potential source of energy saving could be through charging hot sponge

FIGURE 26



ELECTRICAL ENERGY CONSUMPTION IN RELATION TO THE PERCENTAGE OF SPONGE IRON IN CHARGE

FIGURE 27



ELECTRICAL ENERGY CONSUMPTION IN RELATION TO THE DEGREE OF METALLIZATION OF SPONGE IRON

Taken from (27)

iron directly from the DR process. Due to the pyrophoric nature of the sponge iron it would be necessary to ensure a reducing atmosphere, e.g. nitrogen, for the charge transfer. Apart from the HyL I plant, there is insufficient experience in charging hot sponge iron to recommend this technique since, whilst in theory feasible, in practice there are operational problems which currently outweigh the advantages in energy savings which might accrue through use of this technique. Energy recovery of these various types requires prior plant and operation design to ensure effective implementation, and may not be without operating penalties. For example, if steam generation were dependent totally on furnace gas waste heat recovery, there would be periods when steam supply would be interrupted. Furthermore, attempts to use hot sponge iron call for an integration of the DR and EAF processes, making breakdowns more critical and maintenance schedules possibly more complex.

181. Any substantial means of saving electrical energy will normally have a beneficial reduction on environmental impact, particularly where electricity is generated by combustion of fossil fuels. The impact, however, may not be at the same location as the steel plant. Considerations are less clear cut where hydroelectricity is readily available. Furthermore, another factor to bear in mind is that energy recovery may call for substantial additional investment at the construction stage, including supplementary energy supply requirements, which may not in the short term be covered by corresponding savings in operation costs. Additionally, consideration must be given to the energy requirement of materials production.

Residue Utilization and Disposal of Wastes

182. Steel making gives rise to various amounts of usable or unusable materials, the latter generally being termed wastes. Which of these various materials are wastes depends on circumstances and often on local conditions. Good management of materials in steel making calls for minimizing of specific quantities of by-products and wastes produced ; control of environmental problems during reprocessing, transport or depositing of by-products and waste, and minimizing, through recycling, the quantities for ultimate disposal. Solid waste arising from the steel making process comprises : slag, slurries and dust from pollution control, and refractory materials. Plant generated scrap is recycled.

(i) Slag

183. Slag is quantitatively the largest by-production in steel making, the amount and composition depending on the raw materials and quality of steel being produced. The amount can vary over the range 70-170 kg/t liquid steel. Slags usually contain 15-30% iron, which is removed by magnetic separation after cooling and crushing. There is a growing number of civil engineering applications such as river and canal bank reinforcement, road building and railway track ballast. For these applications it is essential that the material should be stable and not swell, which is only possible when the free lime content is controlled. Slags containing relatively high levels of phosphorus are often mixed with natural phosphate rock for use as fertilizers.

(ii) Filter Products from Primary and Secondary Emission Control

184. The qualities and quantities of the raw materials employed in steel making govern the chemical composition of the fume and dust collected. Primary emission

collection gives rise to 12-16 kg/t steel as dust or slurry. Slurries are filtered and pressed or dewatered. Secondary fume cleaning gives rise mainly to fine iron oxide dust.

185. Collected dusts and slurries may sometimes be suitable for recycling to the steel making process by pelletizing or briquetting and recharging to the electric arc furnace. Techniques have now been developed which allow injection of direct reduced iron fines as well as of ore under the slag, thus enabling recycling of these materials. In some cases, however, it is not possible to recycle the dust, for example, because of the presence of lead and zinc or, in the case of alloy or stainless steel making, the presence of nickel and chromium oxides.

186. Where dusts and slurries must be disposed of, secure dumps are essential to avoid contamination of groundwater, for example by heavy metals.

(iii) Refractory Wastes

187. Refractory material arises from the relining of steel making vessels, ladles, etc. Metallic components from this material can be recovered, usually by magnetic separation. Some refractory bricks are reused. The remainder are dumped and in general this material is innocuous.

Transport and Storage of Materials

188. The transport and storage, mainly of raw materials but also of products and waste, may also be a significant source of environmental impact. Air pollution of fine dust may arise from transportation and storage of sponge iron and of slags. Particular care is needed with the handling of direct reduced iron due to its potential for reoxidation and consequent fire and explosion risk. Storage areas should be covered. Transfer points should also be covered and exhausted with dry collection systems (cyclones or baghouses) for non-DRI dusts, and wet systems (scrubbers) for DRI dusts. DRI fines can be briquetted and recycled. Slag storage and handling may also be a source of wind blown dust, which may be reduced by dampening.

189. Scrap handling is a particular potential source of noise and to a lesser extent so is product handling. Acoustic screens are a means of reducing this source of nuisance as well as careful handling operations.

PART V : ENVIRONMENTAL MANAGEMENT WITHIN AND OUTSIDE A DR/STEEL MAKING PLANT

190. There is a growing acceptance that Governmental authorities and industry need to take mutual supportive action in order to ensure effective environmental management in relation to steel making. The main objectives of environmental management are the protection of health, safety and welfare of both the industrial workforce and the general population, the avoidance of unnecessary degradation of the natural environment, the reduction of nuisance and loss of amenity and the wise use of natural resources. Environmental protection policies need to be seen as a whole and in relation to use of resources. Measures to protect the environment outside the plant should not create a health and safety hazard to the workforce. Steel making activities should not destroy the environmental and economic resource base of the surrounding countryside.

191. Whilst public authorities need to assess the environmental protection measures required for the region and ensure that appropriate requirements are met by the industry, both parties have an interest in undertaking this in co-operation. Two important aspects of environmental management where this co-operation is needed is the initial environmental impact assessment of the steel making operation and in the field of monitoring and surveillance.

192. A proper environmental impact assessment enables a cost effective approach towards ensuring inclusion of adequate and appropriate environmental measures at the design stage of the steel making operation (see paragraphs 19 - 27 and references 7 and 8). Monitoring is necessary to ensure that environmental quality and health and safety objectives both within and outside the plant are being met. Monitoring of emissions and effluents is vital not only to ensure compliance with regulations, but also to provide management with information in relation to both process controls and the correct functioning of environmental control equipment. Governments and industry further need to agree on measures to be taken under emergency conditions.

193. Protection of the health and safety of the workforce is a primary responsibility accepted by industry and public authorities (+). In each works there should be a systematic analysis of potential sources of accident, as well as of the incidents which occur, so that suitable preventive measures may be incorporated at new installations. There are three main aspects in relation to safety. The first is the avoidance of the common type of accident such as tripping and slipping due to obstructions, carelessness, lack of cleanliness, etc. The second is one of the plant integrity, depending on adequate design of machinery, use of suitable materials (e.g. to avoid corrosion), proper maintenance of equipment, management of resources, especially water for cooling purposes. The third is the question of avoiding major incidents, e.g. explosives due to hot metal and water or leakage of combustible gases. There should be appropriate contingency plans for accidents.

194. Policies in relation to protection of the working environment should be directed towards control of potential pollution at the source and adequate industrial hygiene monitoring programmes to check on the quality of the working environment. Where control at source is not possible or feasible, the individual liable to exposure should be protected either by personal equipment (the use of which may be restricted by climatic conditions) or removal from the polluted working environment (by job rotation or automation). These two approaches interrelate. Whilst an ideal solution may be to have a fully automated operation

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(+) See Draft Code of Practice referred to in Ref. 23.

with workers enclosed in air conditioned control rooms or protected cabins, this may not be practicable or too costly under certain circumstances. In any case, maintenance has to be undertaken on the plant, which will call for adequate worker protection. A high level of cleaning of the working atmosphere may minimize the risk under most circumstances, but there are operating conditions where extraction equipment may not function effectively. Under these types of conditions personal protection (respirators, clothing, etc.) is essential. There may be conditions where job rotation may be an effective means of guaranteeing that workers are not subjected to undesirable exposures to hazards.

195. All factories should be equipped with medical centres for dealing with initial emergency treatment in the case of accidents and for regular medical supervision of employees, including initial fitness for the job, audiometric checks, checks on personal uptake of potentially dangerous substances, etc. Those responsible for in-plant monitoring of conditions, particularly air pollution and safety measures, should be in regular contact with the medical centre to ensure adequate liaison with health supervision.

196. Mention may also be made of the need for contingency plans in the case of accidents, particularly for major incidents and disasters. All factories should have emergency plans for ensuring that essential services have ready and rapid access to the disaster area. Procedures, tailored to each specific operation, should be established for the proper and safe shutting down of operations, e.g. electric arc furnaces, in the case of accidents. All personnel should be trained in emergency procedures appropriate to their functions and this type of training should also be incorporated into the initial instruction of new employees. Appropriate labelling of emergency equipment etc. is also essential.

197. The right management attitude and management-worker relationships are indispensable to a high level of protection of the working environment. It is essential that pollution control equipment is properly designed, maintained and operated to cater not only for normal situations but also for peak loads. The processes themselves must be correctly run. Proper operation and maintenance calls for not only a high degree of management co-ordination and worker co-operation, but also a high level of training and a concern to impart a consciousness to the workforce concerning environmental protection matters. All new workers should receive adequate training for their functions, as well as medical examination for fitness for the job, and health education concerning potential hazards in the work place. The work force should also be trained in the proper use of protective equipment, e.g. clothing, ear protectors and face-masks, which should be designed for function and comfort.

198. Running of the steel making process, whether it be charging or tapping furnaces, are other important areas where good operating conditions are necessary to minimize emission of pollutants to the working environment. Good practice may be a question of the correct rate of pouring of hot metal or charging of scrap, etc., to minimize the volume of emissions, so as not to overload the pollution extraction equipment.

199. Within the role of training at both management and worker level is the question of making the whole workforce aware of environmental aspects, and a good example must be set from above. Workers' unions and organizations may play an important role in educating their members to be aware of environmental

matters both in relation to internal working conditions and the external environment. With a view to improving environmental conditions and through joint consultations with the management mutually agreed improved operating and maintenance procedures could be adopted. The unions might even take a leading role in suggesting environmentally sound and resource conserving improvements in operating and maintenance practice. It should be appreciated that protection of both the working and external environment is of benefit to all employees and the community in general, as well as to the company. Stability in the workforce is important in attaining good operating practices and calls for good labour relationship throughout the industry. Job rotation, necessary to ensure adequate worker protection from hazardous exposures under specific conditions, may require close co-operation between management and workers' representatives at all levels.

200. Finally, it must also be borne in mind that cleanliness or good housekeeping of the plant is a vital part of the working conditions. This should form the basis of all the efforts to control working environment hazards and in itself can improve motivation and morale. Housekeeping competitions within a plant may act as an incentive, particularly in developing countries.

PART VI : POSSIBLE FUTURE TRENDS AND THEIR ENVIRONMENTAL AND RESOURCE IMPLICATIONS

201. A theoretical scheme of producing 1 ton of liquid steel involving no pollution discharge would be the reduction of pure iron oxide (Fe_2O_3) (1 430 kg) with hydrogen (51 kg or 571 Nm^3) heat being provided by electrical energy (206 x 10^3k cal or 239 kWh for the reduction stage and 320 x 10^3k cal or 372 kWh for the melting stage). Present practice is far from this hypothetical scheme. Furthermore, present practice is facing a number of constraints, whether by the classical or direct reduction routes to steel making. The shortage of supply of the traditional reductants, coke or natural gas, is likely to continue becoming more acute, particularly next century. The supply of high quality raw materials is also likely to become tighter with the need to use lower grade ores and poorer quality hydrocarbons. Energy prices are also likely to continue to increase in real terms. Concern about working conditions and the environment in general will call for strict pollution control and the development of low and non-waste technologies. There are a number of foreseeable trends which would considerably influence steel making and have important environmental and resource implications. This section will review these trends under the headings of : a) process technologies, b) raw materials, reductants and energy and c) environmental protection technologies, bearing in mind that many aspects are interrelated.

a) Process Technologies

(i) Ore Treatment

202. Not all ores are suitable for production of highly metallized products for use in steel making. The important ore property factors are : gangue content, especially silica ; content of deleterious impurities, e.g. As, Cu, Sn ; reducibility ; and tendency to stick, swell or disintegrate during reduction. Ores (or pellets) which undergo major disintegration or swelling during reduction and those with a tendency to stick interfere seriously with direct reduction furnace operation and cannot be used without modification. Dolomite addition to give basic pellets may help to overcome these adverse properties of certain ores. Reducibility is very important in production of a highly metallized product. Ore composition, e.g. the proportions of haematite and magnetite, as well as the ore, or pellet, size and other physical properties are key factors affecting reducibility. Impurities in the original ore can create problems in the processing to steels of specific qualities, give rise to pollution problems and involve additional fluxing materials as well as unnecessary energy consumption in processing and transportation. It would consequently appear advantageous to remove as much as possible of the impurities at the mine site, bearing in mind however that unwanted constituants, i.e. gangue, need to be disposed of in an environmentally acceptable and sound resource management manner.

203. The diminishing availability of high grade ores and the need to use poorer quality ores will lead to a continuing trend towards concentration and beneficiation. No new ore treatment techniques appear to be under development and probably the techniques in the near future will be a combination of classical techniques.

204. It is normal practice to agglomerate ores to give certain size and other physical characteristics needed for the reduction processes employed. Agglomeration tends to add impurities, e.g. sulphur and carbon which have to be eliminated

in the later steel making stage. There is a trend to use natural lumps of iron ore for DR shaft furnaces and also fine ores or concentrates for fluidized bed processes. Briquetting, rather than pelletizing, is another possibility and perhaps new agglomeration processes will be developed. These trends would have a beneficial environmental impact, reducing the discharges arising from agglomeration, as well as a possible saving in energy.

(ii) DR Process (+)

205. Direct reduction processes continue to evolve and new technologies are emerging. Energy considerations will be more and more important. Reference can be made to developments in solid coal use. Computer control for DR processes will also be a future trend.

206. An evolving DR process is the ACCAR process. Developed by Allis-Chalmers Corporation at Milwaukee, Wisconsin, the ACCAR (Allis-Chalmers controlled atmosphere reduction) process employs a ported rotary kiln, together with solid, gaseous or liquid fuels, singly or in combination, to directly reduce iron oxides into steel making grade DRI. This process is illustrated by the flow diagram in Figure 28, which shows a typical plant design encompassing facilities for feed delivery, reduction and cooling, product handling, and exhaust-gas treatment. Central to the process is its ported and refractory-lined rotary kiln, which is shown schematically in Figure 29. Lump ore, oxide pellets, or cold-bonded agglomerates (and coal, if used) are screened to a uniform size range, charged into the kiln at a controlled rate, and heated to reduction temperature by a counter-flowing stream of process gases. Unreformed gaseous and liquid fuels (natural gas, coal gas, or fuel oil) are injected directly into the underside of the hot charge through a series of admission ports along and around the kiln's active zone. The ports, symetrically positioned in eight equally spaced rows, also channel the required process air as they rotate through the kiln's over-bed combustion zone. Material loading is approximately 15% to 20% of the cross-sectional area, and process operating temperatures range from 980 to 1040° C. The injected gas and liquid fuels are heated and reformed within the hot charge, and the consequent reducing agents attack the oxide feed and extract its oxygen to produce DRI. The reduced product discharges from the kiln into an indirect rotary-drum cooler, where its temperature is reduced to about 74° C and is then magnetically separated and screened. The resulting DRI requires no further treatment and is nonpyrophoric in nature. Its metallization generally ranges between 92% and 95% and its carbon content is adjustable within the 0-1% range.

207. In the initial stages of commercialization Allis-Chalmers leased the 50 meter long and 1.65 meter in diameter rotary-kiln facility of the Chesbar Iron Powder Company Ltd. at Niagara Falls, Ontario and subsequently a second kiln, an SL/RN unit 53 meters long and 5.5 meters in diameter that had been mothballed by Falconbridge Nickel Iron Refining at Sudbury, Ontario. The Niagara Falls and Sudbury plants have rated annual capacities of 40 thousand and 265 thousand tons respectively. At present, the former unit is operated only intermittently as a demonstration plant, and the latter is shut down. In operations to date, both units have been dependent on higher-priced fuels, natural gas and oil. Only the smaller kiln at Niagara Falls has used coal to any significant extent, this on a demonstration basis, while the Sudbury kiln had been using natural gas as its major fuel in the summer months and was largely fuel-oil dependent during the winter. A third plant, built at Orissa Sponge Iron Limited, Keonijhar,

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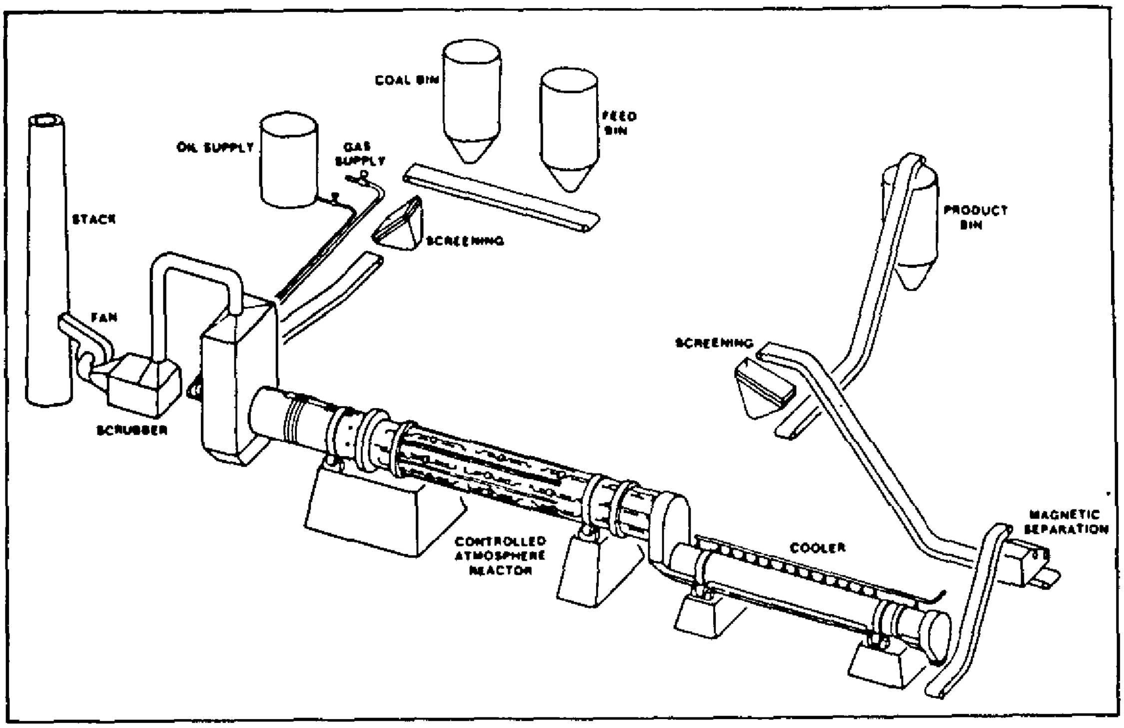
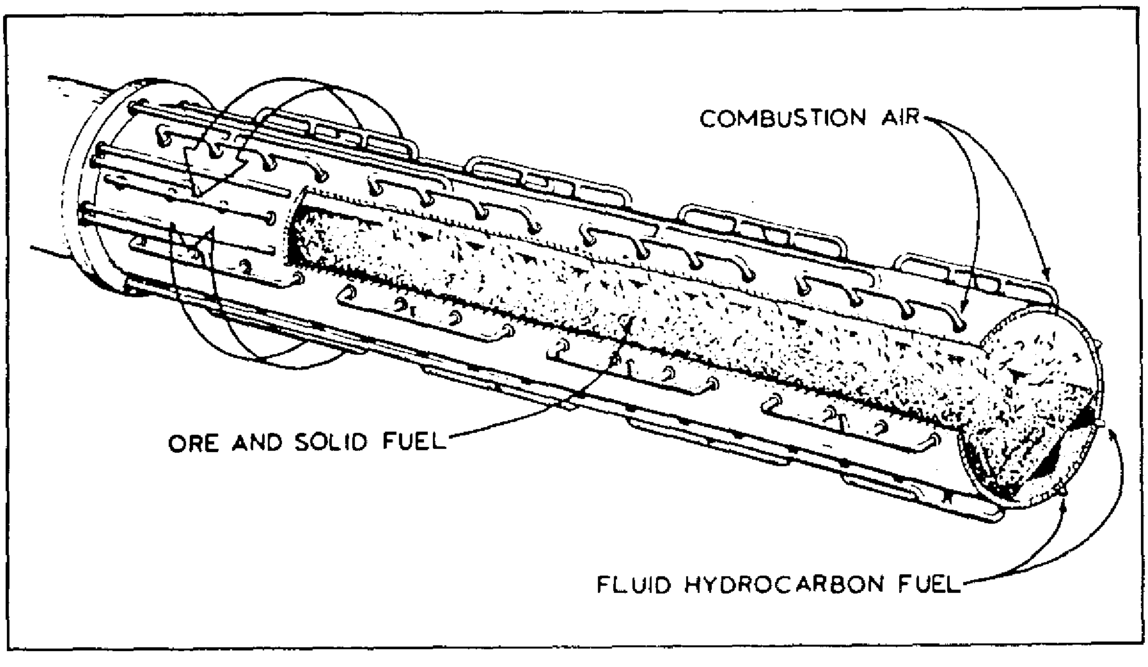
(+) Unless otherwise stated, description of processes are taken from (10).
Note : 1 ton represents 2000 pounds.

FIGURE 28

Flow Diagram for the ACCAR Process



Rotary-Kiln Reactor of the ACCAR Process FIGURE 29



Taken from (10)

a totally coal-based operation, addition of the oil should reduce total fuel consumption and increase plant productivity. The Orissa facility will provide the first commercial experience with a kiln and ancillary facilities based totally on Allis-Chalmers' designs.

208. The newly emerging technologies are coal-based, namely : the Midrex EDR, Ferrocal, Pelletech, Thagard Plasmared, INMETCO and KR processes (10). With the exception of the Plasmared and KR processes, coal is gasified directly in the reduction unit.

209. The Midrex EDR (electrothermal direct reduction) process is based on a vertical shaft type furnace with electrical resistance heating to a top-charged mixture of ore (pellets and lump ore) and coal (see Figure 30). This process co-produces a low sulphur gas (approx. 3.6 M BTU/t DRI) of approximate heating value of 2,000 k cal/m^3 which can be redesigned to use the gas within the system. A pilot testing facility is operating in Charlotte, N.C., USA and a commercial installation has been under construction at the Georgetown Texas Steel Corporation in Beaumont, Texas, USA (10).

210. The Ferrocal process is based on an induction heated vertical downdraft retort with ore-pretreatment and the possible subsequent transformation of the DRI into molten iron (10). Figure 31 gives the flowsheet for this process which was developed by Calderon Automation Inc. of Bowling Green, Ohio, and tested experimentally at the metallurgical research laboratory of Ohio State University USA. Compared to the average energy requirements for other direct reduction methods, this process appears to have a potential for savings in the range of about 11 to 35%, and enables hot metal to be made with non-coking coals.

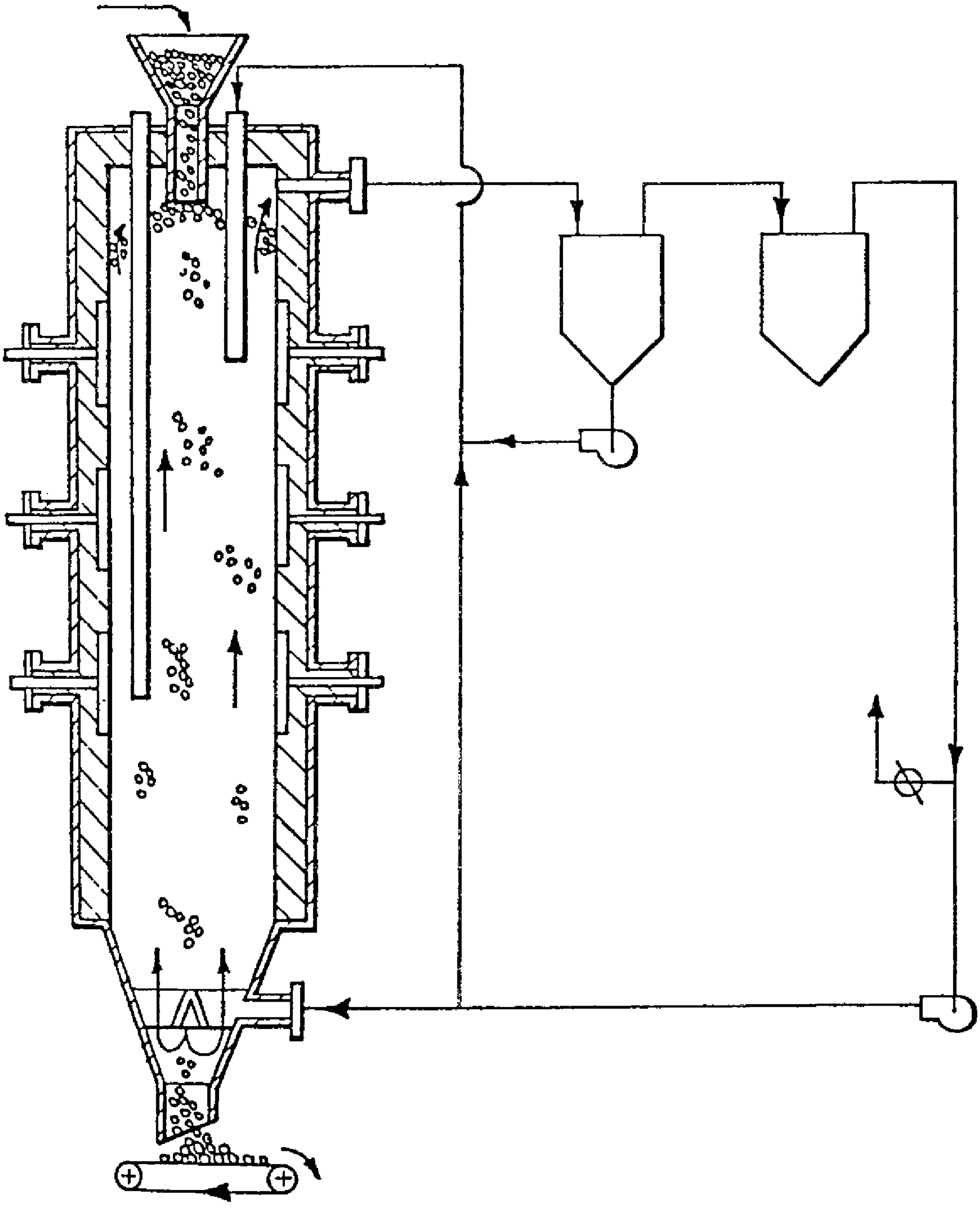
211. The Pelletech process uses self reducing pellets, consisting of iron ore 15-20% carbon fines (non-coking coals, coke, anthracite, or lignite) and 2 to 5% bonding agents (lime and silica), in a modified rotary kiln (for flowsheet, see Figure 32). It is a solid state reduction process which proceeds at a rate much faster than gaseous reduction processes, enabling a potentially higher throughput. The process takes 30 minutes or less compared to the 12 hours or more required for other processes. A cold bonding technique is used for feedstock preparation which is a further advantage. The process was developed by the Pelletech Corporation, Pittsburgh, Penn., USA.

212. The Thagard process employs a high temperature (1,800° C) produced by radiant energy in a reactor with an inert gas blanket to prevent decomposition products from coming into contact with the reactor wall. It is fed with a mixture of ore and solid reductant. Figure 33 gives the basic design of the Thagard high temperature fluid wall (HFTW) reactor. The potential advantages of this process, developed by the Thagard Technology Company, California, USA, include high temperature reduction in milliseconds, high energy conversion efficiency and low energy loss, a flexibility in selection of coals and other solid reductants, no refractory problems and adaptability to nearly complete pollution control. A pilot plant is operating at South Gate, California.

213. In the Plasmared process, reducing gas is produced in a plasma gas generator in which fuel is injected directly into a continuously burning electric arc at 4,000° C. The reducing gas at 1,000° C may thus be used as in any continuously

FIGURE 30

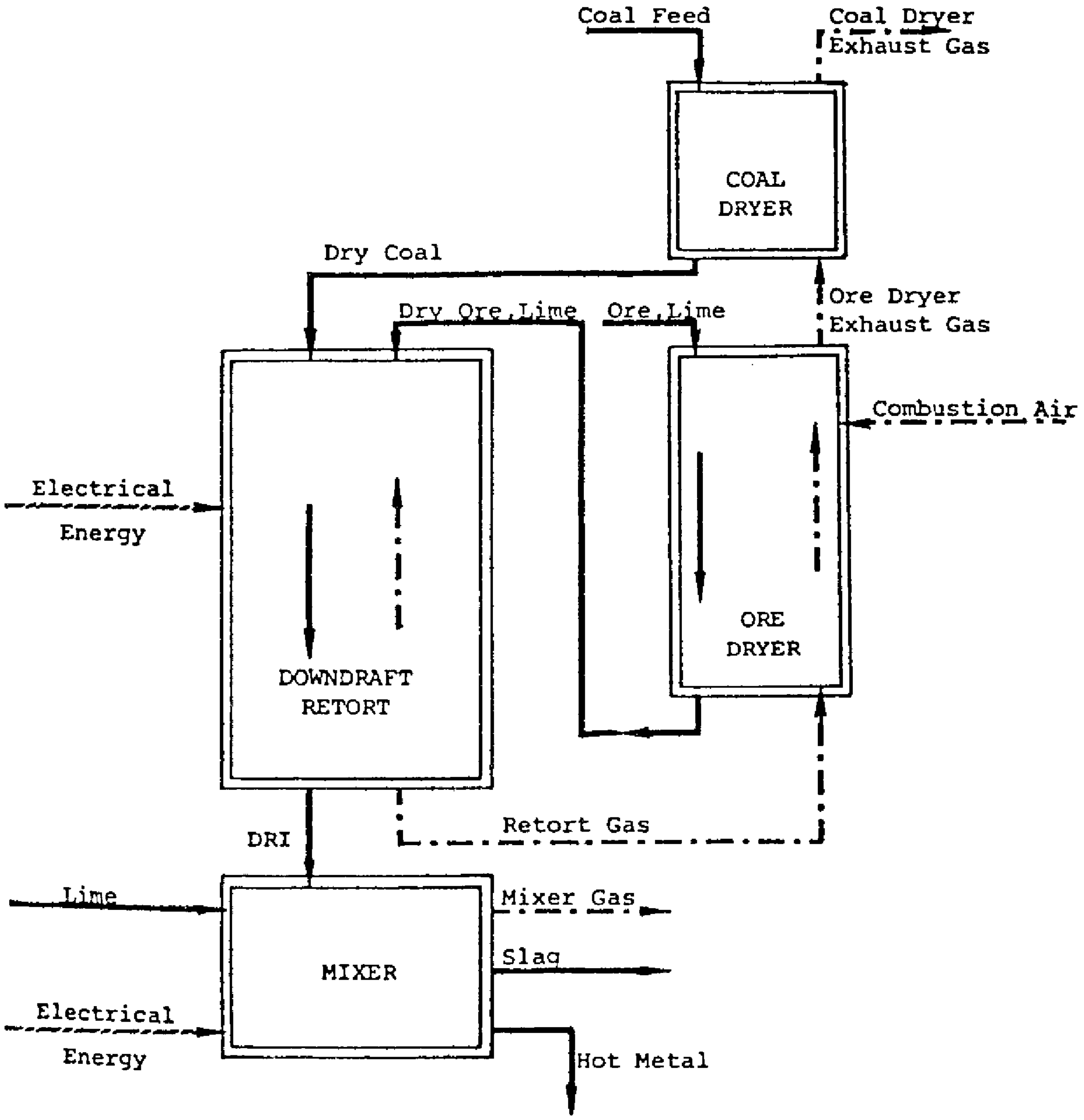
Primary Flowsheet for the Midrex EDR Process



Taken from (10)

FIGURE 31

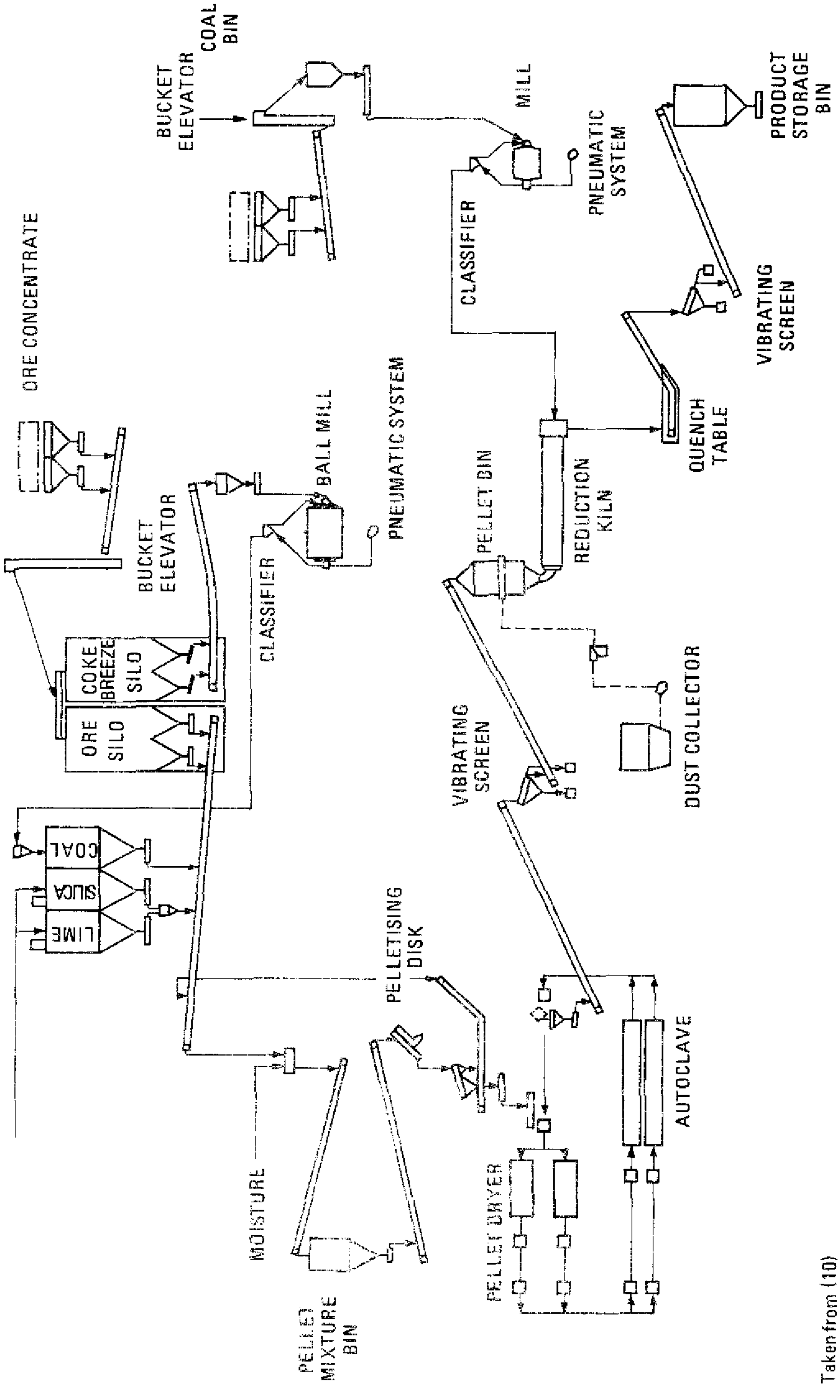
Flowsheet for the Ferrocal Process



Taken from (10)

FIGURE 32

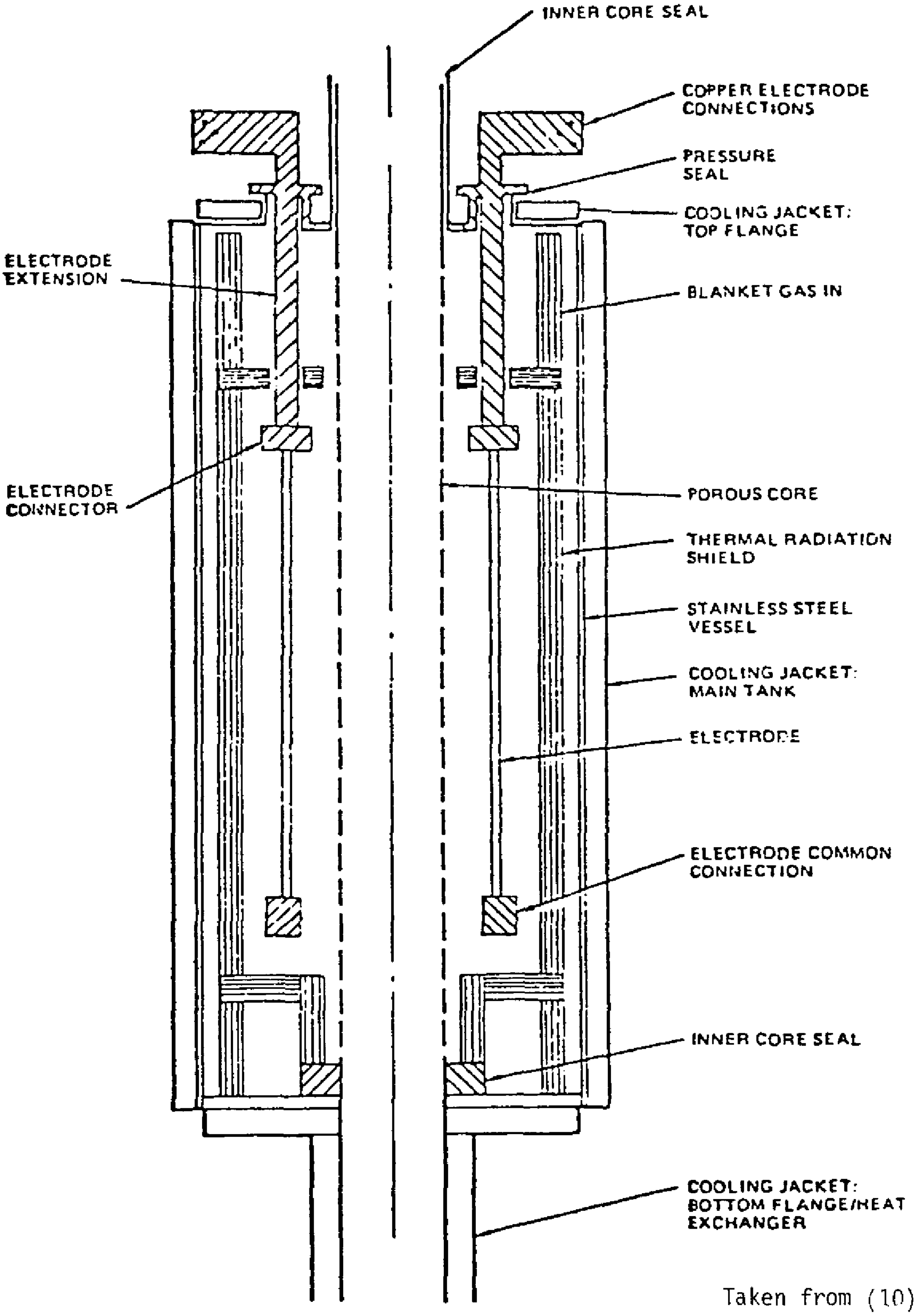
FLOWSHEET FOR THE PELLETECH PROCESS



Taken from (10)

FIGURE 33

Basic Design of the Thagard HTFW Reactor



Taken from (10)

fed vertical shaft process using pellets or lump ore. Figure 34 gives a flowsheet of the process. It has the advantage of being able to use almost any kind of fossil fuel. If coal or sulphur containing fuels are used, the reducing gas must be cleaned and desulphurized before injection to the reduction unit. A favourable specific energy input has been calculated for the Plasmared process compared with the requirements of other technologies : assuring an average 92.5% metallization, the approximate calculated energy input for 1 ton DRI utilizing powdered coal is 0.18 tons of coal and 748 kWh of electricity, or a total of 12 to 13 million BTU assuming a 33.3% coal conversion electricity generating efficiency. A pilot plant has been operated by SKF Steel Engineering AB of Hofors, Sweden, using mainly LPG, but with plans to employ powdered coal.

214. The INMETCO process incorporates a specially designed rotary hearth furnace to produce DRI from self reducing pellets of green strength. Because this furnace avoids the tumbling action common to rotary kilns, its feedstock is prepared without binders, predrying, or hardening. Residence time in the furnace is 15 to 30 minutes, and reported energy requirements are a favourable 9.34 million BTU per ton, including 42 kWh of electricity. The furnace is equipped with an installation to treat fume evolved from the process and to recover noxious substances such as chlorine and sulphur compounds. Outlined by the flowsheet in Figure 35, the process was developed by Inco Research and has been installed commercially at Ellwood City, Pennsylvania to treat waste oxides from specialty steelmaking and so recover the value of the nickel, chromium etc. as well as avoid their dumping. Operated by the International Metals Reclamation Company, a subsidiary of Inco United States, Inc., the Ellwood City plant has successfully produced DRI from a broad range of iron oxides and carbon reductants. The DRI is fed to an electric arc furnace to produce stainless and other specialty steels.

215. The KR process combines a new melter gasifier and a direct reduction shaft substantially similar in design to the commercially proven, gas-based units previously described. As shown by the flowsheet in Figure 36, hot DRI is discharged from the reduction shaft into the lower melter gasifier for conversion to hot metal by excess heat from the partial oxidation of low-quality, non-coking coal. Gasification of the coal in a fluidized bed using oxygen generates hot reducing gas, which, after preliminary scrubbing and temperature adjustment, is directly conveyed to the upper reduction shaft to sustain DRI production. Developed by the Korf Group, the KR process is currently undergoing tests at Kehl, Federal Republic of Germany, where a pilot plant with a maximum pig-iron capacity of 8 tons/hour was started up in 1981. To support pilot construction and further process development, a joint venture has been formed by Korf-Stahl AG and Voest-Alpine AG of Austria.

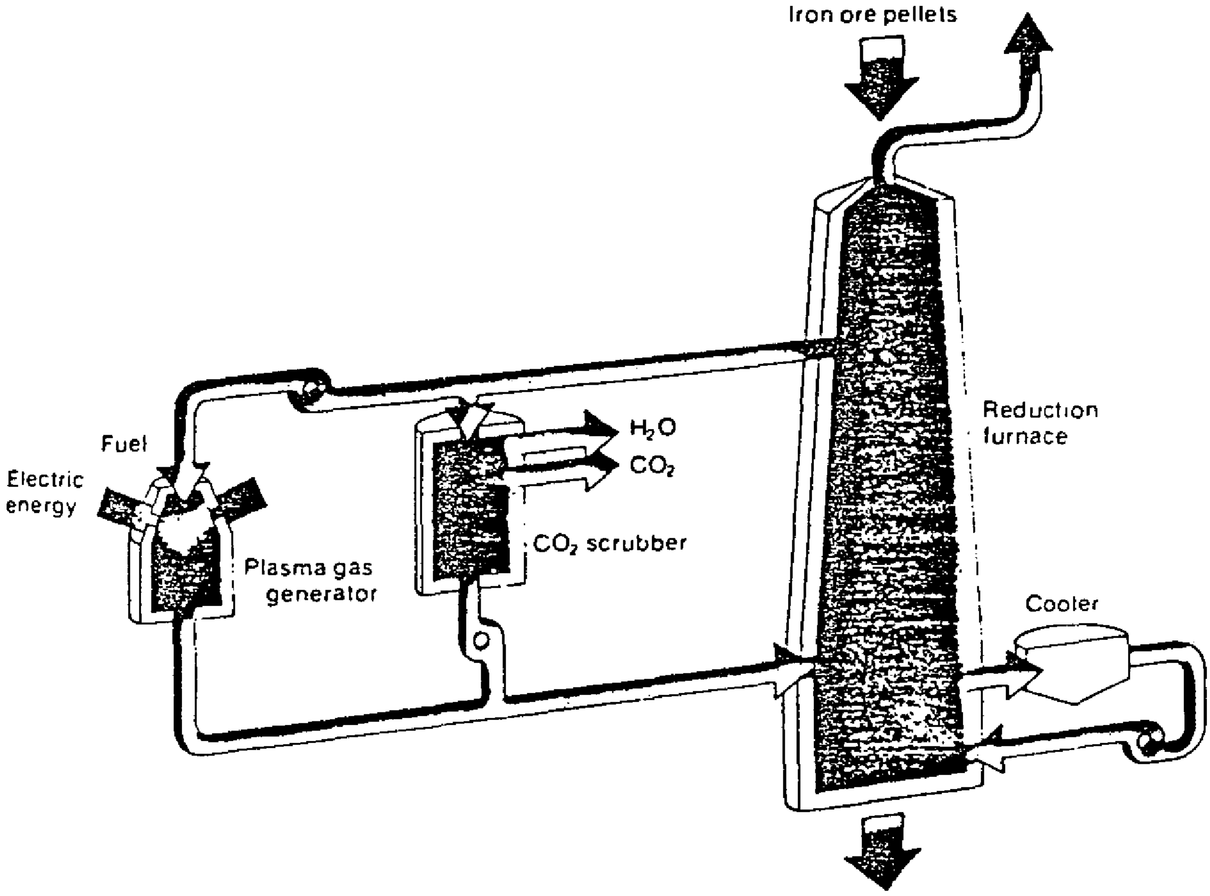
(iii) Steel Making

216. As with the DR process, two basic trends in steel making from DRI can be discerned, namely : improvements in the design and operation of the classical electric arc furnace and other methods for melting sponge iron.

217. A number of technical developments in furnace design and operation are now taking place. The incorporation of sidewall cooling enables an increased 10 to 30% furnace capacity and of oxygen burners up to a 5% increase. Improved refractories increase furnace life and so reduce maintenance costs. New trends

FIGURE 34

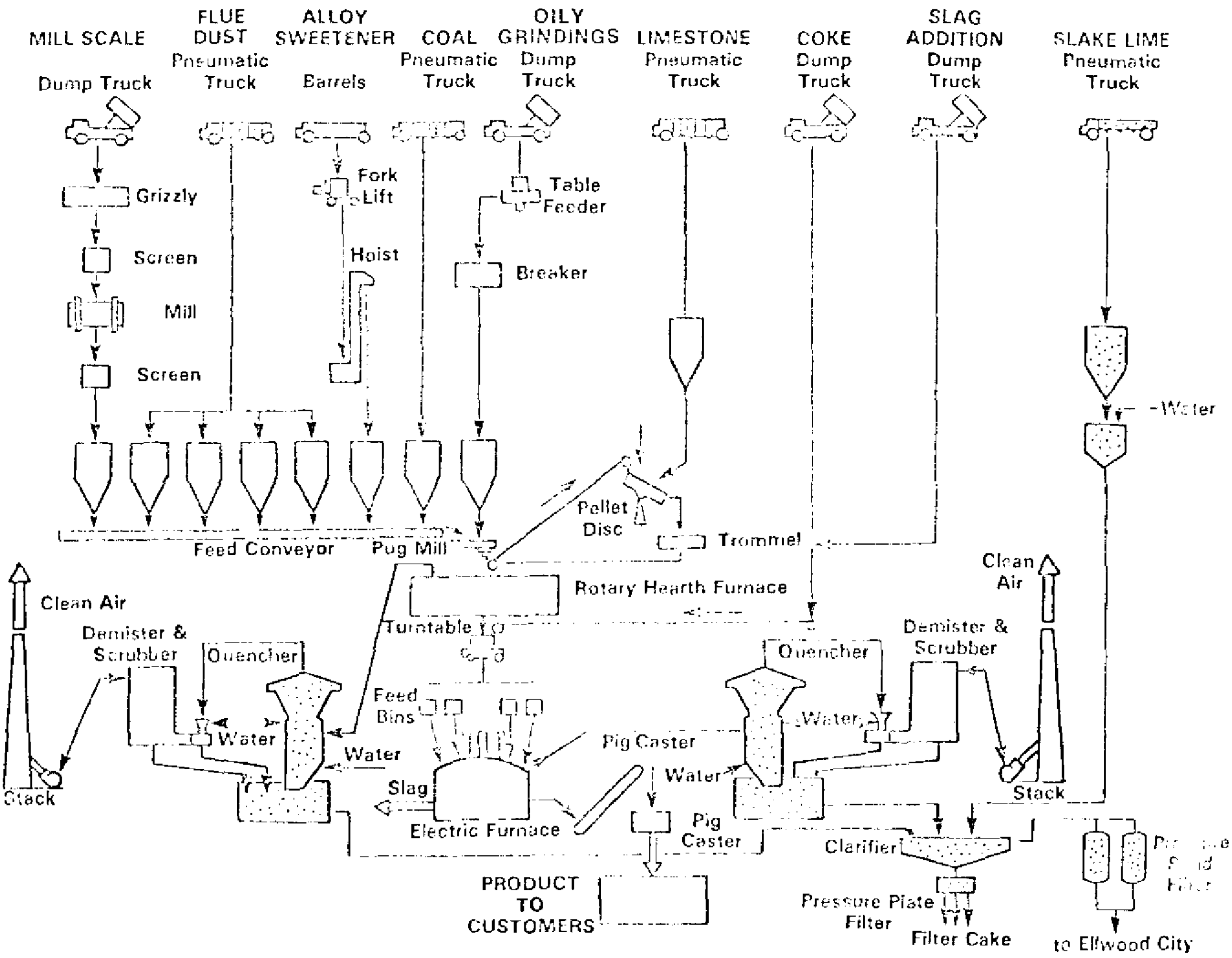
Flowsheet for the Plasmared Process



Taken from (10)

FIGURE 35

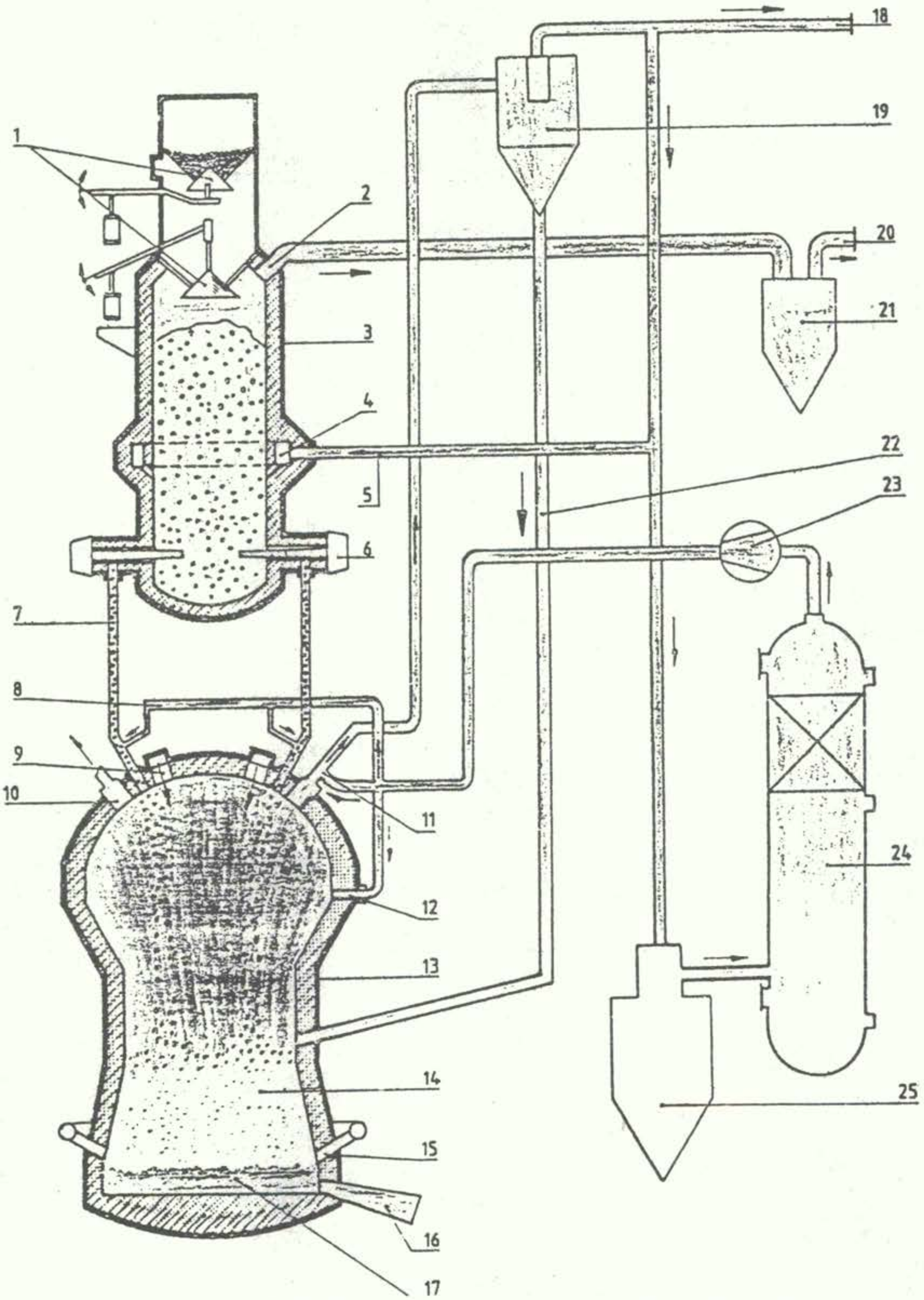
FLOWSHEET FOR THE INMETCO PROCESS



Taken from (10)

KR PROCESS FLOWSHEET

FIGURE 36



1. Ore double bell
2. Top gas outlet
3. Reduction shaft furnace
4. Bustle for reduction gas
5. Reduction gas pipeline
6. Sponge iron discharge screw
7. Sponge iron chutes
8. Cooling gas bustle to sponge iron chutes
9. Coal feeder
10. Gas outlet of melter gasifier
11. Cooling gas inlet to gasifier gas
12. Cooling gas inlet to melter gasifier hood
13. Melter gasifier
14. Coke fluidized bed with melting sponge iron pellets
15. Oxygen tuyeres
16. Hot metal and slag tapping
17. Hot metal bath
18. Hot surplus gas
19. Hot dedusting cyclone
20. Scrubbed top gas
21. Top gas scrubber
22. Cyclone dust recharging
23. Cooling gas fan
24. Cooling gas scrubber
25. Venturi scrubber

Taken from (37)

are occurring in electrode design, manufacture and quality. Furnace design improvements enable lower electrode currents to be used reducing the consumption, and the development of water cooled electrodes reduces surface oxidation. Long arc techniques are permitting improved furnace productivity. Continuous charging, which is commonly employed, reduces electrode mechanical stress and enables better emission collection. The trend toward increased furnace computer control and process automation will improve efficiency. Continuous tapping in a grading furnace or ladle may be foreseen as a possible future development.

218. Research and development on DC electric arc furnaces is being undertaken in a number of countries. The technology already exists for high power AC rectification to DC using solid state diodes and thyristors. A major technical problem is the developing of a practical furnace design since the bath of the DC furnace has to act as one of the electrodes. This type of furnace is claimed to improve operating conditions and reduce electrode consumption and noise.

219. Plasma arc furnaces are also being developed for steel making and small (30-35 ton capacity) units are now available in Sweden, USSR and the German Democratic Republic (27). Plasma arc torches are of two types, the direct and indirect (see Figure 37) and may be operated on DC or 3-phase AC, although the latter is more difficult to design and operate. DC operated furnaces have the problem referred to in the previous paragraph of designing the returning electrode in contact with the steel bath. Besides the claims of improved operating efficiency and the possibility of making very high quality steels, low noise levels would be a further benefit of plasma arc furnaces. Due to the high temperature of the plasma, discharge gases may be ionized and photochemical reactions occur. Consequently precautions must be taken to protect the workforce from ionizing radiation.

220. Other trends which might be adapted to DRI melting in steel making are induction furnaces and oxygen liquid (or gaseous) fuel processes. Each of these techniques, however, are still very much at the laboratory research scale level. Another possibility would be to have an evolution towards a more continuous operation (30), for example by means of :

- a twin furnace as in the SKF process ;
- a real continuous furnace, i.e. combining continuous charging and melting of DRI with continuous refining and tapping, as in the French IRSID experiments.

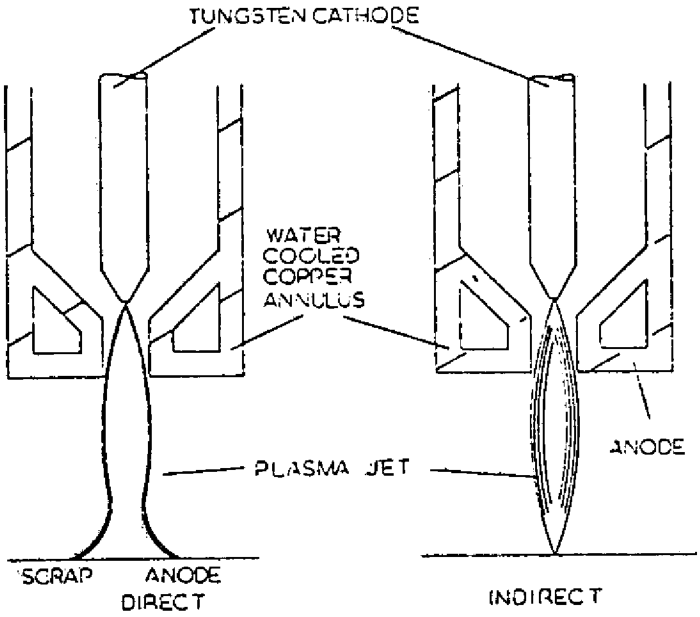
b) Raw Materials, Reductants and Energy

221. Trends with regard to raw materials and reductants are occurring with respect to two different aspects, namely : physical properties and chemical composition. They frequently result from factors such as : technological developments, market and other economic forces and need to improve process operation. There is furthermore growing demand to use energy more efficiently and find more flexible energy sources.

(i) Raw Materials

222. In view of the need in the future to use leaner ores, it is appropriate under this section to consider overall trends in steel making. On the one hand

FIGURE 37



SCHEMATIC REPRESENTATION OF PLASMA FLAME GENERATOR

Taken from (27)

there will be increasing superconcentration of ores for the DR route. On the other hand there will be probably increased efforts to develop direct smelting reduction processes which can use the leaner ores. A number of such processes producing liquid iron, rather than DRI, are under examination, particularly in Sweden, e.g. Elred, Plasmasmelt and Inred processes. These processes, by definition, are outside the scope of this overview.

223. With the growing difficulties in obtaining high quality petroleum coke for manufacture of electrodes and the rapidly increasing price, DR activities are now being directed toward using other materials such as coal. Longer term trends to develop plasma arc melting furnaces may eliminate the need for this type of electrodes altogether.

224. As regards fluxes, the steel making process needs purer quality in general than iron making but it is not a critical consideration when using DRI.

(ii) Reductants

225. Almost all large scale currently operating DR installations are employing reformed natural gas as the reducing agent. In theory it should be feasible to use a reducing gas produced from other fossil fuels such as oil or coke. As has been seen above, a number of processes are being developed for the use of solid reductants, particularly non-coking coals, which are in more abundant supply than natural gas and oil. Similarly poorer quality solid fuels such as lignite and peat are conceivable reductants. Coal gasification might have an important future in the DR route (31). Further trends which could influence the DR route to steel making are developments in use of reductants such as biomass and hydrogen.

226. Agricultural products, particularly forestry products, may be used to produce solid carbon fuels, such as charcoals, liquid fuels such as methanol and ethanol, as well as gaseous methane, each of which could conceivably be used as reductants. Of particular promise is the use of charcoal, which has been tried in Brazil as a reductant. Whilst it could not be considered currently operational for DR, its future use is possible. It is possible to envisage the use of charcoal, in particular, or biomass in general in the DR processes in 3 different ways (32). First, as with coal or other solid hydrocarbon fuels, it could be gasified using existing gasification technologies such as those developed by Lurgi, Winkler and Koppers Totzek and the resultant gas used in the available gaseous direct reduction processes. Second, it could be gasified, using a plasma gas generation as in the Plasmared process described in paragraph 213 above. Third, it could be used as a solid fuel in the available rotary kiln reduction processes as well as those under development.

227. The use of biomass is, however, not without possibly significant environmental implications both in relation to the forestry industry and to the production of the reductant. For example large areas of land are needed to produce wood which may conflict with other land use requirements. There would be need for an extensive transportation infrastructure with its own environmental impacts. Large scale charcoal production could have pollution problems similar to coke manufacture. The Hamburger Stahlwerke has made a feasibility study, the result of which was positive, of gasifying digested sludge from sewage treatment in order to produce reducing gas for their DR unit (33).

228. The potential use of hydrogen as a reductant is of particular interest, since the only reaction by-product would be water (34). Approximately 600 Nm^3 of hydrogen are required to produce 1 t DRI, but currently the cost of hydrogen is too high for its use in steel making. Hydrogen is currently produced from natural gas ; but it would also be technically possible to generate it from other fossil fuels and biomass, by electrolysis or thermal dissociation of water or by biochemical processes, given the supply of energy needed. Use of hydrogen in DR steel making would call for large scale production units and the necessary transportation infrastructure, as well as the appropriate safety measures.

(iii) Energy

229. The trends in energy which could have an impact on the DR route are of four types, namely : more efficient and economical generation of electricity, use of renewable sources of energy, use of high temperature energy generation and use of waste heat. The trends in the recent past have been for increasing costs of electricity in real terms due to rising cost of fossil fuels. Furthermore, the optimistic forecasts for the development of cheap electricity from nuclear energy have not yet materialized. Currently the efficiency of electrical energy generation from fossil fuels averages around 30-35%. Trends in improving efficiency are likely to be slow, but would, along with more economical power generation, have a beneficial impact on the economics of DR steel making.

230. Several possibilities for use of renewable sources of energy exist, particularly in terms of solar energy through agriculture and hydroelectricity. There are extensive potential areas of the tropics such as in Latin America, Africa and South-East Asia for use of biomass. Certain parts of the world still have extensive untapped hydroelectric potential. As pointed out above, agricultural sources of energy, as well as hydroelectricity, are not without potential environmental impacts.

231. In the future, nuclear power could supply a larger proportion of electrical energy generation, at possible costs which would make electrolysis of water or biomass conversion to hydrogen economical. It is also conceivable that in future high temperature nuclear reactors could supply process heat at 900° C or higher and be used to produce reductants directly for the reduction process.

232. Already major efforts are made within the steel industry to reduce energy waste and this trend will continue (35, 36). Possibly one immediate area for potential use of waste heat would be in charging of hot sponge iron (see paragraph 180 above).

c) Environmental Protection Technologies

233. Many of the newly developing processes examined above incorporate pollution abatement features or are in themselves low pollution and non-waste technologies. Furthermore, the trends to use energy more efficiently normally lend themselves to improved environmental protection. Additionally, as has been seen above, a number of new developments are occurring in pollution control techniques which enable improved working conditions as well as environmental protection of the area surrounding the plant to be achieved. Attention is drawn particularly to the potential of noise reduction and air pollution control using

enclosures which are properly designed and integrated into the plant from the conceptual stage.

234. Concerning air pollution, the trend in dust collection is to place hoods nearer the source of emissions in order to reduce the volume of aspirated air. A computerized dust control system could be developed, based on particulate flow rather than gas flow if adequate sensors, not yet available, could be developed. In furtherance of good housekeeping, attention should be drawn to the availability of vacuum systems for collecting dust deposited inside a plant. Improvements in good housekeeping will continue as an important means of improving environmental quality within and outside a plant.

PART VII : SPECIAL CONSIDERATIONS WITH RESPECT TO DIRECT REDUCTION IN DEVELOPING COUNTRIES

235. The electric arc furnace and the development of the mini-steel mill has enabled countries to install for themselves steel making capacities for 60 to 70% of the capital cost required for an integrated steel works. Unlike the classical process which needs an annual production capacity of several million tons to be economically viable and competitive, a mini-steel mill can operate efficiently on a scale as low as 5 t/hour, enabling flexibility. Furthermore, the DR plant has a much larger turn down ratio (i.e. the lowest proportion of the installed capacity at which an installation may continue to function in practice) than a blast furnace, although the specific energy consumption may rise. It has been reported (9) that the turn down ratio can be 40% for DR units and that a direct reduction plant running at 50% capacity would have a supplementary specific energy consumption of 10%. The modular aspect of the DR route also provides another favourable aspect of flexibility.

236. Initially mini-steel mills limited their production to ordinary products not requiring high quality steel ; but developments in electric arc furnace technology now enable highly sophisticated steels to be produced. In the past the mini-steel mill was dependent on the availability of scrap at economic prices. The advent of direct reduction and availability of DRI has provided the mini-steel mill with greater flexibility and independence, as well as with a high quality source of iron enabling attainment of more stringent quality requirements for steels.

237. Currently, technology favours countries with readily available supplies of natural gas and electricity, the potential being particularly favourable at present in a number of developing countries of Latin America, Africa, the Middle East and South-East Asia. With the development of coal based processes and subsequently possibly of the use of biomass, the potential for developing countries to meet their own steel making needs will improve. Furthermore, many developing countries have untapped hydroelectric resources. This new situation will now permit new regional development of the steel industry using different approaches appropriate to the local regional market conditions and supply of raw materials and energy.

238. Industrial operational experience of the direct reduction approach is available in all regions of the world, but environmental criteria are less well known in areas of the world other than the temperate zones. Attention is called to the problems of long range transport of pollutants and their effects, particularly of sulphur oxides and acidity, such as had been observed in Europe and North America, which could also later affect other parts of the world and have environmental consequences, particularly on sensitive ecosystems.

239. The social benefits of industrialization are very important despite the need to avoid the negative aspects. Accelerated economic growth and social betterment are inextricably linked to the pursuit of environmentally sound and sustainable industrial development. Whilst industrial development inevitably brings about changes, it need not be ecologically destructive.

240. Working environmental conditions are also different in developing countries due to both the external physical conditions of climate and the social conditions. As yet there has been little systematic study of these conditions.

241. Environmental training and education of management and the work force in an industry is an essential element in ensuring effective environmental protection. Sound environmental and resource management begins with the senior staff in a plant and it is important for them to be convinced of the overall benefits of environmental protection and the economic soundness of wise resource management. Implementation of appropriate environmental, including health, protection measures calls for the training of the whole work force in proper operation and maintenance of plant and pollution control equipment, in following health and safety procedures, including wearing of protective clothing and equipment, and in ensuring plant cleanliness by good housekeeping practices. In developing countries there is often a shortage of experienced and trained manpower which gives particular emphasis to the exigence of education and training at all levels in a plant.

PART VIII : CONCLUSIONS

242. Production of steel by a new route with direct reduction of iron ore and melting of reduced products in electric arc furnaces is growing, particularly in developing countries. At the UNEP/UNIDO meeting of experts, held 26 - 30 April 1982 in Puerto Ordaz, Venezuela, the environmental and resource aspects of this new route were examined and the findings have been incorporated in this technical review. On the same occasion the meeting of experts visited the SIDOR and FIOR direct reduction units. Whilst the new route can give better environmental conditions than the classical routes based on the use of iron ore or scrap, strict measures must be applied to protect efficiently workers and inhabitants around plants. The UNEP/UNIDO meeting adopted two sets of environmental management guidelines, one for DRI production and the other for DRI melting in electric arc furnaces, which are meant to provide guidance to Governments and industry in the development and implementation of environmental protection policies for this new route to steel making. These Guidelines are being issued separately in the UNEP Industry and Environment Guidelines Series.

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