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COMPARATIVE EVALUATION OF NEWLY DEVELOPED TECHNOLOGIES FOR APPLICATION IN MINI STEEL PLANTS

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	COMPARATIVE EVALUATION OF NEWLY DEVELOPED TECHNOLOGIES FOR APPLICATION IN MINI STEEL PLANTS		

TABLE OF CONTENTS

1. INTRODUCTION

1.1 Basic Ideas Concerning Technologies to be Adopted by Developing Countries

1.2 Summary

1. INTRODUCTION

1.1 Basic Ideas Concerning Technologies to be Adopted by Developing Countries:

Mini steel plants or small scale steel plants, integrated or not, are the best solutions for iron and steel industry in developing countries to both flat and non flat products.

Anyway, the adopted technology must allow the use of local resources and assimilation by the available human resources too.

In general, the conception of the engineering role in developing countries is:

1st step : knowing how to copy the existing technologies, adapting them to the resources and human conditions of the regions (countries) where they will be erected. The intensive use of local resources is fundamental for a developing objective;

2nd step : The development of new technologies for the intensive and, if possible, exclusive use of the national resources.

When there is an effort to adapt existing technologies, a great parcel of the second step is already elaborated.

If people of a country do not know how to adapt an economical and technological model, which may allow them to make a good use of their own resources, they will never be developed, even if they are given international help.

For example, in steel industry and energy, the technological models valid for developed countries may not be advisable for developing ones because they may lead to a total foreign dependency that, in its turn, will prevent the development of a model eventually better suited to local conditions (that means "not to know how to copy") (0).

1.2 Summary

The better known ironmaking processes are discussed and classified in Indirect Processes, Direct Processes and Direct Smelting Processes. The importance of the charcoal blast furnace for developing countries is demonstrated. Development of the Direct Smelting Processes - all of them pig iron producers - is also analised.

Steelmaking Processes are classified as follows: Open Hearth Furnaces, Oxygen Processes and Electric Processes. The Open Hearth is being replaced by other steelmaking processes.

Erection or expansion of steel plants in developing countries should meet the following conditions:

- make intensive use of domestic resources

- be based on updated and proven technologies
- demand relatively low investment
- be tailored for the national or regional market, with an eventual surplus for export.

The actual tendency in steelmaking for the route hot metal production/oxygen steelmaking processes is explained.
A final decision, however, can also be taken once the specific conditions of the case under consideration are well known.
In general terms many technologies may be considered "newly developed", in spite of being well known, because they are being modernized in order to keep competitive with really new ones.
The developing countries should adopt the following technologies, feasible because they are well known, proven, updated and competitive:

- Ironmaking processes: small coke blast furnace, charcoal blast furnace, low shaft electric furnace, rotary kiln processes (as the SL/RN process), gaseous reductant direct reduction (MIDREX and HYL III) and direct smelting processes (COMBISMELT and COREX).
- Steelmaking processes: oxygen steelmaking, specially the EOF process, and electric arc furnaces.

The importance of knowing about scrap availability is stressed, before dimensioning the ironmaking plant and defining the technological route for steel production.
The main data and consumption figures of the better known ironmaking and steelmaking routes are given.
Finally, an indication is made of the steps to be followed in a comparative evaluation of the different iron and steelmaking processes. Such evaluation will lead, on a first approach, to the best technical and economical route for steel production under a set of specific site conditions.
There exist wellknown, proven and low investment technologies to be adopted by developing countries, even on small scales of production.
There is no general solution. Each case has to be individually analysed.
Attention to the development of continuous casting processes is strongly recommended. There are many improvements under way in the billet continuous casting, whereas the new thin strip continuous casting promises to be a solution for the flat product minimill (abt. 500.000 tpy).
A complement for small scale flat production is the HSRC (Hot Strip Reversing Compact) developed by Voest Alpine.

2. IRON MAKING PROCESSES (IRON ORE PRODUCTION PROCESSES)

2.1 Indirect Processes

2.1.1 Coke Blast Furnace

2.1.2 Charcoal Blast Furnace

2.1.3 Low Shaft Electric Furnace

2.1.4 Self Reducing Pellets or Carbon-Bearing Iron Oxide Pellets

2.2 Direct Processes

2.2.1 Rotary Kiln Processes (Solid Reductant)

2.2.1.1 SL / RN

2.2.1.2 KRUPP - CODIR

2.2.1.3 ACCAR

2.2.1.4 D R C

2.2.1.5 TISCO Process

2.2.2 Retort Processes (Solid Reductant)

2.2.2.1 HOGANAS

2.2.2.2 KINGLOR-METOR

2.2.3 Shaft Furnace Processes - Moving Bed (Gaseous Reductant)

2.2.3.1 MIDREX

2.2.3.2 HYL III

2.2.3.3 NSC

2.2.3.4 ARMCO

2.2.3.5 PUROFER

2.2.3.6 Wiberg-Soderfors / PLASMARED

2.2.4 Shaft Furnace Process - Static Bed (Gaseous Reductant)

2. IRON MAKING PROCESSES (IRON ORE REDUCTION PROCESSES)

In the iron ore reduction processes the iron ore, reacts with a reducing agent under suitable conditions of temperature and pressure, producing metallic iron. The reduction processes are classified as follows:
- Indirect Processes
- Direct Processes
- Direct Smelting Processes

2.1 Indirect Processes:

In these processes, the reduction of the ore, the melt of the burden and the carbon absorption by the melt occur all in the same equipment. The product is liquid hot metal, which after solidification is called pig iron. An average analysis for steel grade pig iron is (1):

Fe = 94,71 %
C = 4,20 %
Si = 0,60 %
Mn = 0,30 %
P = 0,14 % (max.)
S = 0,05 % (max.)

In case of foundry grade pig iron the percentage of Si is higher. The iron ore gangue is slagged off, together with charged additives.
The main uses for the pig iron , as a raw material are in the foundry and steel industry. For oxygen steelmaking processes it is the indispensable raw material, having also growing importance for the electric steelmaking processes.

The following are the best known processes for pig iron production:

2.1.1 Coke Blast Furnace:

The blast furnace is expected to remain the world's chief source of iron units for steelmaking, as long as adequate supplies of suitable coking coals remain available at competitive cost (2). Iron-Bearing Materials - The major raw materials are ore, sinter and pellets. As a rule the iron bearing materials are screened in order to remove fines and to improve burden permeability, thus increasing wind and production rates and allowing smooth burden movement.

That portion of the ore which is too fine to be charged directly is usually agglomerated in a sintering plant.

Pellets are agglomerates made from very fine iron ore concentrates (minus 0;074 mm or minus 200 mesh), to which a small quantity of fuel and a binder have been added. (2)

Coke - The main function of coke is to produce the heat required for smelting as well as to provide the chemical reagents carbon and carbon monoxide for reducing the iron ore. In addition, it supplies the carbon dissolved in the hot metal (about 40 to 45 Kilograms per metric ton of iron, equivalent to 80 to 90 pounds per net ton). Since the coke retains its strength at temperatures above the melting temperature of pig iron and slag, it provides the structural support that keeps the unmelted burden materials from falling into the hearth. Because of chemical equilibrium limitations, the carbon monoxide produced in the blast furnace can not be completely consumed in the reduction of the burden. Therefore, the gas leaving the top of the furnace contains sufficient carbon monoxide to have a calorific value of 3 to 4 million joules per normal cubic metre (715 to 955 kcal/Nm^3). This gas is used to preheat the blast and to generate power for driving the blowers; thus, much of the energy is returned to the blast furnace. The excess gas may be used in other sections of the plant.
Fluxes - The major function of the fluxes - limestone and/or dolomite - is to combine with the coke ash and the gangue from the ores to make a fluid slag that can be drained readily from the furnace hearth. The ratio of basic oxides must be controlled carefully to preserve the sulphur-holding power of the slag as well as the fluidity. In instances where the acids in the coke ash and ore gangue are not sufficient to make enough slag volume, silica gravel or quartzite is added with the charge.

To feed the giant blast furnaces the burden preparation is critical. The iron-bearing material must present a high Fe content and the coke ash should not be higher than 10%, whereas sulfur should be as low as possible.

Regarding daily production, there are blast furnaces from 180 tpy to more then 10.000 tpy of hot metal. In the last decades the concept of blast furnace meant giant units with 1, 2, 3 and even more millions of tons of pig iron per year, aiming at a "scale economy" which nowadays is questioned. In many situations, smaller coke blast furnaces are the better technical and economical solution.

If a developing country is able to organize the necessary supply of iron ore and coke, a small scale blast furnace probably will be the solution for iron and steelmaking. Of course, it is necessary to lower the investment, but a good design may achieve this condition.

Right now a brazilian engineering company is developing a technical and economical feasibility study for an indian company to erect a coke blast furnace for 60.000 tpy of foudry pig iron. The study is under way and the first figures lead to very favourable figures.

Table 1 shows a complete list of the brazilian coke blast furnaces. All of them belong to government owned companies (3).

Table 2 shows the brazilian production of pig iron by company (4).

Table 3 shows the brazilian production of pig iron by process (5). More than 60 % of the brazilian production of pig iron comes from coke blast furnaces. As the coking coal reserves of the country are limited in quantity and quality, it is necessary to import large amounts of coking coal. In 1986 the consumption of coking coal was 9.564 x 10^3t, 1.150 x 10^3t of which were domestic and 8.414 x 10^3t imported. In short, this technology led to a strong foreign dependence.

2.1.2 Charcoal Blast Furnace

The production of pig iron in the charcoal blast furnace may be a good solution for several developing countries, where the conditions for reflorestation are favourable. Quite a few countries of Latin America, Africa and Asia present such conditions.
Some advantages of this iron making route are:
Well known technology
Easy operation and high reliability
High quality pig iron
Lower investment
Employment for a large number of people from the rural population.

Fig. 1 shows a section ofthe Charcoal Blast Furnace. The Charcoal blast furnace presents some basic differences towards the coke blast furnace, as follows (6):

Temperature:
Temperature in the reserve zone is about 150°C lower (800°C as against 950°C) in the charcoal than in the coke blast furnace.
Residence Time:
Residence time of the ore in the charcoal furnace is about half that of the coke blast furnace.

Ore in Burden:
Since charcoal has a much lower apparent density (230 Kg/m³) than that of coke (500 Kg/m³), the volume taken by the ore in the charcoal blast furnace (15%) is about half that in the coke blast furnace (30%). This factor, together with the differences between charcoal and coke, account for the following peculiarities:

* The charcoal blast furnace demands a highly reducible ore or agglomerate.
* The charcoal blast furnace is less demanding in regard to the size and crepitation properties of the ore, since the gas flow is more affected by the reductant than by the ore.

Blast Temperature:
The blast temperature in charcoal blast furnace is limited to around 850°C.
Higher temperatures lead to a richer top gas, with no further decrease in the "coal rate".

Slag:
Charcoal blast furnace iron is known to be of higher grade than that of coke blast furnace, because of its lower sulphur content. This is particularly true in Brazil, where low phosphorous iron ore produces an iron which is low in both sulphur and phosphorous. Furthermore, the low ash content (abt. 3%) reduces the charcoal blast furnace slag volume up to 120 Kg/t, with low basicity (usually 0,9), allowing additional energy savings.

Refractory:
The lower blast temperature means a lower flame temperature and lower strain regarding the lining, which may be of cheaper quality (50% Al_2O_3). As a further consequence, cooling is limited to shell cooling with no need of boxes and other cooling devices.

Top Gas Temperature:
Also the top gas temperature is lower in the case of the charcoal blast furnace: 90°C to 120°C, as against 150 to 200°C for the conventional coke blast furnace.

Use of Sinter:
As shown by (4), the replacement of screened ore by sinter does not result in any charcoal savings unless the furnace is operating in the so called "critical productivity range (27 to 33 t/m^3-day). Even in this range, the saving is small.

Size:
The charcoal blast furnace has an upper limit as to its size, mainly due to low mechanical resistance of the charcoal. There are only three such furnaces in the range of 800 to 1200 tpd, which is the top size. Another four or five furnaces have a capacity of 400 to 500 tpd, one of them being the new furnace started up in early 1986 with several improvements. All others, totalling over 100 furnaces, have a capacity between 60 and 200 tpd.

Blast Preheating:
The small size of the charcoal blast furnace and its lower blast temperature

make it possible to eliminate the conventional stoves for blast preheating, substituing them by metallic heat exchangers called "glendons", which cost substancially less. The few already mentioned furnaces bigger than 400 tpd, however are outfitted with stoves, with the exception of the most modern one, already mentioned, which operates with glendons giving 800°C in the blast.

Fans:
Because of the lower density of the charcoal the permeability of the burden is better and consequently the pressure drop through the furnace is low (3 to 5 m of water column). Simple fans in series may therefore be used to provide the blast air, in lieu of heavy blowers.

Investment:
The small size and simplicity of the charcoal blast furnace, with its simple air blowing and heating devices, unexpensive instrumentation and gas washing, almost manual pig caster, simple raw material handling and storing and low-cost refractory lining demands very low investment.
This is in the range of about US$ 50.00 to 60.00 per ton to yearly capacity, as against US$ 120.00 to 150.00 in the case of the conventional coke blast furnaces.
See Annex 1 "The Charcoal Blast Furnace in Brazil" - ABM October 1987.
As Annex 2 the article "Operating Experience With Charcoal Blast Furnace nad EOF Steelmaking in Brazil".
H. C. Pfeifer and O. E. Simões - International Conference on Alternative Routes for Iron and Steel under Indian Conditions. 8-10th February 1988-JAMSHEDPUR India.

Usually the charcoal blast furnace is fed with natural pellet ore. The use of sinter or pellets, when available, improve the operation. The immediate analysis of charcoal is the following:

Fixed C	70	-	75	%
Volatile Matter	20	-	25	%
Ash	3	-	5	%
P (as P_2O_5)	0,06	-	0,08	%

and the consumption per ton of pig iron is:

	m^3	kg/t (dry basis)
Net quantity charged to furnace	2,90	640,0
Fines recovered (below 9,5 mm)	0,35	123,0
Losses	0,25	35,0
Gross quantity	3,50	798,0

Brazil is the major producer of charcoal pig iron and the individual capacity of blast furnaces in operation varies from 20.000 tpy to 350.000 tpy pig iron.

During 1986 the production of charcoal pig iron was the following:

Total Production	7.550.533 t
Integrated steel plants	3.129.050 t
For export	2.369.822 t
For domestic sales	2.051.661 t

With the exception of ACESITA which is government owned, all other brazilian charcoal pig producers are private companies.

Vanishing natural forests and growing cost of reforestation are leading to efforts to improve the efficiency of charcoal ironmaking, by measures aiming at improvements in reforestation, charcoal making and blast furnace construction and operation, all of them directed to decrease specific charcoal consumption.

In 1978 UNIDO sponsored and issued a extensive paper about charcoal ironmaking (7). The issue of a new, updated edition of this document would be highly recommendable.

In a recent paper (8) an analysis is made of the effect of all possible improvements in reforestation, charcoalmaking and blast furnace construction on the specific charcoal consumption. The paper shows that these improvements, all based on already existing technology, may increase 3,8 times the yearly production of pig iron with the charcoal produced on one hectar of land. In other words, a conventional charcoal blast furnace (60.000 to 150.000 tpy) today produces 3,5 tpy of pig with the charcoal from 1 hectare of reforested area on a continuous basis. Once all improvements are accomplished, such production may reach as much as 13,4 tpy.
Tables 2 and 3 give the brazilian production of pig iron for each company and by process. Table 4 gives the steps to decrease the charcoal consumption (8).

2.1.3 Low Shaft Electric Furnace Process.

A low shaft electric furnace (LSEF) is used in this process to reduce iron ore and produce liquid pig iron. Figure 2 shows a schematic representation of the low shaft electric furnace. The furnace consists of a melting chamber with three or more consumable electrodes. Openings are provided in the roof for charging the burden of agglomerated or lump ore, coke or charcoal or coal, and limestone (2).

The LSEF is a good solution for developing countries with availability of cheap electric energy, since it is a well known technology with high reliability.

According to a paper presented to the World Bank, in November 1977, by MANNESMANN/DEMAG/MIDREX/IKOSA (9), the consumption of charcoal is 1,8 m^3 per ton of pig iron (abt. 423 kg). Off gas is about 1,5 Gcal per ton of pig iron with 2.500 kcal/Nm^3, and may be used as reducing gas in direct reduction processes or as fuel.

The process allows the use of high ash coke. The use of a domestic coke with the following analysis has already been proposed to a brazilian company:

C fix (dry basis)	avrg. 65 %
Ash	25 - 30 %
Volatiles matter	5 %
S	2,2 % (max.)
Moisture	6,0 %

The anticipated consumption was 0,46 t coke/t.

There are a few LSEF producing pig iron in Brazil (see Table 3). One steel industry has 2 LSEF, each one equipped with a 20 MW transformer. Each furnace produces 240 t/day in 8 taps. Availability is above 90% and electric energy consumption is 2.000 kWh/t pig iron. See Tables 2 and 3 giving the brazilian production of pig iron by company and process.

2.1.4 Self Reducing Pellets or Carbon-Bearing Iron Oxide Pellets

In this technology iron oxide fines, lime, silica and carbon fines are mixed, pelletized and hardened.

The process owners of this technology claim that the uniformly disseminated carbon particles create numerous reduction centers throughout the pellet matrix where reduction occurs simultaneously, accelerating reduction and permitting higher temperatures without an adverse effect. The result is a much faster reaction rate. In addition, at the higher temperature, carbon monoxide is generated throughout the pellet matrix which causes an increase in the partial pressure of CO which favours reduction thermodynamics as well as causing the carbon monoxide to diffuse much more deeply in the pellet cavities.

Test results have shown that the reduction rate with carbon-bearing pellets is much faster than that obtained by the diffusion of external carbon monoxide into conventional iron oxide pellets under similar conditions. Carbon-bearing pellets can be reduced completely and melted in a short-shaft furnace such as a cupola in less than one hour (10).

There are, at least, two companies developing this technology:

A - Pellet Technology Corp., from Pittsburg/USA, with the PELLETECH (PCT) Process, where the carbon-bearing pellets are hardened in an autoclave. According to PTC a 5 t/h cupola was built in Calcuta/India, solely to reduce pellets prepared by the MTU - Pelletch process. Test programs demonstrated that a variety of specified compositions can be produced from carbon-bearing iron oxide pellets. Including DRI (sponge iron) was produced with carbon bearing pellets.

B - Fundição Tupy S.A., from Joinville/SC Brazil, with the Self Reducing Pellet Process (SRP), where the pellets are cold hardened. Fundição Tupy is a very important brazilian foundry and receives the pig iron by truck from other brazilian states, the average distance being about 1.000 km. In Imbituba seaport, 250 km from Joinville, pyrite cinders (fines) and mineral coal are available. The Tupy research center started developing cold hardened self reducing pellets (or carbon-bearing pellets). These SRP were tested in a pilot cupola existing in the research center. Proportional of SRP was increased in the metallic charge from 10% to 100% with good results. The second step was the erection of a industrial demonstration plant for about 900 t/month of hot metal in the Fundição Tupy industrial area. The plant operated during several months (86/87) and presently some changes are being made in the furnace. As a matter of fact the plant is a modified hot blast furnace. Once the changes are the tests will start again and it is expected to work out until the end of 1988 all parameters necessary to complete the design of an industrial plant for 60.000 tpy hot metal, to be erected in Imbituba during 1989 (11).

These technologies (PTC and SRP) may be a solution for cases where iron ore fines and reductant are avaliable.

2.2 Direct Processes:

The reduction reactions between ore and reductant occur with iron ore in solid state.

The product is called sponge iron or DRI (direct-reduced iron). Usually the DRI has more than 90% of total iron and 85% as metallic iron, resulting in a metallization degree higher than 90%.

The gangue remains in the DRI and is slagged off in the melt shop (steel or foundry plant).

Carbon content may change from 0,05% in solid reductant processes to 2,5% in gaseous reductant processes, but it is important to know if the carbon is combined (cementite) or free.

The major part of DRI production is used as a substitute for scrap in electric arc steelmaking furnaces (EAF). DRI derived from virgin iron units is a relatively pure material which dilutes contaminants in the scrap and improves the steel quality. The availability of low cost scrap and the high cost of energy restrict the use of DRI in most highly industrialized countries. Direct processes are especially favored in those locations that are endowed with abundant reserves of inexpensive natural gas, non-coking coals, and/or hydroelectric power, and which have access to suitable iron ores or agglomerates (2).

It is possible to use DRI in foundries and other steel making processes, in variable proportions.

The brazilian production of DRI is relatively low, since the country has only two direct reduction plants in operation:

- One rotary kiln - SL/RN Process - at Aços Finos Piratini
- One static bed shaft furnace - HYL I Process - at USIBA

A PUROFER Plant operated from 1976 to 1979 and was shutdown. The Table 5 shows the brazilian production of sponge iron (DRI) from 1977 to 1986. Table 6 gives the world Production of DRI in 1986, of which 53,5% was produced by the MIDREX Process.

Direct Reduction processes may be classified as follows:

- Rotary Kiln Processes (solid reductant)
- Retort Processes (solid reductant)
- Shaft Furnace Processes - moving bed (gaseous reductant)
- Shaft Furnace Processes - static bed (gaseous reductant)
- Fluidized Bed Processes (gaseous reductant)

In the processes using solid reductant coal is charged directly in to the process kilns, sometimes as, screened run of mine coal and sometimes after washing.

In the processes using gaseous reducing the reductant gas is produced outside of the reduction furnace. Natural gas is reformed in a catalyst bed with steam or with top gas from the reduction reactor (CO_2).

Partial oxidation processes which gasify liquid hydrocarbons, heavy oil and coal are also discussed. The reformer and partial oxidation gasifier are interchangeable for several of the DR processes. See Annex 6 giving a brief summary of the reducing gas generation schemes.
Table 7 gives a list of Direct Reduction Plants Producing Steelmaking grade DRI.

2.2.1 Rotary Kiln Processes (Solid Reductant)

In these processes the reducing gas is generated from hydrocarbons in the reduction furnace and all the rotary kilns operate as described in the Annex 7. In some countries the DRI produced in Rotary kilns is a good solution (technical and economical).
The rotary kiln processes in operation are the following:

2.2.1.1 SL/RN Process:

This is the better known rotary kiln process, which has developed greatest experience. There are SL/RN plants operating in several countries (see Table 7), using different raw materials and scaling from 30.000 t to 180.000 t DRI per annum (12).
The process has great flexibility in relation to raw material, as shown by the paper "Flexibility of SL/RN coal based Direct Reduction in respect of raw materials and fuels" (12), presented in 1983.
Table 8 shows the analysis of coals used in Lurgi Direct Reduction Kilns
Table 9 shows the analysis of iron ores used in Lurgi Direct Reduction Kilns
In Aços Finos Piratini - Brazil (1 kiln of 60.000 tpy) the DRI is produced from high quality pellets and lump ore, whereas the coal has a high ash content (13).
In SIDERPERU - Peru there are 3 kilns with 100.000 tpy DRI nominal capacity, operating based on pellets and anthracite and coke breeze.
In New Zeland Steel - New Zeland iron sand concentrate and a high volatile and high reactivity coal are being used.
The 4 New Zeland Steel SL/RN kilns are designed to produce up to 900.000 tpy of sponge iron. NZS is using the kiln off gas to produce steam to operate a 30-35 MW power plant (14).
In Iscor - South Africa lump ore and non coking coal are used in four SL/RN kilns, designed to produce up to 720.000 tpy of DRI. Iscor is using the kiln off gases to produce about 4.500 t/day of low pressure steam for the integrated steam network of the plant.

Highveld Vanadium and Steel Company - South Africa operates 13 Lurgi rotary kilns producing low metallization sponge iron. This material is hot charged into Low Shaft Electric Furnaces to produce pig iron (15).

2.2.1.2 Krupp Codir Process.

There is one plant in operation in South Africa and one under construction in India (Table 7).

2.2.1.3 ACCAR Process.

There are plants in Canada and India (Table 7).

2.2.1.4 DRC Process.

There are plants in the United States and South Africa (Table 7)

2.2.1.5 TISCO Process.

There is one industrial plant in India (Table 7).

2.2.2 Retort Processes (Solid Reductant).

There are two processes in operation.

2.2.2.1 Hoganas Process.

Developed in Sweden in 1910 and still in commercial use. Most of the sponge iron produced is sold as iron powder (2).

2.2.2.2 Kinglor-Metor Process.

The K-M is a process for small DRI scale production (20.000 tpy per reator) and is described in the Annex 8.

2.2.3 Shaft Furnace Processes - Moving Bed (gaseous Reductant).

A typical example of the Shaft Furnace Process - Moving Bed is the MIDREX Process. So, the MIDREX Process description as describe in the Annex 9 serves too in general terms, for the other processes.
The DRI produced in Shaft Furnaces Processes - Moving Bed can be delivered to the customer as pellets/lumps, or as cold Briquettes or as HBI (Hot Briquetted Iron).
The Shaft Furnace Processes - Moving Bed (Gaseous Reductant) are (2).

2.2.3.1 MIDREX Process

The MIDREX Process is the best known direct reduction process worldwide and production of MIDREX plants is bigger than that of all other processes together (see Table 7). A typical analysis of Shaft Furnace - Moving Bed DRI is

Fe_{total}	91 - 93	%
Fe_{met}	83 - 88	%
Metallization	92 - 95	%
C	1 - 2,5	%
Gangue	3,1 - 7,9	%
P	0,02 - 0,04	%
S	0,005 - 0,015	%

2.2.3.2 HYL III - The HYL III has plants in operation and under construccion in Mexico (see Table 7).

2.2.3.3 NSC - Nippon Steel corporation (see Table 7).

2.2.3.4 ARMCO (see Table 7).

2.2.3.5 PUROFER (see Table 7).

2.2.3.6 Wiberg - Soderfors/Plasmared

In the original Wiberg process in Soderfors (Sweden) the reducing gas for the shaf furnace was produced at about 1039°C, by recycling about 65% of the shaft furnace top gas in an electrically heated coke or charcoal carburator (2). It was a plant for 25.000 tpy DRI, consuming 960 kWh and 210 kg of coke per to of DRI. The SKF developed a plasma process called PLASMARED. The PLASMARED was recently adapted to the Wiberg - Soderfors process as a means of heating up the cleaned top gas before recycling. Capacity of the Wiberg - Soderfors /PLASMARED plant is about 70.000 tpy DRI and consumptions are 850 kWh and 180 kg of coal per ton of DRI (11).

2.2.4 Shaft Furnace Process - Static Bed (gaseous reductant).

2.2.4.1 HYL I

The HYL I was a pioneer in the industrial production of sponge iron. There are some plants in operation in Mexico, Brasil, Venezuela, Indonesia and Iraq, but nowadays it is an obsolete process, the reason why HYL developed the HYL III process (see Table 7).

2.2.5 Fluidized Bed Processes (gaseous reductant).

In these processes iron ore fines are reduced by hidrogen in a fluidized bed and the reduced material is always hot briqueted.

2.2.5.1 HIB

A plant was erected in Puerto Ordaz - Venezuela to produce more than 700.000 tpy of high iron briquettes with 70% metallization, intended to be charged in american blast furnaces.
The operation was never satisfactory and according to a recent announcement the plant will be modified to produce 750.000 tpy MIDREX DRI (16).

2.2.5.2 FIOR

There is an industrial Fior DR Plant in operation near Puerto Ordaz in Venezuela (see Table 7).

2.3 Direct Smelting Processes or Indirect Processes in two stages.

These processes are variants of the blast furnace because the product obtained is pig iron.
Reaction take place in two reactors: the Reduction Reactor where the iron ore is dried, heated up and reduced by gases generated in the Smelter Reactor; The Smelter Reactor or Smelter Gasifier Reactor, where the final reduction, occurs and the DRI smelts and absorbs carbon.
The Direct Smelting Processes are the way to get the advantages of the Indirect Processes with higher flexibility in relation to raw materials and energy.
The technical and economical incentives to develop these processes, compared to the coke blast furnace are:

- use of a wide range of iron ores
- possibility of using a wide range of coals, thus becoming independent of coke.
- being economic even in relatively small scale
- less environmental problems (17)

The Direct Smelting Processes pay special attention to the use of the waste energies from the reactors, which as can be used

- for the production of steam for many purposes, including electric power generation.
- as fuel gas in pelletizing, foundries, steel plants, ceramics etc.
- as clean gas (sinthesis gas) in the chemical industry
- as clean gas (reducing gas) in Direct Reduction

The following processes are the Direct Smelting processes:

- COMBISMELT
- COREX
- SC
- COIN
- KAWASAKI
- ELRED
- INRED
- PLAMASMELT

See Annex 3 "Smelting Reduction Processes for Iron and Steel making"
O Nyquist - IISI - Rio de Janeiro, October 1986.

2.3.1 COMBISMELT (18) (19).

Fig. 3 shows the Schmematic representation of Combismelt.
The Combismelt Technology uses a combination of SL/RN rotary kiln as Reduction Reactor producing sponge iron and SAF - Submerged Arc Furnace for hot metal production.
The waste energies of the furnace are used for steam production.
In New Zeland Steel four SL/RN rotary kilns feed two electric melting furnaces to produce 700.000 tpy pig iron (14).
The waste energie is used to produce steam which generates 30 - 35 MW (11).
In Highveld Vanadium and Seel Coorporatim - South Africa there are 13 Lurgi rotary kilns, producing relatively low metallization sponge iron, to feeding 7 low shaft electric furnaces to produce more than 1 million of steel per year.

2.3.2 COREX (20) (21)

Fig. 4 shows the schematic representation of COREX with export gas (20).
Fig. 5 shows the schematic representation of COREX without export gas (20).
The Reduction Reactor receives iron ore and aditives from the bins and reducing gas from the smelter gasifier producing DRI which is discharged hot to the smelter/gasifeir.
The Smelter Gasifier Reactor receives oxygen and coal, which is instantaneously dried and degaseified, where the resulting char is gasified in the fluidized bed. The hot DRI is charge continuously being finally reduced, smelter and carbon enriched.
The great flexibility of the Corex process is ilustrated by the following tables:
Table 10 - Iron ores used in the COREX pilot plant until 1987 (21).

Table 11 - Coals used in the COREX pilot Plant until 1987 (21).

Table 12 - Classification of Coals for COREX - The KR Process (20).

All the iron ores and coals (Table 10 and 11) were successfully tested in the Kehl / West Germany - Demonstration Plant, which capacity of 60.000 - 80.000 tpy hot metal.

In May 1986 the following Brazilian raw materials where tested during a 10 day period:

Metallurgical coal	with 17,0 % ash
Noncoking coal	with 21,0 % ash
Pellets	65,21 % Fe
Lump ore	67,50 % Fe

The test was successful and about 1.100 ton of pig iron were produced.

Table 13 presents the diagram and consumption figures expected for a COREX industrial plant operating with Brazilian raw materials, as well as the pig iron analysis the off gas composition and volume. This project is being discussed.

Right now (Jan 88) the first COREX industrial plant is being commissioned. Located near Pretoria - South Africa at ISCOR Pretoria Works this plant has a production capacity of 300.000 tpy hot metal.

See annex 4 "COREX - The Coal Based Smelting Reduction Process" - G. Papst and J. Flickenschild - may 1987.

2.3.3 SC (SUMITOMO)

See Fig. 6 for schematic representation.

2.3.4 COIN

See Fig. 7 for schematic representation.

2.3.5 KAWASAKI

See Fig. 7 for schematic representation.

KAWASAKI Process intends to use fine ores instead of pellets or lump ore.

2.3.6 INRED

See Fig. 9 for schematic representation.

2.3.7 ELRED (2) (17)

See Fig. 9 schematic representation.
The ELRED process uses iron ore fines and pulverized coal. The prereduction reactor operates a fluid bed under pressure (5 - 7 bar). The prereduced material with about 65% metallization is continously discharged from the bottom of the prereduction reactor to are Smelter Reactor which is a DC arc furnace for final reduction and melting.
A hollow electrode is located in the center of the furnace roof and is connected to the negative pole of the rectifier. The positive pole is connected to a bottom electrode, which is in direct contact with the iron melt. The arc, which is submerged in foaming slag, extends vertically down toward the bath(2).

2.3.8 PLASMASMELT (2)

See fig. 11 schematic representation.
The PLASMASMELT Process uses iron ore fines and coke. The pre-reduction reactor operates a fluid bed and reduces the iron ore to about 50% metallization. The pre- reduced iron is injected together with flux and coal into the hearth of the molten iron using plasma-arc torches having an electrical consumption of about 1.200 kWh/t hot metal.
The smelter reactores similar to a shaft furnace and is filled with coke, being the coke consumption of about 50 Kg/t hot metal.

3. STEELMAKING PROCESSES

3.1 Open Hearth Steelmaking Process

3.2 Oxygen Steelmaking Processes

3.2.1 The LD Process

3.2.2 The Oxygen Bottom Blown Process

3.2.3 The E O F Process

3.3 Electric Steelmaking Processes

3.3.1 Electric Arc Furnace Processes

3.3.2 Induction Furnace Processes

3.3.3 Plasma Furnace Processes

3. STEELMAKING PROCESSES

The world steel production is based on 3 main routes:
- Open Hearth Steelmaking
- Oxygen Steelmaking
- Electric Steelmaking

Until after World War II the Open Hearth was the main steelmaking process, having now been replaced by the Oxygen Steelmaking Processes.
In 1985 oxygen steelmaking processes produced worldwide about 58% of the total steel production, the electric processes about 25% and the open hearth about 17%. The tendency for the near future, however is a further decrease in open hearth production.
In Brazil, in 1986, steel production reached 21.3 million ton, 72,7 % of which came from oxygen processes, 24,9% from electric processes and only 2,4% in Open Hearth process (5).
The tendency is that new plants will be based on oxygen steelmaking.

3.1 Open Hearth Steelmaking Process

The O.H.S.P. used to be the main steelmaking process but is now being replaced more and more by the other processes.
However, if a developing country which is still operating OH furnaces locks the financial resources to shut down the OH plant and to erect a new one, the solution is to adapt the KORTEC - Submerged Blowing Process, in operation in Brazil (CSP) and Hungary (OKU), as a first step of modernization and cost reduction. With very low investment the productivity will be increased with considerable energy savings. The conversion of traditional Open Hearth furnaces to the KORTEC - Submerged Blowing Process is very easy and the necessary submerged tuyeres can be installed during a normal furnace repair.
See Table 14 for process description.
Table 15 gives the advantages and operational data of operating OH furnaces with submerged oxygen blowing.

3.2 Oxygen Steelmaking Processes

These processes can be classified as follows:
- The LD Process.
- The Oxygen Bottom Blown Processes.
- The new concept called EOF - Energy Optimizing Furnace.

3.2.1 The LD Process

Plants utilizing top blowing oxygen have been in operation since 1952-53 at Linz and Donawitz in Austria.

Today the LD Process is the world leading Process in Steelmaking (2).
Fig. 12 and 12A give information about the oxygen blowing process variations (22), which means processes based on LD converter and LD converter variations.

3.2.2 The Oxygen Bottom Blown Process.

Fig. 13 shows the development of the Oxygen Bottom Blown Process from 1968 to the present.
Fig. 14 and 15 give information about the KMS process, installed in Eisenwerk - Gesellschaft Maximilians-hutte M B H (3 x 60 t) and Georgmarienhutte (1 x 125 t), in West Germany.
By bottom injection of oxygen, lime and carbon it is possible to vary the ratios of cold metallic charge/hot metal between 25% / 75% an 75% / 25%. The goal is the steel production without using hot metal. The post combustion technique is used to combust a sizeable portion of the CO above the bath to CO_2 and to transfer as much as possible of the generated heat back into the bath (23).
Even after the post combustion the off gas has some energy content to be used for steam generation and other uses.

3.2.3 The EOF Process (Energy Optimizing Furnace)

The EOF Process is a new oxygen steelmaking process, low in investment and operational cost.
In short, the process and its main advantages can be described as follows:
The EOF is a hearth furnace for the production of liquid steel with coal and oxygen from varying ratios of hot metal and scrap, combining the principles of oxygen blowing and scrap preheating.
The main process principle underlying the EOF is to introduce oxygen into the bath to react with carbon, creating CO gas which is subsequently burned to CO_2 above the bath within the furnace vessel. The heat generated by the oxygen reactions is efficiently used to melt scrap that has been prviously preheated. The carbon required for the reaction is introduced into the bath either as a constituent of molten pig-iron or in the form of solid carbon which is injected into the bath and reacted with liquid steel to create an artificial pig-iron.
Sensible heat in the waste gases is utilized for stepwise preheating of the scrap in refractory-lined scrap preheater consisting of several preheating sections located above the furnace roof.
Main advantages are:
* Submerged horizontal oxygen blowing through special tuyeres;

* Use of a circular shaped, compact furnace in which heat losses are reduced;
* 95% afterburning of CO to CO_2 in the furnace, transferring energy to the steel bath by radiation;
* Scrap preheating with the EOF's hot off-gases up to 850°C and quick charging of scrap;
* Extreme flexibility with regard to the metallic charge mix;
* Proven high plant availability; commercially proven technology
* Minimum amount of auxiliary equipment, no high power electricity distribution system;
* Utilization of water-cooled elements for walls and roof.

See Fig. 16 schematic representation of the EOF.
See Fig. 16 for information about the EOF.
See Fig. 17 for the history and development of the EOF.
See Fig. 18 for Operating Facts and Figures.
See Fig. 19 for Steel Quality Products and EOF Benefits.
At present there is one 30 t EOF operating since 1982 at Companhia Siderurgica Pains(CSP), in Brazil, with a yearly production of 200.000 t of liquid steel.
A new 30 t EOF is under erection at CSP, to be commissioned in March 1988.
A 60 t EOF is under construction at Siderurgica Alipertl S.a. (Sao Paulo - Brazil), to be commissioned in May 1988 and designed to produce 400.000 tpy of liquid steel.
In 1989 the EOF Steel production will be of 800.000 t, equivalent to 3.5% of the Brazilian Steel Production.
Annex 4: "The EOF process: Performance and out look". R. Weber and H. C. Pfeifer - International Conference of Iron and Steel Tecnology - Brazilian Society for Metals - São Paulo, Brazil, November 1986.

3.3 Electric Steelmaking Processes

In these processes the energy to melt down the metallic charge and to heat up the bath to the teeming temperature is supplied by electric power. These processes are classified in accordance with the way of transfering the eletric power to the metallic charge.
Due to increasing cost of electric energy steelmaking will possibly decrease its share as melting process, but the tendency today is that all steel plants, independent of process chosen, are installing Ladle Furnaces, that means an electrical furnace for refining the steel and to adjust its correct teeming temperature.

3.3.1 Electric Arc Furnaces Processes

More than 20% of world steel production is produced in the Electric Arc Furnace, an efficient and flexible equipment for steel production since any kind of cold metalic charge, as different types of scrap, sponge iron and pig iron may be used as feeding material.
Current passes from one electrode down through an arc and the metal charge, then from the charge up through an arc to another electrode. Although single, two or three-phase can be used for steelmaking, furnaces employing three-phase current are used almost exclusively(2).
Today, there are some so-called Direct-Current Direct-Arc Furnaces in operation, where the current passes from one electrode through an arc and the metal charge to an electrode in the bottom of the furnace(2).
In EAF operation some factors as % of DRI charging, metallization of DRI and tap to tap time are important, as shown in the following tables:
Table 20 - Power consumption with DRI charging.
Table 21 - Influence of metallization.
Table 22 - Influence of the tap to tap time on power consumption.

3.3.2 Induction Furnace Processes

Current is induced in the metallic charge by an oscillating magnetic field.
Usually first class scrap and pig iron are used as a charge for induction furnaces, which are installed in many foudries.

3.3.3 Plasma Furnace Processes

Basically the plasma furnace can be regarded as an electric arc furnace, in which the graphite electrodes are replaced by metallic electrodes and the electric arc by the plasma arcs (24).
Taking advantage of the technology developed by VEB - Freital, Voest Alpine acquired an exclusive licence for the building and operation of plasma furnaces.
So, a 45/60 t plasma furnace was installed at the Voest - Alpine works in Linz and put into operation in Nov. 1983.
The plasma furnace has already produced 25.000 t of alloy steel.
Some of the advantages expected for the plasma furnace are:

- better metallic yield
- lower noise level
- no shock loads on power grid
- no electrode consumption (25).

4. TECHNOLOGIAL ROUTES FOR STEEL PRODUCTION IN DEVELOPING COUNTRIES (Iron Making + Steel Making).

4.1 Remarks

4.2 Considerations about Technological Routes

4.3 Technological Routes for Iron and Steel Production

4. TECHNOLOGICAL ROUTES FOR STEEL PRODUCTION IN MINI STEEL PLANTS IN DEVELOPING COUNTRIES

4.1 Remarks

4.1.1 The main characteristics to be met by such plants should be:

- intensive and, if possible, exclusive use of domestic resources (raw materials, energy, labour etc).
- to be based on existing and proven technology
- to be tailored for the domestic or regional market in case an agreement is reached with neighboring countries; eventually a small surplus for export may be contemplated.
- low investment.

4.1.2 For the purpose of this paper the definition of mini steel plant is a plant with capacity between 50.000 and 500.000 tpy of steel.
Exceptionally the limit might go up to 800.000 or even 1.000.000 tpy.

4.1.3 Today the general tendency for steel production is to follow the route hot metal/oxygen steelmaking, in view of lower electric power consumption as compared to the alternative route cold metallic charge/electric arc furnace. Electric power is not only expensive but also in considerable shortage in many countries, which also do not have networks with the necessary short-circuit power to supply high-powered arc furnaces.
On the other hand, however, there are countries with availability of hydroelectric power at reasonable price, as well as iron ore. In this case the production of hot metal in low shaft electric furnaces may be a good solution. This shows the importance of a thorough knowledge of local conditions before a decision is taken.

4.1.4 At present quite a few electric arc furnaces are using pig iron and even hot metal in the composition of their metallic charge. In Brazil, for instance, it is usual to charge up to 30 % - and even 40 % - of pig iron into the EAF. Table 23 shows electric energy consumption and metallic yield in an arc furnace as function of the percentage of pig iron in the charge (27). Such data were obtained in a highly efficient steel plant producing 900.000 tpy liquid steel in two EAF of 115 t capacity each.

4.1.5 There is a further advantage in routes which go through pig iron production: the possibility of supplying raw material to foundries, which also play an important role in the industry of a developing country.

4.1.6 To be "eligible" for a developing country, a technological route should be based on existing and well proven technologies. On one hand all existing technologies are undergoing significant developments, and the charcoal blast furnace is a good example. But some recently developed technologies, like for instance the plasma in the production of hot metal, are promissing solution but should prove seccessful in commercial plants of developed countries before being taken up by any emerging country.

4.2 Considerations about Technological Routes:

In chapters 2 and 3 many processes were presented; from now on, however, all data will be referred to the better known, experienced and proven processes, already in operation or about to be adopted by developing countries, namely:

4.2.1 Ironmaking Indirect Process:

Charcoal blast furnaces data; in some cases small coke blast furnaces and low shaft electric furnaces data will be considered.

4.2.2 Ironmaking Direct Reduction Process - Solid Reductant:

SL/RN data.

4.2.3 Ironmaking Direct Reduction Process - Gaseous Reductant:

MIDREX datas (HYL III may be considered too)

4.2.4 Ironmaking Direct Smelting Process:

COMBISMELT and COREX data.
COMBISMELT uses proven processes as the rotary kiln and the low shaft electric furnace. COREX is considered here because the Kehl demonstration plant size - 60.000 / 80.000 tpy hot metal - is an industrial plant size for many developing countries and the first industrial plant for 300.000 tpy of hot metal is being commissioned right now (January 1988).

4.2.5 Oxygen Steelmaking Process:

EOF data, because it is a new concept developed in an emerging country to operate under such a country's conditions. At the same time it is a proven process, able to use high percentages of solid charge and, when using predominant percentages of liquid charge, the consumptions figures are similar to the wellknown and proven LD process and its LD process variations. (See Tables 16, 17, 18 and 19)

4.2.6 Electric Steelmaking Process:

EAF - Electric Arc Furnace data.

4.3 Technological Routes for Iron and Steel Production

4.3.1 Scrap + Direct Reduction Plant (DRI) + Electric Arc Furnace Steel Plant:

4.3.2 Scrap + Hot Metal Production (Pig Iron) + EOF

4.3.3 Scrap + Direct Reduction Plant (DRI) + Hot Metal Production (Pig Iron) + EOF;

NOTE: The quantity of scrap available in the country is very important when deciding about the ironmaking plant size

4.3.4

If a developing country has large availability of scrap or does not have the raw material for ironmaking, sometimes it may be more economical to import scrap/DRI/pig iron. In this case the technological routes for steelmaking are:

4.3.4.1 Scrap/DRI/pig iron - EAF

4.3.4.2 Scrap/DRI/pig iron - Cupola Furnace - EOF:

This route is valid for countries where the electric energy supply is limited or its price is high. Annex 6 shows a preliminary proposal for a steel plant based on scrap - cupola furnace - EOF with an initial production of 50.000 tpy of liquid steel, which may be increased in two steps to 150.000 tpy.

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SHEET 32 OF 52

COMPARATIVE EVALUATION OF NEWLY DEVELOPED TECHNOLOGIES FOR APPLICATION IN MINI STEEL PLANTS

5. TECHNOLOGICAL ROUTES FOR IRON AND STEEL PRODUCTION: MAIN DATA

5.1 Indirect Ironmaking Process: Characteristics, Main Reductant and Energy Consumptions.

5.2 Direct Reduction and Direct Smelting Process: Characteristics, Main Reductant and Energy Consumptions

5.3 Electric Arc Furnace Process and LD Steelmaking Process: Metallic Charge and Main Energy Consumption

5.4 EOF Steelmaking Process: Metallic Charge and Main Energy Consumption.

5. TECHNOLOGICAL ROUTES FOR IRON AND STEEL PRODUCTION: MAIN DATA

5.1 Indirect Ironmaking Processes

5.1.1 Characteristics:

Process Items	A. Coke Blast Furnace	B. Charcoal Blast Furnace	C. Low Shaft Electric Furnace
1.Furnace	Blast Furnace	Blast Furnace	L.S.E.F.
2.Production per Furnace	60.000 tpy to more than 3x10^6 tpy	20.000 tpy to 350.000 tpy	20.000 tpy to 150.000 tpy (350.000 tpy)
3.Iron Ore	Pellet/Sinter/high grade lump ore	Lump Ore/Pellets/ Sinter	Lump Ore/Pellets/ Sinter
4.Reductant	High grade metallurgical coal/coke	Wood / Charcoal	Coke / Char / Charcoal
5.Energy(heat)source	Coke	Charcoal	Electric Energy
6.Product	Liquid Pig Iron	Liquid Pig Iron	Liquid Pig Iron
7.Investment(US$ per ton of yearly capacity)	325,00	60,00	200,00
8.Advantages	High reliability, well known and proven	High reliability, well known and proven Low investment.Use of renewable energy.	High reliability, well known and proven.
9.Disvantages	It needs high grade metallurgical coal and high quality iron ore or agglomerates. Relatively high investment (coke plant included).	It is necessary to invest in Reforestation (up to US$ 150,00 per t/year, if 100% of charcoal is to derive from artificial forests).	Intensive eletric energy consumer Relatively high investment.

Remarks: A7: coking plant included
C2: (350.000 tpy) means with hot charging of DRI

5.1.2 Main Reductant and Energy Consumptions

Process Items	Unit	Gcal/U	A Coke Blast Furnace		B Charcoal Blast Furnace		C Low Shaft Electric Furnace	
Itens			U/t	Gcal/t	U/t	Gcal/t	U/t	Gcal/t
1.Metallurgical Coal (Domestic+Imported)	t	7,69	0,71	5,46	-	-	-	-
2.Domestic Metallurgical Coal (17% ash)	t	6,80	-	-	-	-	-	-
3.Domestic Coke (25 - 30% ash)	t	6,00	-	-	-	-	0,46	2,76
4.Domestic Reductant Coal (30 - 35% ash)	t	4,70	-	-	-	-	-	-
5.Domestic Steam Coal (40% ash)	t	5,20	-	-	-	-	-	-
6.Charcoal	t	6,80	-	-	0,825	5,56	0,40	2,76
7.Natural Gas	1000 Nm³	8,95	-	-				
8.Electric Energy	kWh	0,0025	108	0,27	100	0,25	2.000 (850)	5,00 (2,13)
9.Total in Gcal				5,73		5,81		7,76
10.Total in (kWh + Gcal)			108	5,46	100	5,56	2.000	2,76
Credits Coal + Gas	U	Gcal		2,23		1,94		1,34
11.Total less credits in Gcal				3,50		3,87		6,42
12.Total: Gcal kWh				3,23 108		3,62 100		1,45 2.000

Main Source : Energy Balance of Brazilian Steel Plants COENGE - ABM (Brazilian Society for Metals) Porto Alegre 23/25 July 1986.

Remarks:

C3: LSEF operating exclusively with domestic coke
C6: LSEF operating exclusively with charcoal
B6: Gross consumption

C8: (850) means 850 kWh/t pig iron when the LSEF receives hot DRI. Right New Zeland Steel is consuming about 1.000 kWh/t, but the goal is to achieve 850.

Note: Conversion factor for kcal into kWh is 2.500 kcal per kWh, according to ABM.

5.2 Direct Reduction and Direct Smelting Processes

5.2.1 Characteristics

Items / Process	A SL/RN	B MIDREX	C COREX	D COREX + MIDREX
1.Furnace	Rotary Kiln	Shaft	Reduction Reactor/Smelter Gasifier	Reduction Reactor/Smelter Gasifier + MIDREX shaft
2.Production per Furnace	30.000 to 180.000 tpy	300.000 to 700.000 tpy	100.000 to 500.000 tpy	300.000 tpy pig iron + 375.000 tpy DRI
3.Iron Ore	pellets and natural pellet ore	pellets and natural pellet ore	pellets - sinter-natural pellet ore	pellets - sinter-natural pellet ore
4.Reductant	Reducing Coal	Reducing gases	Coals (coking and non coking)	Coals and clean export gas
5.Energy	Reducing Coal	Natural gas	Coals	Coals
6.Product	DRI	DRI	Liquid Pig Iron	Liquid Pig Iron and DRI
7.Investment(US$/t--year)	125,00	200,00	423,00 (257,00)	319,00 (245,00)
8.Advantages	Very flexible in regard to raw materials.	High reliability	Pig iron producer with non coking coals.	Pig iron and DRI production in the same complex.
9.Disadvantages	Each plant is a new experience	Minimum economical size 300.000 tpy	First industrial plant is being commissioned now.	

Notes: C7: Estimated investment with oxygen plant included - (US$ 257/t: oxygen plant is not included).
D7: Estimated investment with oxygen plant included - (US$ 245/t: oxygen plant is not included).

5.2.2 Main Reductant and Energy Consumption

Process / Items	UNIT	Gcal/U	A SL/RN U/t	A SL/RN Gcal/t	B MIDREX U/t	B MIDREX Gcal/t	C COREX U/t	C COREX Gcal/t	D COREX + MIDREX U/t	D COREX + MIDREX Gcal/t
1. Metallurgical Coal (domestic + imported)	t	7,69	-	-	-	-	-	-	-	-
2. Domestic Metallurgical Coal (17% ash)	t	6,80	-	-	-	-	1,065	7,24	0,426	2,90
3. Domestic Coke (25 - 30% ash)	t	6,00	-	-	-	-	-	-	-	-
4. Domestic Reducting Coal (30 - 35 ash)	t	4,70	1,195	5,64	-	-	-	-	-	-
5. Domestic Steam Coal (40% ash)	t	5,20	-	-	-	-	-	-	0,070	0,36
6. Charcoal	t	6,80	-	-	-	-	-	-	-	-
7. Natural Gas	1000 Nm³	8,95	-	-	0,302	2,70	-	-	-	-
8. Electric Energy	kWh	0,0025	117	0,29	125	0,31	430	1,08	251	0,63
9. Total in Gcal				5,91	-	3,01	-	8,32	-	3,89
10. Total in (kWh + Gcal)			117	5,62	125	2,70	430	6,16	251	3,26
Credits Coal + Gas	U	Gcal	-	-	-	-	-	3,44	-	-
11. Total less credits in Gcal				5,91		3,01		4,88		3,89
12. Total: Gcal				5,62		2,70		2,72		3,26
kWh				117		125		420		251

Sources: SL/RN - Aços Finos Piratini, COENGE - ABM July 1986.
The Piratini SL/RN plant does not use the waste energy.

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	PREPARED BY Sergio W.G.SCHERER	ISSUE DATE 26.01.88	SHEET 38 OF 52
	TITLE COMPARATIVE EVALUATION OF NEWLY DEVELOPED TECHNOLOGIES FOR APPLICATION IN MINI STEEL PLANTS		

MIDREX - Informations from MIDREX
CORFX - Proposal from Korf Engineering to a Brazilian Iron ore mining company.
COREX + MIDREX - KTS studies based on the above proposal - COREX plant producing 300.000 tpy pig iron and the MIDREX plant based on clean export gas, producing 375.000 tpy DRI.

5.3 Electric Arc Furnace Process and LD Steelmaking Process: Metallic Charge and Main Energy Consumption

Process			A SL/RN + EAF		B MIDREX + EAF		C COKE B.F. + LD	
Items	UNIT	Gcal/U	U/t	Gcal/t	U/t	Gcal/t	U/t	Gcal/t t
1.Cold DRI	t	(*)	0,672	3,97	0,70	2,11		
2.Hot DRI	t	(*)	-	-	-	-	-	
3.Liquid pig iron	t	(*)	-	-	-	-	1.01	3,54
4.Solid pig iron	t	(*)	0,168	0,65	0,14	0,54	0,06	0,21
5.Internal scrap	t	(*)	0,130	0,77	0,13	0,39	0,05	0,18
6.Purchased scrap	t	(*)	0,150	0,89	0,15	0,45	-	-
7.Oxygen	Nm³	0,0016	24	0,04	24	0,04	55	0,09
8.Electric Energy	KWh	0,0025	600	1,50	600	1,50	50	0,13
9.Total in Gcal				7,82		5,03		4,15
10.Total: Gcal + kWh				5,96 + 744		3,15 + 752		3,62 + 206

(*) Metallics have the Gcal/t value calculated above in 5.1.2 and 5.2.2.

Notes: The DRI can be replaced by scrap, total or partially. All the available scrap should be consumed. Therefore the availability of scrap is very important to decidade the ironkaming plant size. Solid pig iron means purchased pig iron.

5.4 EOF Steelmaking Process: Metallic Charge and Main Energy Consumption

Process			C Charcoal BF + EOF		D LSEF + EOF		E COREX + EOF		F COREX - MIDREX + EOF	
Items	UNIT	Gcal/U	U/t	Gcal/t	U/t	Gcal/t	U/t	Gcal/t	U/t	Gcal/t
1.Cold DRI	t	(*)	-	-	-	-	-	-	-	-
2.Hot DRI	t	(*)	-	-	-	-	-	-	0,610	2,34
3.Liquid pig iron	t	(*)	0,56	2,17	0,56	3,60	0,56	2,73	0,488	1,87
4.Solid pig iron	t	(*)	0,54	2,09	0,54	3,47	0,54	2,64	-	-
5.Internal scrap	t	(*)	0,02	0,08	0,02	0,13	0,02	0,10	0,022	0,08
6.Purchased scrap	t	(*)	-	-	-	-	-	-	-	-
7.Oxygen	Nm^3	0,0016	80	0,13	80	0,13	80	0,13	80	0,13
8.Electric Energy	kWh	0,0025	50	0,13	50	0,13	50	0,13	50	0,13
9.Total in Gcal				4,59		7,46		5,73		4,55
10.Total: Gcal +kWh				4,05 + 214		1,62 +2341		2,00 + 583		3,65 + 382

(*)Metallics have the Gcal/t value calculated above in 5.1.2 and 5.2.2.

Notes: Solid pig iron means purchased pig iron and may be totally or partially replaced by scrap. (See table 18).
Column D: If the technological route Rotary Kiln - LSEF - EOF is chosen, electric energy consumption decreases to about 50/60 %.

6. TECHNOLOGICAL ROUTES FOR STEEL PRODUCTION: PROCESS SELECTION

To erect or to increase the steel production in a developing country the following steps must be given for the steelmaking process selection.

6.1 In the selection of the best suited steelmaking process for installation or expansion of steel production in a developing country the following steps are necessary:

- To determine the country's or the region's steel consumption, in order to get a first idea on the steel plant's size.
- To gatter information about the available raw materials (quantity and quality, location etc).
- To know the country's energy resources, like mineral coal, natural gas, liquid fuels, electric power generation and distribution system.
- To determine the country's or region's scrap availability.
- To identify the existing infrastructure as transportation systems, water, urban areas etc.
- To know about labour conditions and availability.

6.2 Information listed in items 5.1 and 5.2 above inform about the technical feasibility of the different ironmaking process, whereas item 5.3 gives the background for the correct choise of the steelmaking process.
Since the desired plant capacity as well as scrap availability are known, it will be possible to decide about both inronmaking and steelmaking capacity.

6.3 A first approach on economic feasibility of the different technological routes for iron and steelmaking will be provided by filling in the following tables:

Table 24 : Prices of raw materials and main supplies C&F plant.
Table 25 : Estimated feasibility of the ironmaking plant.
Table 26 : Estimated feasibility of the steelmaking plant.

6.3.1 It is necessary to fill in the above tables for each technological route and location envisaged.

6.3.2 As an example, tables 26, 27 and 28 are given, filled in for the technological route charcoal blast furnace/EOF under brazilian conditions.

6.4 Finally, it is necessary to find out about possible financing conditions since in many instances financing terms and the technological route have a close connection.

6.5 Having followed all steps above there are conditions now at last, to decide in a first approach about the best suited technological route for the envisaged steel plant and to work out a more detailed feasibility study.

7. SOME EXAMPLES OF TECHNOLOGICAL ROUTES FOR IRON AND STEEL PRODUCTION IN DEVELOPING COUNTRIES

7.1 Brazil

7.2 Paraguay

7.3 Argentina

7.4 Venezuela

7.5 Peru

7.6 Mexico

7.7 Siria

7.8 New Zealand

7.9 India

7.10 South Africa

7.11 Mozambique

7.12 Burma

7.13 Others: Indonesia, Iraq, Trinidad Tobago, Nigeria, Saudi Arabia, Malaysia, Iran, Egypt and Libya.

7. SOME EXAMPLES OF TECHNOLOGICAL ROUTES FOR IRON AND STEEL PRODUCTION IN DEVELOPING COUNTRIES

7.1 Brazil, year 1986. Pig iron production was 20,2 million tons 62,3 % of which produced in coke blast furnaces, and 36,5 % in charcoal blast furnaces and 1,2 % in charcoal low shaft electric furnaces.
Steel production amounted to 21,2 million tons, where of 72,7 % came from oxygen processes, 24,9 % from electric arc furnaces and 2,4 % from open hearth furnaces (rapidly decreasing).

7.1.1 The II PSN (National Steel Industry Plan) gives the the guide lines for the expansion plan which intends to go for an installed capacity of 50 million tons for the year 2000.
There will be expansions of the existing production areas and new areas will be developed.
A great share of the actual production areas' expansion will be based on the technological route coke blast furnace, since the big state plants owned are already based on this technology.
I order to decrease the coke rate, coke based steel plants are adopting the technologies of coal fines injection, natural gas injection, and oxygen enrichment of the blast. There is a technical cooperation agreement between Brazil / USSR covering these technologies. Charging of metallics (DRI) into the blast furnace is also being considered, as a means of increasing hot metal production without further coke consumption.

7.1.2 Electric arc furnace production will be expanded according to the availability of both scrap and pig iron, provided the energy price does not grow out of control.
In some areas it will be necessary to compare the routes scrap - pig iron - electric arc furnace versus pig iron - scrap - EOF.
SIDERURGICA ALIPERTI S.A., a private company located downtown Sao Paulo, decided about 18 months ago to cancel a new electric arc furnace steel plant and in its place to build a steel plant based on the EOF - ladle furnace - continuous casting route.
ALIPERTI produces about 200.000 tpy of charcoal pig iron. The new EOF-LF-CC steel plant is under erection and will be commissioned in May 1988. The capacity is 400.000 tpy of liquid steel and the investment "battery limits" is US$ 36 million (US$ 90/t-year of capacity)

7.1.3 Along the 900 km railway from Carajas iror ore mines to Ponta da Madeira sea port (north of Brazil) there are some charcoal blast furnaces being commissioned. Probably very soon these blast furnaces, instead of exporting pig iron, will go over to produce steel via EOF process, exporting billets.

Furthermore, near Ponta da Madeira sea port there is an integrated steel plant under planning, intended for slab export. The technology for this plant is not yet decided, but it will operate based on Carajás ore, some local charcoal and mainly imported coal. Through Ponta da Madeira port there is an annual export flow of 25 million tons of iron ore.

7.1.4 Another iron and steel producing unit is being planned within the near future at Corumbá, at the brazilian border with Bolivia, were important iron and manganese ore deposits are located. Corumbá is linked by railway to Santa Cruz de la Sierra/Bolivia in the west as well as to São Paulo and Santos to the east. The technological route for the Corumbá plant will be based partly on charcoal (blast furnaces), partly on bolivian natural gas (direct reduction).

The production of a certain amount of ferro-alloys is also being contemplated at Corumbá.

7.1.5 In the south of Brazil steel production will also be expanded, based on mineral coal, since all brazilian mineral coal mines and deposits are in this region. The ironmaking routes will probably be the SL/RN direct reduction, already operating for almost 15 years at Aços Finos Piratini, and the COREX process.

7.2 Paraguay - Paraguay lacks iron and manganese ore deposits, but both may be easily supplied, via Paraguay River, from the Corumba iron and manganese mines.

Near Assuncion an integrated steel plant, operating charcoal blast furnaces (2 x 87.500 tpy) - LD steel plant (183.000 tpy steel) and rolling mill for 150.000 tpy of non flat rolled products, has been erected and is in operation since 1987.

7.3 Argentina - In the north of Argentina Alto Hornos de Zapla operate an integrated steel plant based on charcoal blast furnaces.

The main Argentinian steel production area is located on the Parana River bank.

SOMISA is an integrated steel plant based on coke blast furnace with imported metallurgical coal. ACINDAR and DALMINE SIDERCA are integrated steel plants based on Direct Reduction (MIDREX Process) - Electric Arc Furnace. These plants operate basically with domestic and brazilian iron ores (lump ore and pellets).
Once Argentina has large amounts of natural gas and since it is very easy to supply the main steel production area with high grade brazilian iron ore, both by sea and river transport it is likely for any new Argentinian steel plant to be based on Direct Reduction (MIDREX or similar).

7.4 Venezuela - During many years SIDOR operated based on low shaft electric furnaces - open hearth furnaces.
In view of the good iron ore deposits and the large amounts of natural gas available in Venezuela, during the 70's an integrated steel complex was erected for the production of flat and non flat produts, based on direct reduction (4 MIDREX and 4 HYL I units) - electric arc furnaces.
In the same area (Ciudad Guayama) of SIDOR, there is another direct reduction plant employing FIOR process (the only FIOR plant worldwide). There is still another one based on the HIB (high iron briquette) process, but this plant is being modified to MIDREX process.

7.5 Peru - SIDERPERU operates on the following basis:

. Ironmaking - 3 rotary kilns (SL/RN), producing up to 100.000 tpy sponge iron, and a coke blast furnace (imported coke).
. Steelmaking - LD and electric arc furnace steel plants.
. Rolling mill for flat and non flat products.

SIDERPERU needs to expand its steel production to one million tons per year.
Since the electric energy supply is critical, but there are pellets available from a pelletizing plant and considering that domestic mineral coal is suitable for the COREX process, the Peruvian steel expansion might well be based on the route COREX (pig iron) - oxygen steel plant.

7.6 Mexico - During the 50's there was a scrap (domestic and imported from USA) shortage and the HYL Group decided to develop a direct reduction process based on the large mexican reserves of natural gas.
The result was the HYL I direct reduction process, in operation up to now but which is being replaced by the new and much more efficient HYL III.

7.7 Siria - Siria has natural gas and low grade iron ore and wishes to erect a steel industry. There are two routes under considerations for Sirian conditions:

COREX process with imported coal; and MIDREX process, importing certain amounts of high grade iron ore to blend it with the domestic ore.

7.8 New Zealand - Based on the available raw materials, iron ore from iron sand containing Ti and a high volatile, high reactivity mineral coal, N.Zealand at first developed the route rotary kiln (SL/RN) producing DRI - Electric Arc Furnace steel plant. Recently the technological route was shifted to Rotary kiln (SL/RN) producing DRI, hot discharged into low shaft electric furnace (pig iron) LD steel plant.

7.9 India - India has several rotary kilns in operation and under erection, according to the SL/RN, ACCAR, TISCO and CODIR processes (28).

7.10 South Africa - In South Africa some good examples for the use of non coking coal for iron and steel making may be found. The main plants are the following:
ISCOR plant (Vanderbijlpark) - 4 rotary kilns (SL/RN process) producing each up to 180.000 tpy DRI.
ISCOR plant (Pretoria) - COREX plant for 300.000 tpy of pig iron and export gas, now being commissioned (January 1988).
HIGHVELD VANADIUM AND STEEL CORP. (Withbank) producing vanadium and steel via rotary kilns (SL/RN) producing low metallization sponge iron, hot discharged into low shaft electric furnaces - LD plant.

7.11 Mozambique - The technological route for ironmaking, in a first step, could be: low shaft electric furnace using Tete iron ore, containing Ti and V, Tete mineral coal and electric energy from Cabora Bassa hydropower plant.
In a second step for steelmaking the technological route might be: rotary kiln producing reduced material, hot discharged into low shaft electric furnace - oxygen steel plant.

7.12 Burma has in operation a coal based Kinglor-Metor plant producing 20.000 tpy of DRI; production may be increased by adding other modules of similar capacity.

7.13 Many developing countries with large reserves of natural gas, with and without own iron ore, like Indonesia, Iraq, Trinidad Tobago, Nigeria, Saudi Arabia, Malaysia, Iran, Egypt and Libya installed or are installing steel production based on the route gascous reductant direct reduction - electris arc furnace.

8. RECOMMENDATIONS / CONCLUSIONS

8.1 Many countries have adopted newly developed technologies for the installation of an iron and steelmaking industry based on domestic resources.

8.2 There are a few well-known, proven and updated technologies for the erection of feasible steel plants, integrated or not, with relatively small scale of production and low investment.

8.3 Steel plants in developing countries should meet the following conditions:

. make intensive use of domestic resources
. be based on proven and updated technologies
. demand low investment
. be tailored for the domestic market with eventual surpluds for export.

8.4 The investment and operational parameters of the different technological routes for iron and steelmaking are known and allow a preliminary comparative evaluation. Nevertheless, for a definitive comparative evaluation it is necessary to know for each specific case all the local parameters and the financing conditions.

8.5 It is also necessary to pay the same attention to the financing aspects as that given to the technical and economical aspects.

8.6 Every now and again developing countries receive financing proposals for the erection of relatively large scale plants for export programs. This can be a good solution economically, but it is recommended that such countries be careful and assure safe guaranties that the balance of payments be positive both in the short and the long range.

8.7 It is recommended to pay attention to the continuous casting systems, because there are great improvements taking place regarding billet as well as slab casters (29). It is necessary to be aware of processes like horizontal casting and rotary continuous casting for billets and the continuous casting of strip developed by SMS - Schloemann Siemag AG.
The first unit for continuous casting of strips is under erection at NUCOR steel plant - USA to produce 820.000 tpy of strips with the following dimensions: width 1.100 to 1.350 mm and thickness 50 mm (30).
This solution and others like HSRC (hot strip reversing compact) developed by Voest Alpine assure that there will be a technical and economical feasibility for steelmaking producing hot rolled flat products between 500.000 to 1.000.000 tpy.

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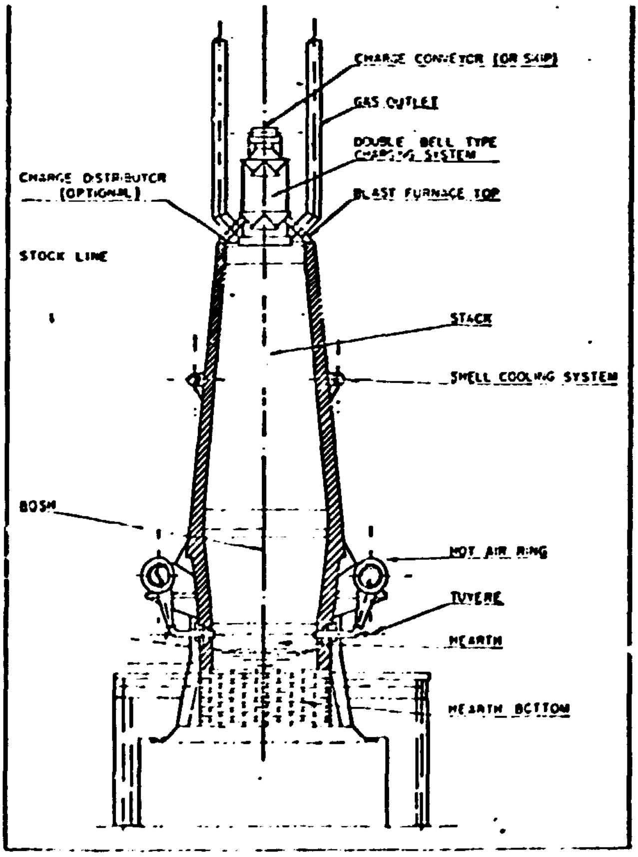
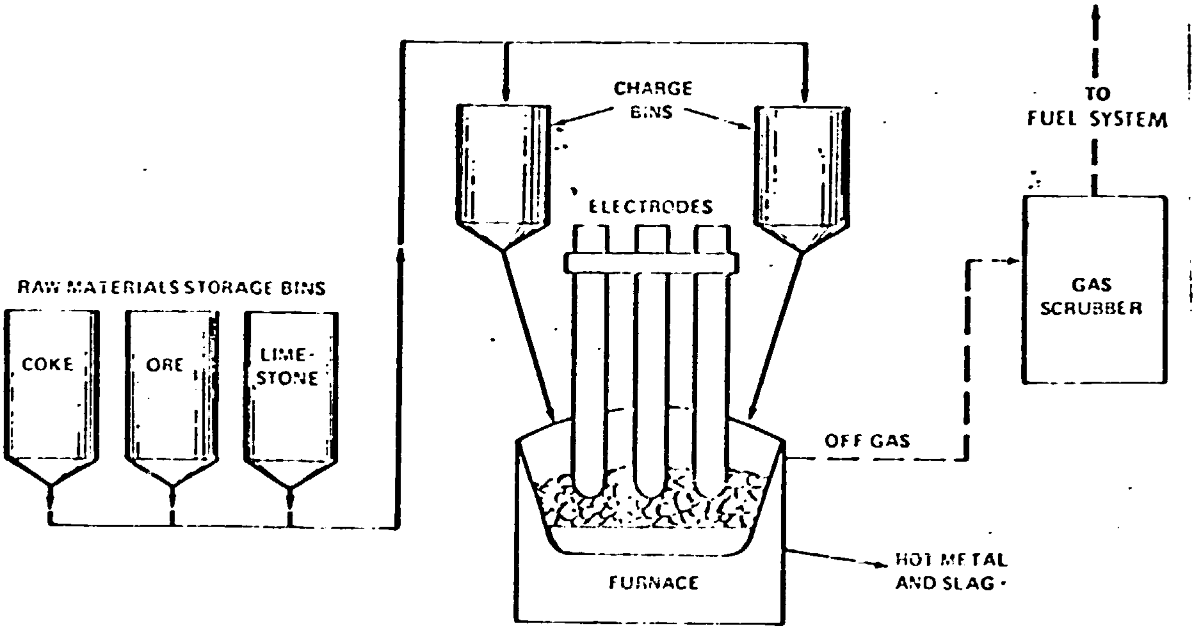
	TITLE COMPARATIVE EVALUATION OF NEWLY DEVELOP TECHNOLOGIES FOR APPLICATION IN MINI STEEL PLANTS			

FIGURE 1



The Charcoal Blast Furnace Section

FIGURE 2



SCHEMATIC REPRESENTATION:
LOW SHAFT ELECTRIC FURNACE FOR PRODUCING LIQUID PIG IRON

FIGURE 3

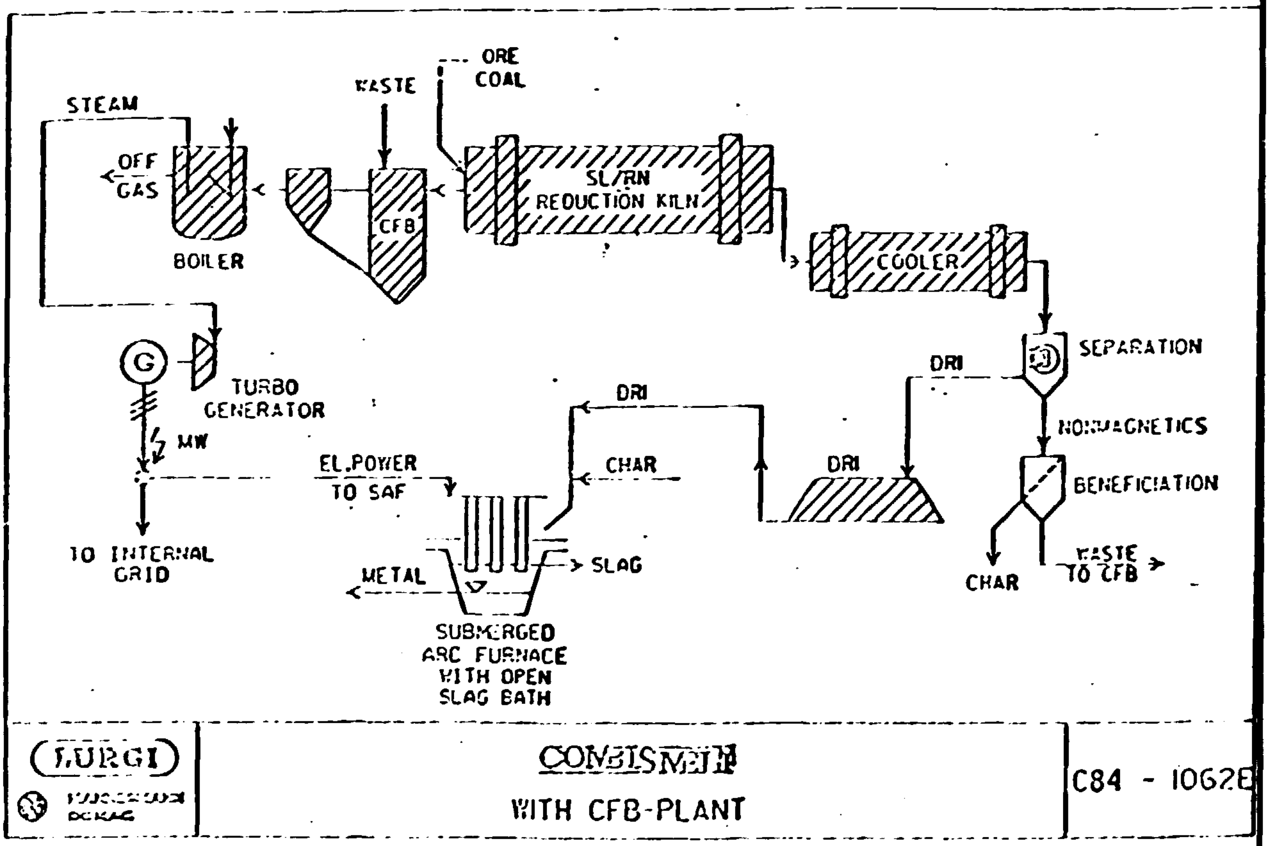

ORE
COAL
WASTE
STEAM
OFF GAS
BOILER
CFB
SL/RN REDUCTION KILN
COOLER
SEPARATION
DRI
NONMAGNETICS
BENEFICIATION
CHAR
WASTE TO CFB
DRI
DRI
CHAR
G
TURBO GENERATOR
MW
TO INTERNAL GRID
EL.POWER TO SAF
METAL
SLAG
SUBMERGED ARC FURNACE WITH OPEN SLAG BATH
LURGI
COMBISMELT
WITH CFB-PLANT
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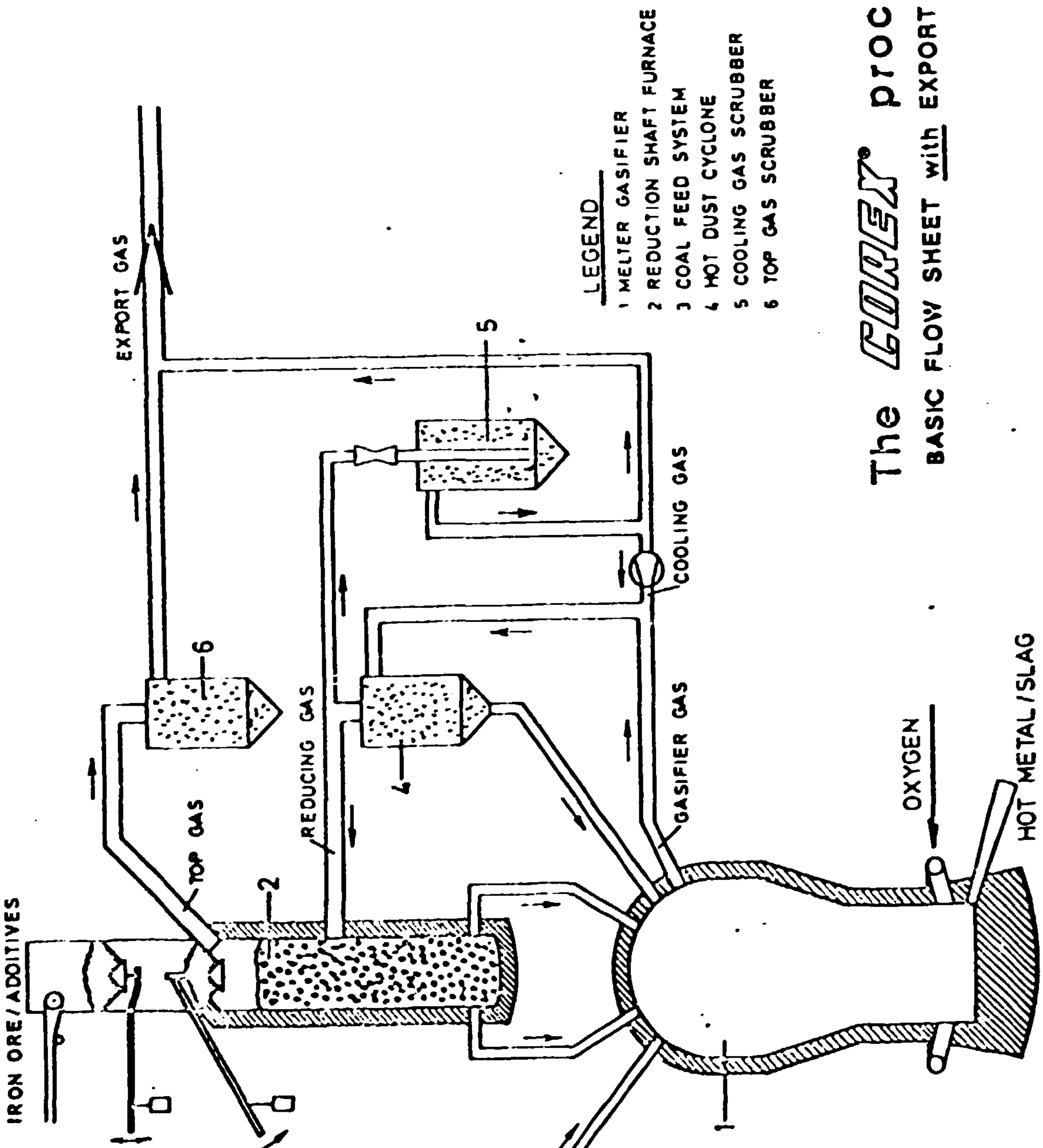
FIG. 4



The COREX® process

BASIC FLOW SHEET with EXPORT GAS

nr. CLT 87/047 July 29th, 1987

KTS

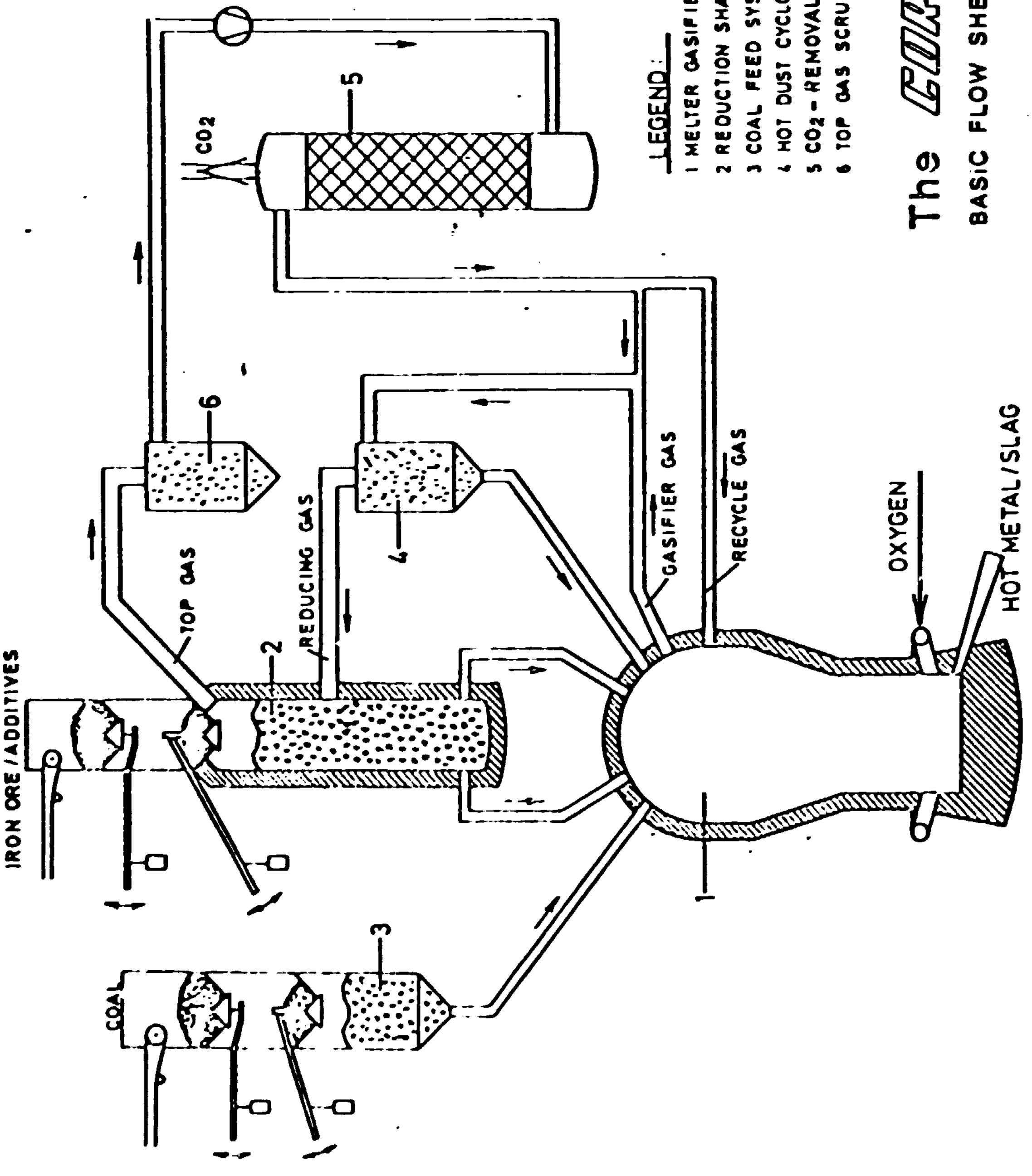
PREPARED BY: S.W.G. Scherer

ISSUE DATE: Jan 26th, 1988

SHEET OF

TITLE: COMPARATIVE EVALUATION OF NEWLY DEVELOP TECHNOLOGIES FOR APPLICATIVE IN MINI STEEL PLANTS

FIGURE 5



LEGEND:
1 MELTER GASIFIER
2 REDUCTION SHAFT FURNACE
3 COAL FEED SYSTEM
4 HOT DUST CYCLONE
5 CO_2 - REMOVAL
6 TOP GAS SCRUBBER

The COREX® process

BASIC FLOW SHEET without EXPORT GAS

FIGURE 6

SCHEMATIC REPRESENTATION: SC PROCESS

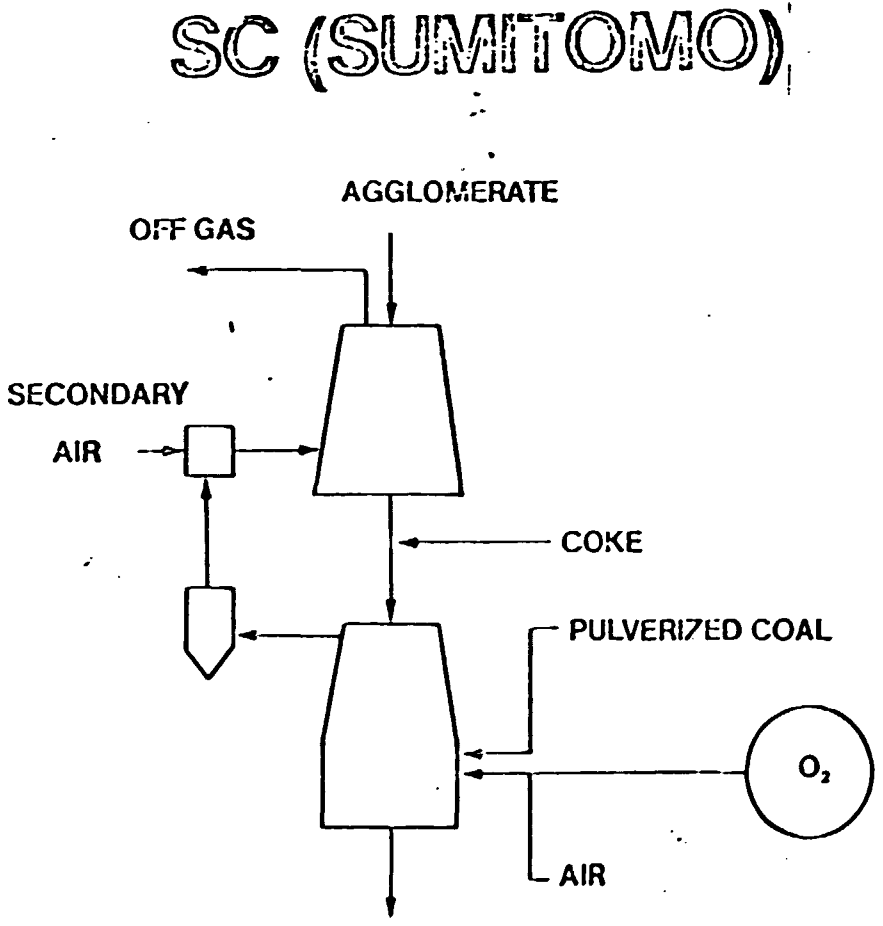


FIGURE 7

SCHEMATIC REPRESENTATION: COIN PROCESS

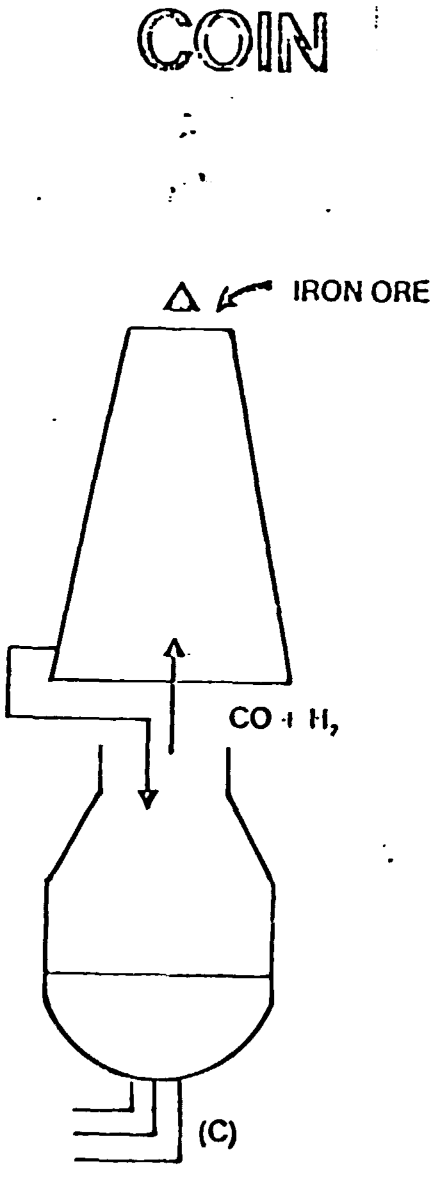


FIGURE 8

SCHEMATIC REPRESENTATION: KAWASAKI PROCESS

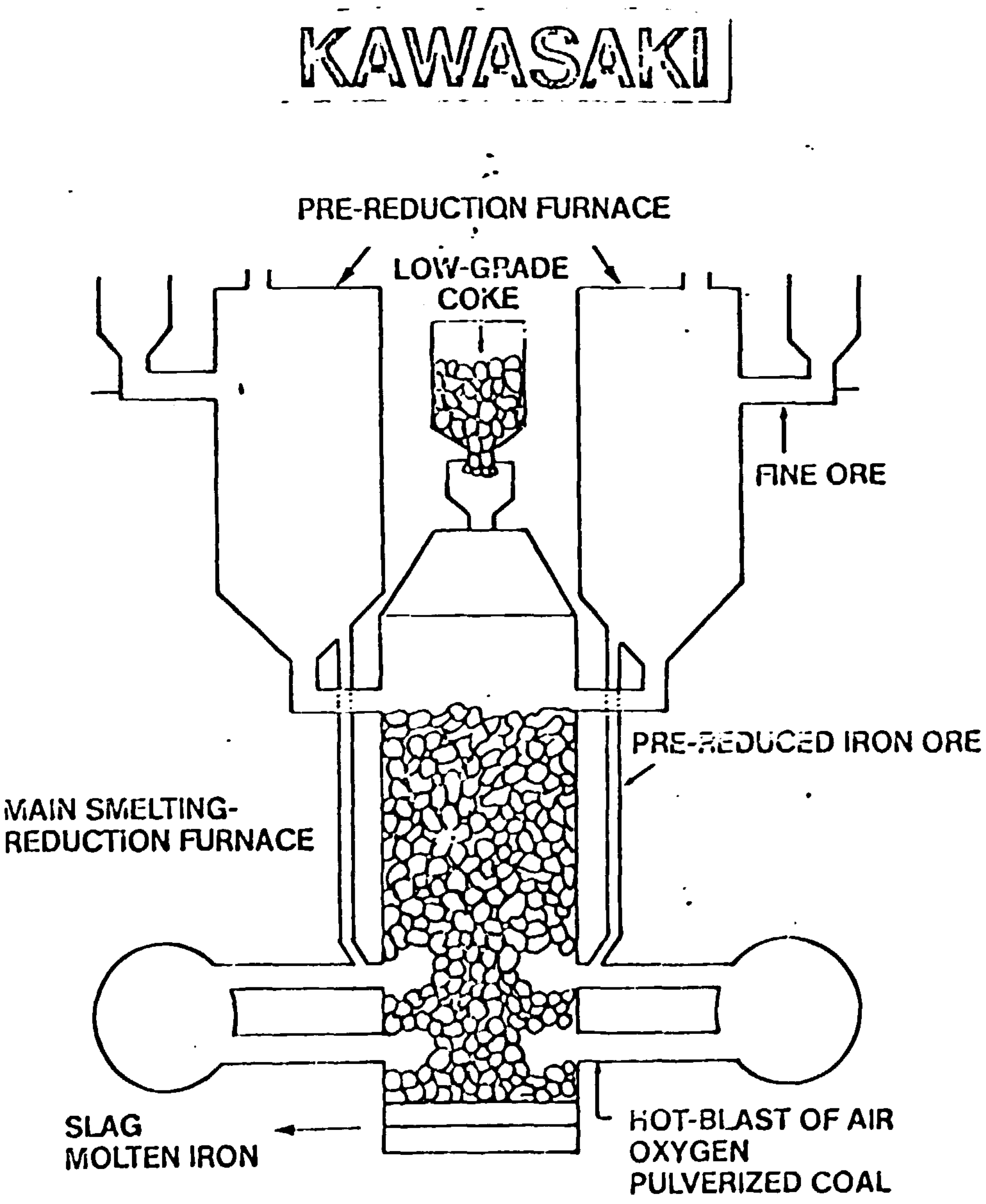


FIGURE 9

SCHEMATIC REPRESENTATION: INRED PROCESS

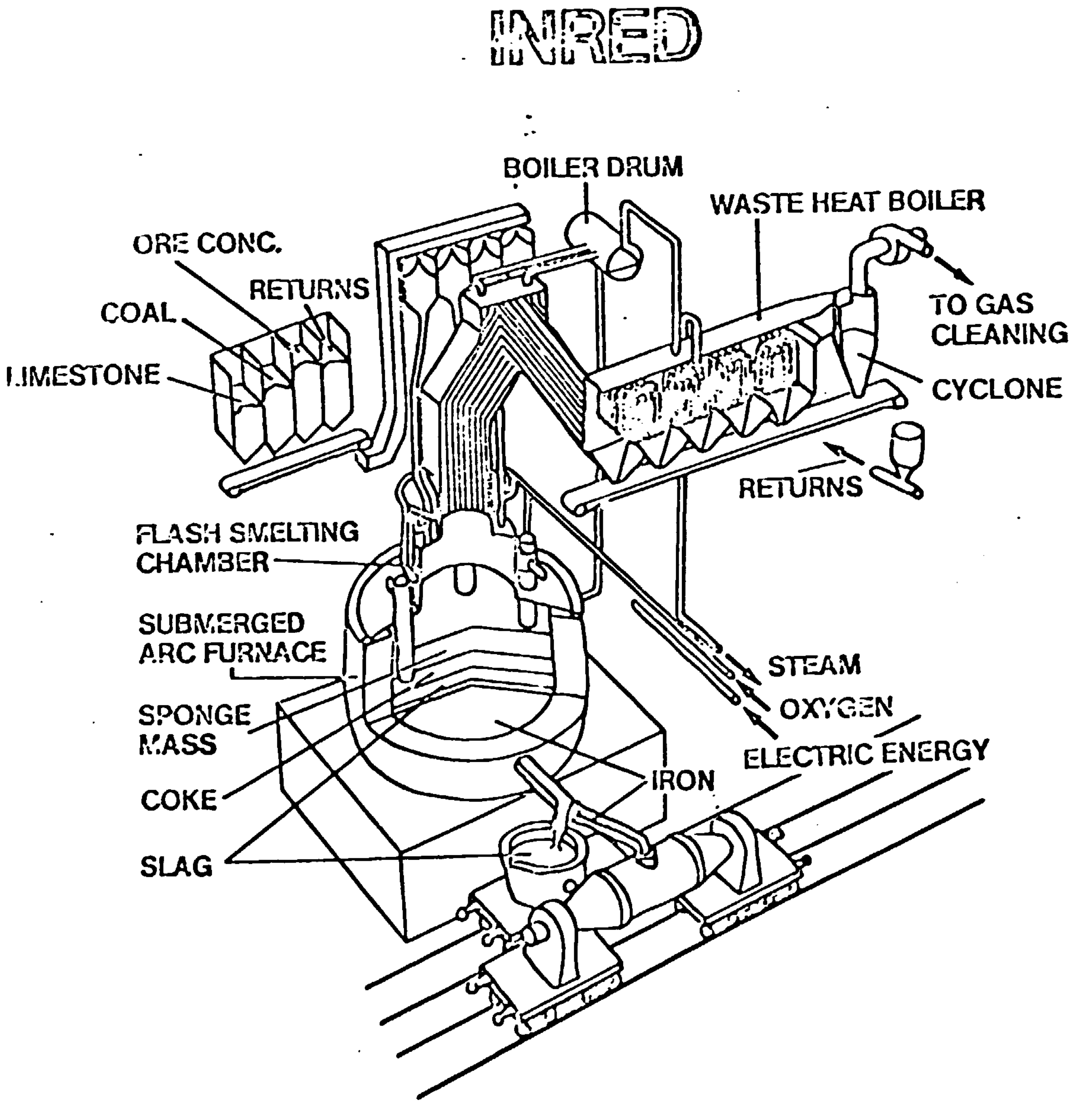


FIGURE 10

SCHEMATIC REPRESENTATION: ELRED PROCESS

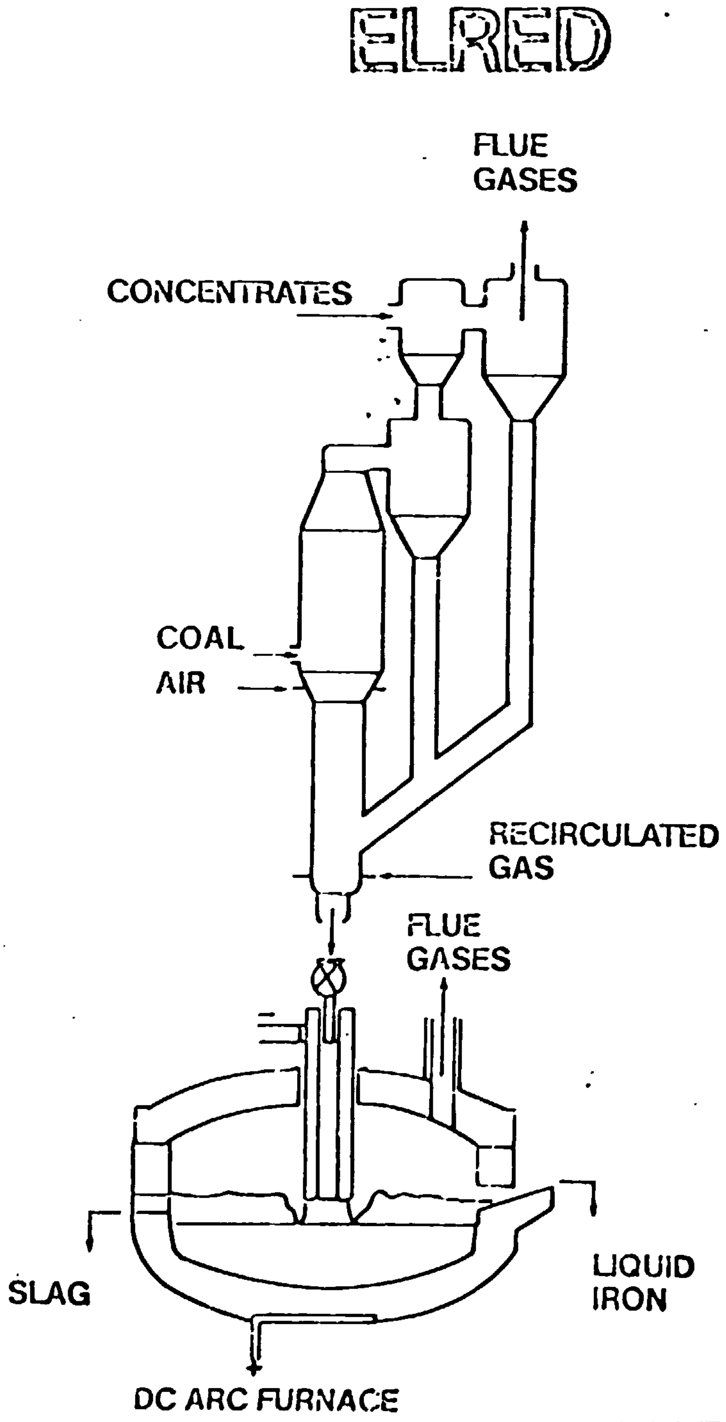
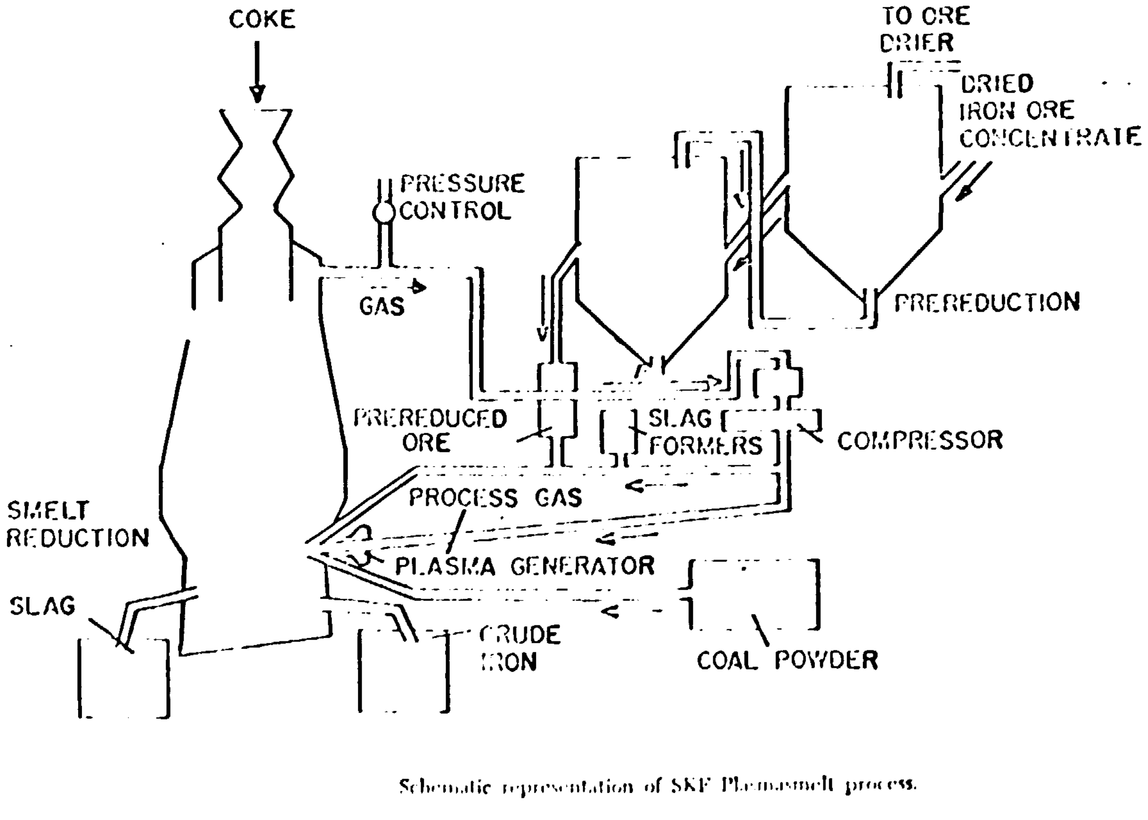


FIGURE 11

SCHEMATIC REPRESENTATION: SKF PLASMASMELT PROCESS



Schematic representation of SKF Plasmasmelt process.

FIGURE 12

OXYGEN BLOWING : PROCESS VARIATIONS

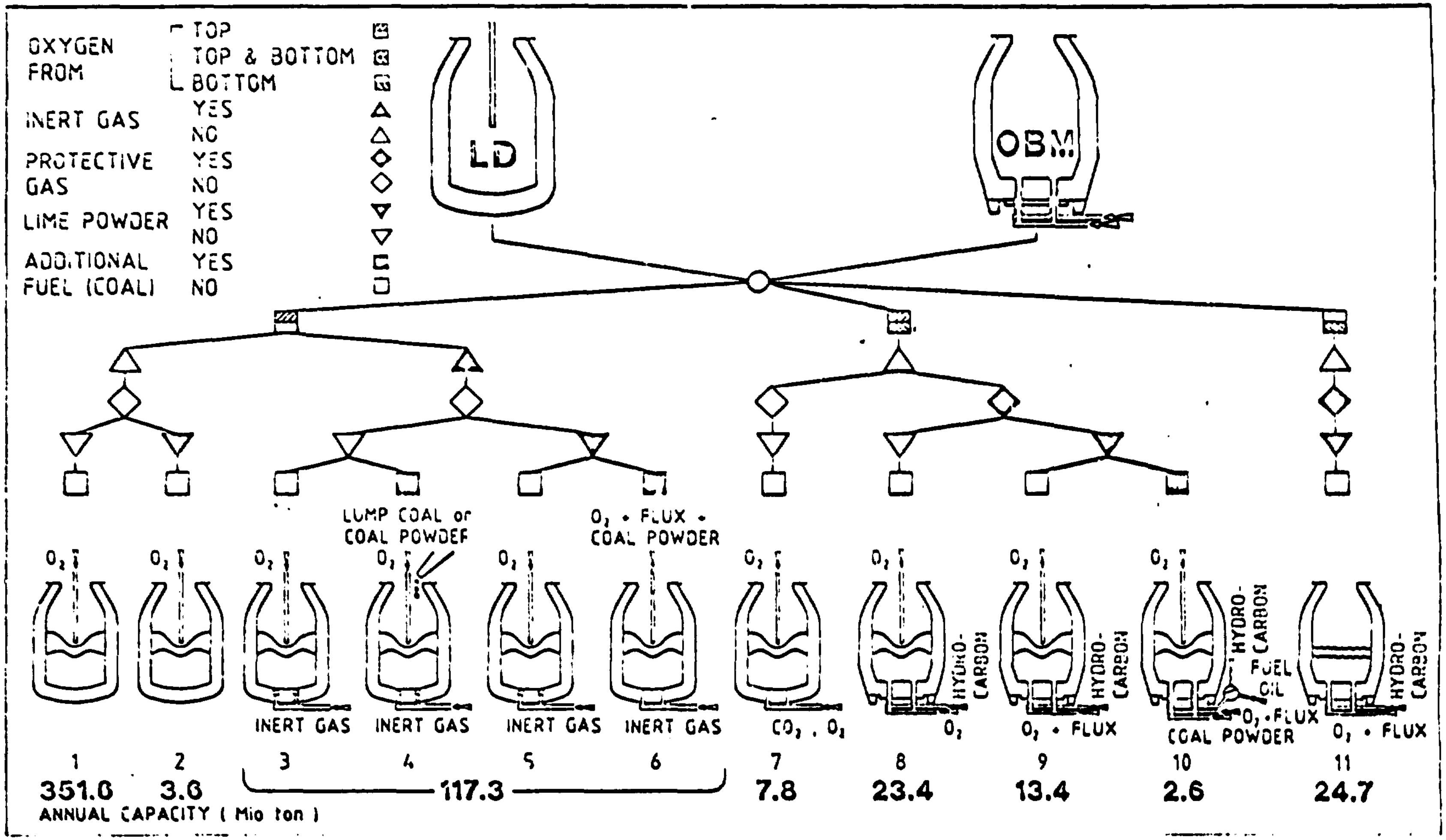


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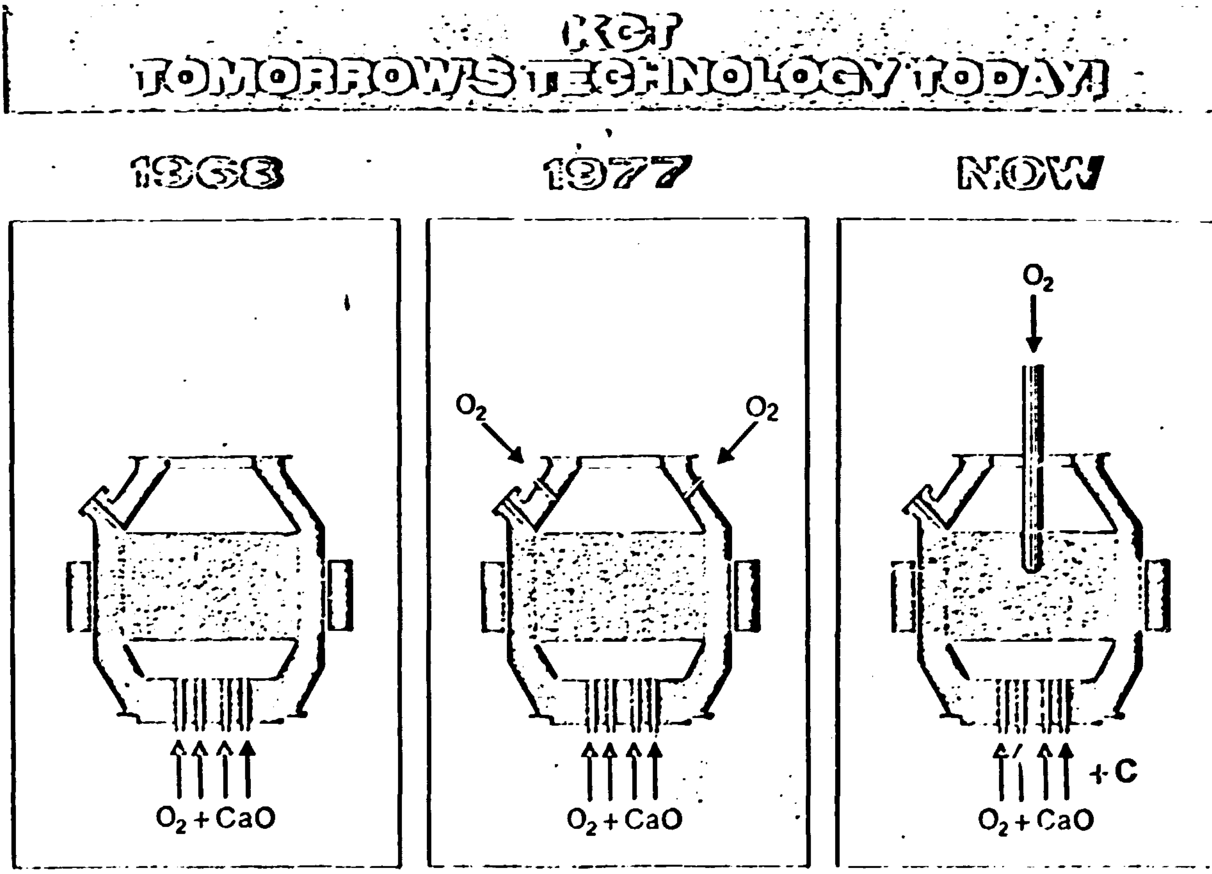
FIGURE 12A

OXYGEN BLOWING PROCESS VARIATIONS:
ABBREV.-FULL DESCRIPTION-COMPANY

ABBREV.	FULL DESCRIPTION	COMPANY	O_2 FROM TOP OR BOTTOM	INERT GAS	PROTECTIVE GAS	LIME POWDER	ADDITIONAL FUEL (COAL)	TYPE OF PROCESS	ANN. CAPAC. (MIO T)
LD BOP LD-CL LD-PJ LD-GTL LD-AOB	LINZ - DONAWITZ BASIC - OXYGEN PROCESS LD - CIRCULATING LANCE LD - PULSATING JET LD-GAS THROUGH THE LANCE LD-ARGON OXYGEN BLOWING	NIPPON KOKKAN USSR. INLAND UNION CARBIDE, INLAND UNION CARBIDE	▨	△	◇	▽	☐	1	351.6
LD-AC OLP	OXYGEN LANCE POWER	ARBED IRSID	▨	△	◇	▼	☐	2	3.6
 UBDT LD-KG LD-AB LD-BC TBM BSC-BAP LBE LD-KB	LD - BODENSPÜLEN UNTERBAD DOSENTECHNIK LD - KAWASAKI GAS LD - ARGON THROUGH BOTTOM LD-BOEL C.R.M. THYSSEN BLAS-METALLURGIE KOMBINIERTES BLASEN KRUPP BODENSPÜLEN BSC-BATH AGITATION PROCESS IJMUIDEN BATH STIRRING JONES & LAUGHLING LANCE BUBBLING EQUILIBRIUM LD - KOMBINIERTES BLASEN	VOEST-ALPINE KAWASAKI NIPPON STEEL C BOEL, C.R.M. THYSSEN AG HOESCH KRUPP BSC HOOGOVENS ESTEL J & L ARBED MANNESMANN	▨	▲	◇	▽	☐	3	117.3
	MAKING STEEL FROM 100 % IRON HOOGOVENS - BSC	LICENSINTORG ESTEL / BSC	▨	▲	◇	▽	▣	4	
LBE KG-LI	LANCE BUBBLING EQUILIBRIUM KAWASAKI GAS LIME INJECTION	ARBED KAWASAKI	▨	▲	◇	▼	☐	5	
ALCI	ARBED LANCE COAL INJECTION	ARBED	▨	▲	◇	▼	▣	6	
LD-OTB LD-STB LET	LD-OXYGEN TOP & BOTTOM BLOWING LD-SUMITOMO TOP & BOTTOM BLOW LANCE EQUILIBRIUM TUYERES	KOBE SUMITOMO SOLMER	▩	△	◇	▽	☐	7	7.8
LD-OB	LD - OXYGEN THROUGH BOTTOM	NIPPON STEEL	▩	△	◆	▽	☐	8	23.4
LD-HC K-BOP K-OBM STB-P	LD - HAINAUT SAMBRE C.R.M. KAWASAKI BOP OBM - COMBINED BLOWING LD-SUMITOMO TOP & BOTTOM BLOWING POWDER	HAINAUT SAMBRE + C.R.M. KAWASAKI KLOCKNER-CRA SUMITOMO	▩	△	◆	▼	☐	9	13.4
KMS KS COIN	KLOCKNER MAXHUTTE STAHLHERSTELLUNG KLÖCKNER-STAHLERZEUGUNGS-VERFAHREN KRUPP COAL OXYGEN INJECTION	KLOCKNER-CRA + MAXHUTTE KLOCKNER-CRA KRUPP	▩	△	◆	▼	▣	10	2.6
OBM Q-BOP LWS	OXYGEN BOTTOM MAXHUTTE QUICK BASIC OXYGEN PROCESS	KLOCKNER-CRA MAXHUTTE IRSID	▨	△	◆	▼	☐	11	24.7

FIGURE 13

OBM, K-OBM AND KMS: PROCESS



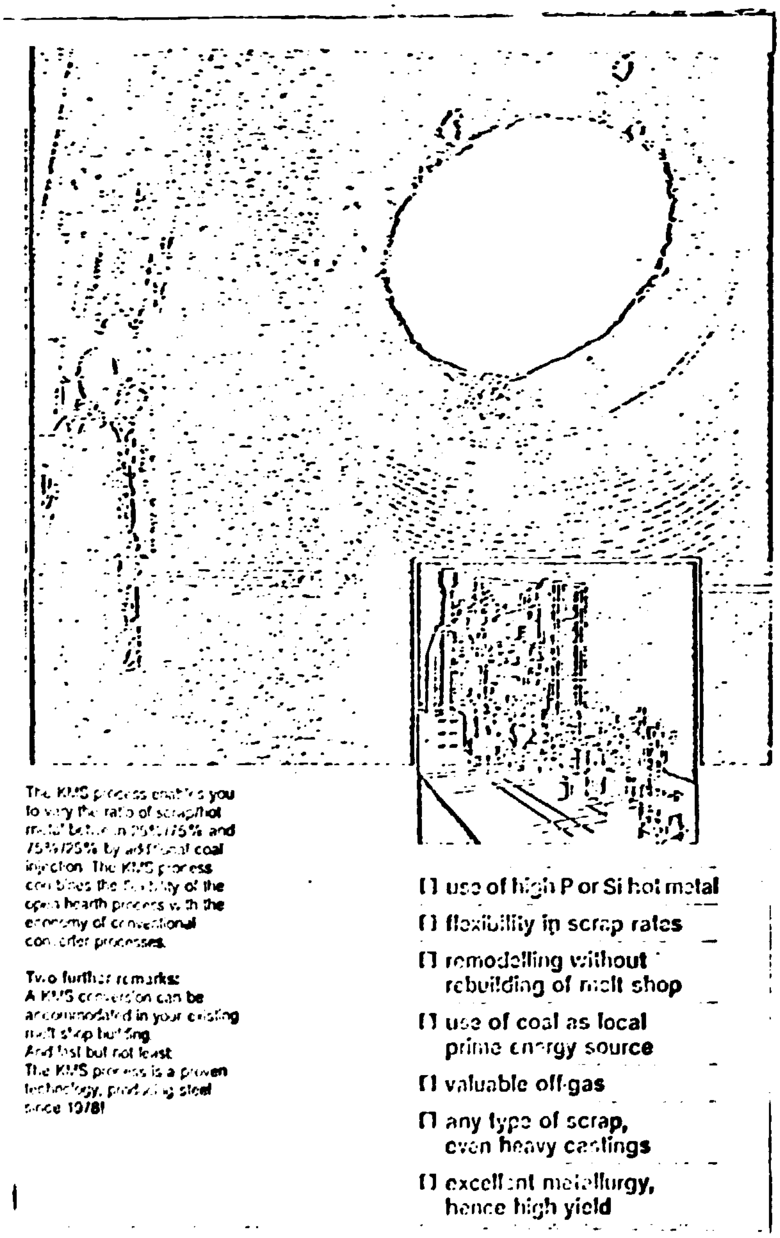
OBM
Pioneer oxygen bottom blown process higher yield, no slopping, advanced metallurgy.

K-OBM
All advantages of OBM plus energy optimisation through combined blowing and post combustion.

KMS
Energy efficiency from coal injection plus unrivalled metallurgy from K-OBM.

FIGURE 14

OUR SOLUTION: KMS,FLEXIBLE AND ECONOMIC



The KMS process enables you to vary the ratio of scrap/hot metal between 25%/75% and 75%/25% by additional coal injection. The KMS process combines the flexibility of the open hearth process with the economy of conventional converter processes.

Two further remarks:
A KMS conversion can be accommodated in your existing melt shop building.
And last but not least
The KMS process is a proven technology, producing steel since 1978!

- ☐ use of high P or Si hot metal
- ☐ flexibility in scrap rates
- ☐ remodelling without rebuilding of melt shop
- ☐ use of coal as local prime energy source
- ☐ valuable off-gas
- ☐ any type of scrap, even heavy castings
- ☐ excellent metallurgy, hence high yield

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rr. CLT 87/047 July 29th, 1987

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TITLE
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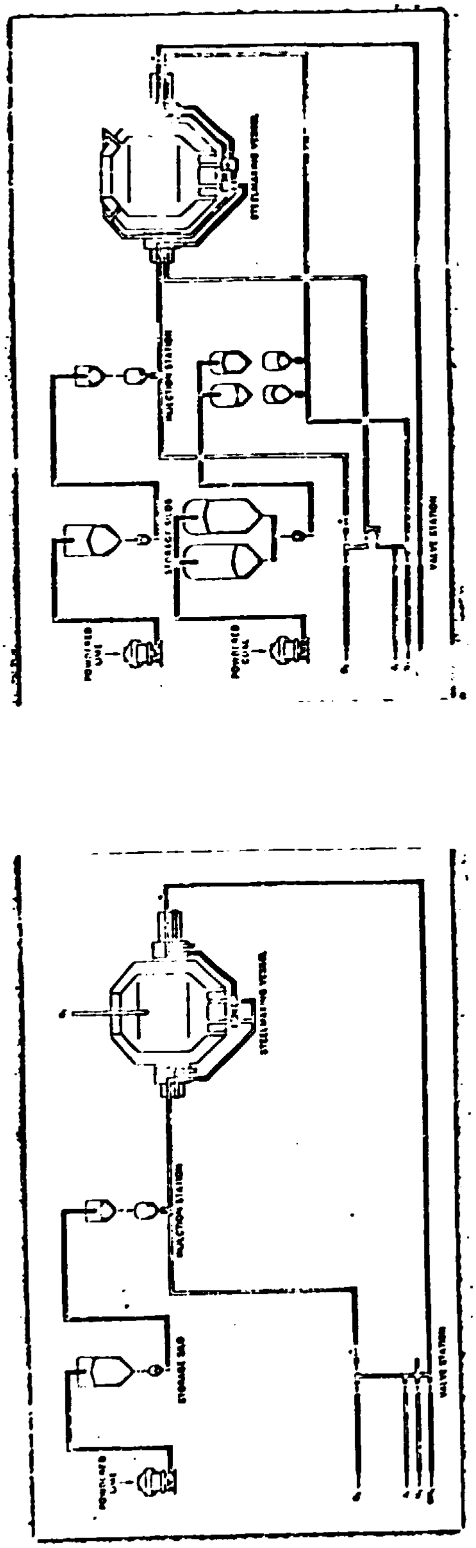


FIGURE 15

K-OBM AND KMS/KS: PROCESS

nr. CLT 37/047 July 29th, 1987

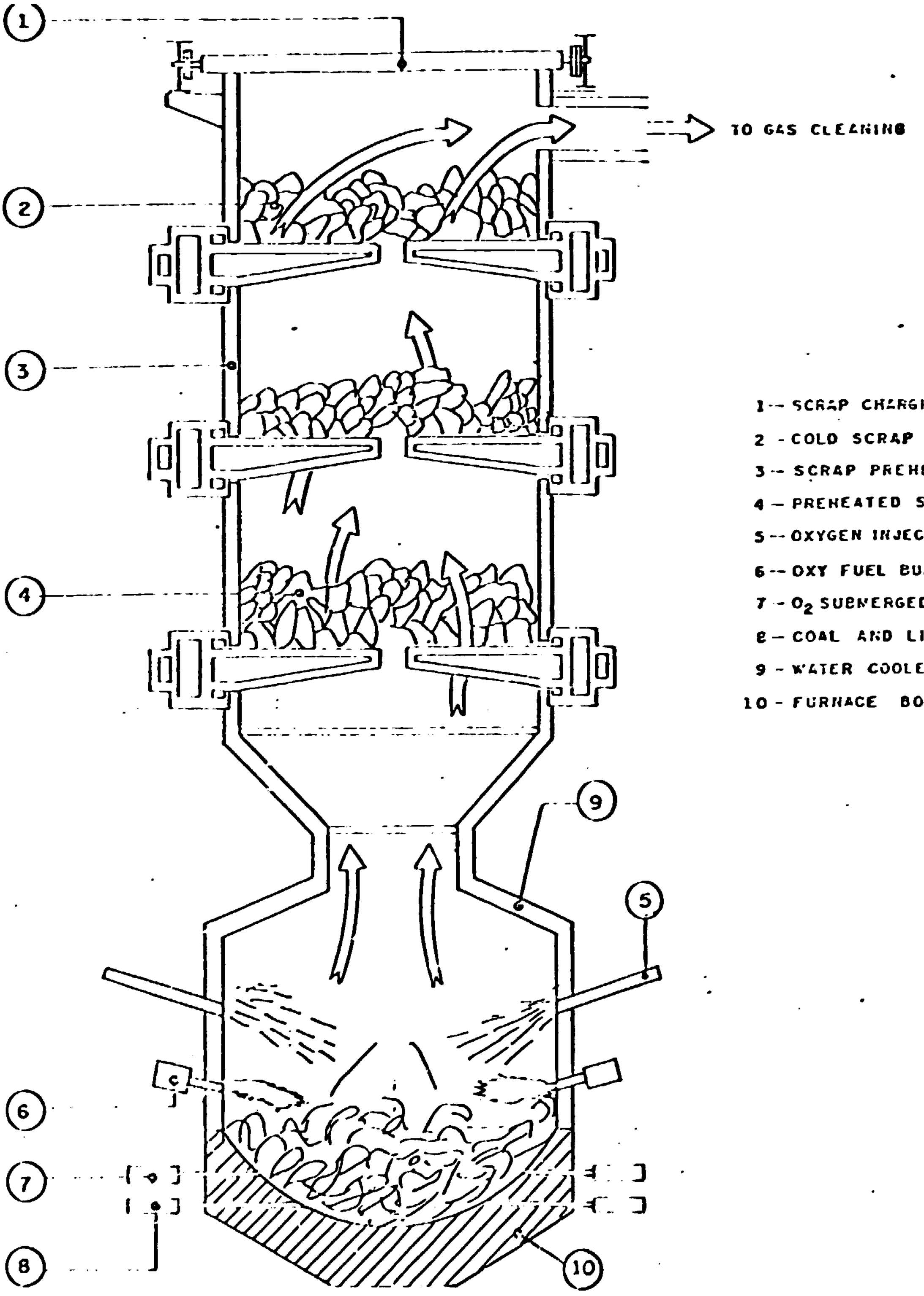
PREPARED BY S.W.G. Scherer | ISSUE DATE Jan 26th, 1988 | SHEET OF

KTS

TITLE
COMPARATIVE EVALUATION OF NEWLY DEVELOP TECHNOLOGIES FOR APPLICATION IN MINI STEEL PLANTS

FIGURE 16

EOF (ENERGY OPTIMIZING FURNACE) SCHEMATIC



1 -- SCRAP CHARGING COVER
2 - COLD SCRAP
3 -- SCRAP PREHEATER
4 — PREHEATED SCRAP
5 -- OXYGEN INJECTION
6 -- OXY FUEL BURNERS
7 - O_2 SUBMERGED TUYERES
8 — COAL AND LIME INJECTION
9 - WATER COOLED ELEMENTS
10 - FURNACE BOTTOM

TABLE 1

LIST OF THE BRAZILIAN BLAST FURNACES
COKE BASED

COMPANY	BLAST FURNACE	PIG IRON T/DAY	PIG IRON T/YEAR	TOTAL VOLUME M^3
C S N	AF1	2.600	841.000	1.350
	AF2	3.034	885.000	1.556
	AF3	7.349	2.493.000	3.815
AÇOMINAS		5.300	1.930.000	2.761
C S T		9.680	3.258.000	4.415
USIMINAS	AF1	1.800	650.000	885
	AF2	1.750	640.000	885
	AF3	5.800	2.118.000	2.700
COSIPA	AF1	3.400	1.224.000	1.830
	AF2	6.100	2.196.000	3.180

TABLE 2
BRAZILIAN PRODUCTION OF PIG IRON BY COMPANY

UNIT: T

PRODUCTS	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
COKE PIG IRON	5.537.281	6.198.938	7.281.880	7.743.887	6.425.515	6.702.699	8.091.011	10.744.429	12.131.550	12.618.396
AÇOMINAS	-	-	-	-	-	-	-	-	-	708.017
C S N	1.590.201	1.835.481	1.958.419	2.155.852	2.185.232	2.244.662	2.705.690	2.433.073	3.355.330	3.558.709
COSIPA	1.481.867	1.904.802	2.398.718	2.631.901	2.174.666	1.745.405	2.775.519	2.741.585	2.580.003	2.149.349
C S T	-	-	-	-	-	-	135.300	2.615.503	3.146.141	3.339.712
USIMINAS	2.465.193	2.458.655	2.924.743	2.956.134	2.065.617	2.712.632	2.474.502	2.954.268	3.050.076	2.862.609
CHARCOAL PIG IRON	3.843.091	3.844.109	4.431.534	4.941.396	4.370.015	4.124.643	4.853.510	6.479.979	6.839.896	7.550.533
CIMETAL	65.861	67.525	78.805	119.556	88.779	58.971	153.558	167.703	193.972	200.585
ACESITA	210.968	201.081	269.454	449.580	417.606	396.788	494.063	599.322	562.252	591.648
CIA.FERRO BRASILEIRO	99.650	104.864	89.282	105.784	98.901	96.117	42.743	94.248	55.773	66.496
CIA. BARBARÁ	101.969	99.247	111.429	124.926	125.005	101.979	53.976	81.387	94.845	109.723
CIA. BELGO MINEIRA	588.588	600.739	571.460	660.239	715.199	814.272	781.588	832.809	867.346	831.428
COSIM	60.867	8.635	33.026	51.610	28.238	42.700	8.755	78.325	67.646	18.072
CIA. SID. PAINS	133.294	144.419	146.954	172.144	142.337	160.122	164.172	209.408	222.785	251.196
LAFERSA	31.766	39.536	33.754	45.567	41.862	40.221	35.329	44.414	40.458	48.603
MANNESMANN S.A.	382.277	397.918	440.949	423.083	411.312	359.335	347.639	539.668	561.021	685.502
MATALPEN	-	-	30.418	38.455	36.991	558	-	-	-	-
SID. BARRA MANSA S.A.	142.951	144.367	154.704	157.854	151.482	155.788	156.929	167.596	147.218	153.062
SID. ALIPERTI S.A.	161.084	128.464	144.407	145.577	122.812	150.730	148.033	190.532	186.324	172.735
INDEPENDENT PRODUCERS	1.863.716	1.907.314	2.326.891	2.447.021	1.989.491	1.747.062	2.466.725	3.474.567	3.840.256	4.421.483
TOTAL	9.380.372	10.043.047	11.713.414	12.685.283	10.795.530	10.827.342	12.944.521	17.224.408	18.971.446	20.168.9[illegible]

SOURCE: CONSIDER BRAZILIAN METALLURGICAL INDUSTRIAL COUNSIL - STATISTICAL YEARBOOK - 1987

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S.S. AGREEMENT
nr. CLT 87/047 July 29th, 1987

S.W.G. Scherer

Jan 26th, 1988

SHEET OF

COMPARATIVE EVALUATION OF NEWLY DEVELOP TECHNOLOGIES FOR APPLICATION IN MINI STEEL PLANTS

TABLE 3

BRAZILIAN PRODUCTION OF PIG IRON BY PROCESS

UNIT: T

PROCESS	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
BLAST FURNACE	9.191.499	9.863.260	11.415.801	12.455.567	10.571.761	10.620.427	12.702.215	16.942.821	18.677.984	20.023.819
COKE	5.537.281	6.198.938	7.281.880	7.743.887	6.425.515	6.702.699	8.091.011	10.744.470	12.131.543	12.618.035
CHARCOAL	3.654.218	3.664.322	4.133.921	4.711.680	4.146.246	3.917.728	4.611.204	6.198.351	6.546.441	7.405.784
ELECTRIC REDUCTION FURNACE	188.873	179.787	178.087	229.752	219.452	206.865	242.559	286.914	282.651	243.837
TOTAL	9.380.372	10.043.047	11.593.888	12.685.319	10.791.213	10.827.292	12.944.774	17.229.735	18.960.635	20.267.656
PARTICIPATION OF EACH PROCESS										
BLAST FURNACE	98.0	98.2	98.5	98.2	98.0	98.1	98.1	98.3	98.5	98.8
COKE	59.0	61.7	62.8	61.1	59.5	61.9	62.5	62.3	64.0	62.3
CHARCOAL	39.0	36.5	35.7	37.1	38.5	36.2	35.6	36.0	34.5	36.5
ELECTRIC REDUCTION FURNACE	2.0	1.8	1.5	1.8	2.0	1.9	1.9	1.7	1.5	1.2

SOURCE: IBS: BRAZILIAN STEEL INDUSTRY INSTITUTE - STATISTICAL YEARBOOK - 1981/1987

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Nr. CLT 87/047 July 29th, 1987
S.W.G. Scherer
Jan 26th, 1988
SHEET
OF
COMPARATIVE EVALUATION OF NEWLY DEVELOP TECHNOLOGIES FOR
APPLICATION IN MINI STEEL PLANTS

TABLE 4

THE AMOUNT OF PIG IRON PRODUCED - EACH YEAR - FOR EACH HA (10.000 m^2) OF PLANTED TREES

T PIG IRON/HA-YEAR

Blast Furnace / Wood Yield		Standard			Optimized			
		100 % NPO	100 % Sinter	35 % NPO 65 % Pellets	100 % NPO	Coal Injection 100 % NPO	35 % NPO 65 % Pellets	Coal Injection 35 % NPO 65 % Pellets
9.440 Kg dry wood/Ha-year	A	3.45	3.90	3.90	3.70	4.30	4.05	4.70
	B	4.00	4.60	4.60	4.30	5.00	4.50	5.50
	C	4.60	5.25	5.25	4.90	5.75	5.40	6.30
14.400 kg dry wood/Ha-year	A	5.28	6.00	6.00	5.60	6.56	6.20	7.20
	B	6.17	7.00	7.00	6.55	7.64	7.20	8.40
	C	7.04	8.00	8.00	7.48	8.72	8.25	9.60
20.000 kg dry wood/Ha-year	A	7.34	8.32	8.32	7.80	9.10	8.60	10.00
	B	8.53	9.68	9.68	9.10	10.60	10.00	11.60
	C	9.74	10.15	10.15	10.40	12.15	11.45	13.40

9.440 KG DRY WOOD/HA-YEAR: ACTUAL AVERAGE PRODUCTION MEANS 23.6 STERES/HA-YEAR (STERES = M^3 OF WOOD)
14.400 KG DRY WOOD/HA-YEAR: ACTUAL SUPERIOR AVERAGE PRODUCTION MEANS 36.0 STERES/HA-YEAR
20.000 KG DRY WOOD/HA-YEAR: FUTURE AVERAGE PRODUCTION MEANS 50.00 STERES/HA-YEAR

A - 0.30 T CHARCOAL/T DRY WOOD OR 3.33 T DRY WOOD/T CHARCOAL
B - 0.35 T CHARCOAL/T DRY WOOD OR 2.86 T DRY WOOD/T CHARCOAL
C - 0.40 T CHARCOAL/T DRY WOOD OR 2.50 T DRY WOOD/T CHARCOAL

OPTIMIZED BLAST FURNACE MEANS STANDARD BLAST FURNACE WITH RAW MATERIALS DRYING, AIR BLAST DRYING, AIR BLAST HEATING TO 1000 °C.

nr. CLT 87/047 July 29th, 1987
S.W.G. Scherer
Jan 26th, 1988
SHEET OF
COMPARATIVE EVALUATION OF NEWLY DEVELOP TECHNOLOGIES FOR APPLICATION IN MINI STEEL PLANTS

TABLE 5

BRAZILIAN PRODUCTION OF SPONGE IRON(DRI)
PERIOD 1977 / 1986

UNIT: T

YEAR	AÇOS FINOS PIRATINI SL/RN PROCESS	COSIGUA PUROFER PROCESS	USIBA HYL 1 PROCESS	TOTAL
1977	18.904	137.629	201.526	358.059
1978	27.571	64.224	196.571	288.366
1979	38.440	94.376	191.301	324.117
1980	50.615	-	224.178	274.793
1981	31.371	-	194.668	226.039
1982	39.359	-	187.127	226.486
1983	35.022	-	219.579	254.601
1984	51.347	-	193.104	244.541
1985	45.077	-	240.070	285.147
1986	51.622	-	243.655	295.277

SOURCE: CONSIDER STATISTICAL YEARBOOK 1987.

TABLE 6

1986 DRI CAPACITY AND PRODUCTION*

COUNTRY	CAPACITY (Mt/y)	PRODUCTION (Mt)
Argentina	0.93	0.95
Brazil	0.32	0.30
Burma	0.04	0.03**
Canada	1.00	0.69
Egypt	0.72	0.03
India	0.30	0.17
Indonesia	2.30	1.30
Iran	0.73	0.00
Iraq	0.49	0.00
Malaysia	1.32	0.58**
Mexico	2.03	1.37
New Zealand	0.87	0.26
Nigeria	1.02	0.11
Peru	0.10	0.06
Qatar	0.40	0.49
Saudi Arabia	0.80	1.17
South Africa	1.11	0.79
Sweden	0.07	0.00
Trinidad	0.84	0.38
U.K.	0.80	0.00
U.S.A.	0.40	0.16
U.S.S.R.	1.25	0.75
Venezuela	4.50	2.92
W. Germany	1.28	0.17
TOTAL	23.62	12.68

*Steelmaking grade DRI ** Estimated

SOURCE: DIRECT FROM MIDREX
1ST QUARTER 1987 VOL. 12 NR. 1

TABLE 7

Direct Reduction Plants Producing Steelmaking-Grade DRI

(Installed or Under Construction as of June 1, 1987)

Start Up Year	Plant	City	Country	Process	No. Of Units	Type Of Fuel	Capacity (MTPY)	Status
1957	Hylsa 1M	Monterrey	Mexico	HyL I	1	Gas	0.10	Idle
1960	Hylsa 2M	Monterrey	Mexico	HyL I	1	Gas	0.27	Converted
1967	Tamsa	Veracruz	Mexico	HyL I	1	Gas	0.24	Operating
1969	OSM	Portland	USA	Midrex	2	Gas	0.30	Dismantled
1969	Hylsa 1P	Puebla	Mexico	HyL I	1	Gas	0.31	Closed
1970	Thyssen	Oberhausen	W Germany	Purofer	1	Gas	0.15	Dismantled
1970	NZS 1	Glenbrook	New Zealand	SL/RN	1	Coal	0.17	Operating
1971	NHSW	Hamburg	W Germany	Midrex	1	Gas	0.40	Operating
1971	GSC	Georgetown	USA	Midrex	1	Gas	0.40	Operating
1972	Armco	Houston	USA	Armco	1	Gas	0.33	Closed
1973	NML	Niagara Falls	Canada	Accar	1	Gas/Coal	0.04	Closed
1973	K-M	Buttrio	Italy	K-M	1	Coal	0.01	Closed
1973	Sidbec 1	Contrecoeur	Canada	Midrex	1	Gas	0.40	On Standby
1973	Piratini	Charqueadas	Brazil	SL/RN	1	Coal	0.07	Operating
1973	Dunswart	Benoni	S Africa	Codir	1	Coal	0.15	Operating
1974	Hylsa 3M	Monterrey	Mexico	HyL I	1	Gas	0.48	Converted
1974	Usiba	Bahia	Brazil	HyL I	1	Gas	0.25	Operating
1975	Stelco	Red Lake	Canada	SL/RN	1	Coal	0.35	Closed
1976	Arvedi	Cremona	Italy	K-M	1	Coal	0.04	Dismantled
1976	SMC	Falconbridge	Canada	Accar	1	Gas/Oil	0.24	Dismantled
1976	SIDERCA	Campana	Argentina	Midrex	1	Gas	0.33	Operating
1976	SIDOR I	Matanzas	Venezuela	HyL I	1	Gas	0.36	Operating
1976	Fior	Matanzas	Venezuela	Fior	1	Gas	0.40	Operating
1977	Cosigua	Santa Cruz	Brazil	Purofer	1	Oil	0.35	Dismantled
1977	NSC	Hirohata	Japan	NSC	1	Kerosene	0.15	Closed
1977	SIDOR	Matanzas	Venezuela	Midrex	1	Gas	0.35	Operating
1977	Sidbec 2	Contrecoeur	Canada	Midrex	1	Gas	0.60	Operating
1977	Hylsa 2P	Puebla	Mexico	HyL I	1	Gas	0.63	Operating
1977	NISCO	Ahwaz	Iran	Purofer	1	Gas	0.33	Idle
1978	DRC	Rockwood	USA	DRC	1	Coal	0.06	Closed
1978	ACINDAR	Villa Const	Argentina	Midrex	1	Gas	0.60	Operating
1978	QASCO	Umm Said	Qatar	Midrex	1	Gas	0.40	Operating
1978	Krakatau	Kota Baja	Indonesia	HyL I	1	Gas	0.58	Operating
1979	SIDOR	Matanzas	Venezuela	Midrex	3	Gas	1.28	Operating
1979	BSC	Hunterston	UK	Midrex	2	Gas	0.80	Idle
1979	Sordac	Khor Al Zubair	Iraq	HyL I	2	Gas	0.49	Idle
1979	Hylsa 2M5	Monterrey	Mexico	HyL III	1	Gas	0.25	Operating
1980	ISCOTT	Point Lisas	Trinidad	Midrex	1	Gas	0.42	Operating
1980	Krakatau	Kota Baja	Indonesia	HyL I	1	Gas	0.57	Operating
1980	SIDOR II	Matanzas	Venezuela	HyL I	2	Gas	1.41	Operating
1980	Siderperu	Chimbote	Peru	SL/RN	3	Coal	0.10	Operating
1980	SIIL	Paloncha	India	SL/RN	1	Coal	0.03	Operating

CONTINUATION OF TABLE 7

Direct Reduction Plants Producing Steelmaking-Grade DRI

(installed or Under Construction as of June 1, 1987)

Start Up Year	Plant	City	Country	Process	No. Of Units	Type Of Fuel	Capacity (MTPY)	Status
1981	SKF	Hofors	Sweden	Plasmared	1	Gas	0.07	Closed
1981	Nordferro	Emden	W Germany	Midrex	2	Gas	0.68	Idle
1981	S.DOR II	Matanzas	Venezuela	HyL I	1	Gas	0.70	Operating
1981	Mining Corp	Maymo	Burma	K-M	1	Coal	0.02	Operating
1982	Hadeed	Al-Jubail	Saudi Arabia	Midrex	1	Gas	0.40	Operating
1982	ISCOTT	Point Lisas	Trinidad	Midrex	1	Gas	0.42	Operating
1982	DSC	Warri	Nigeria	Midrex	2	Gas	1.02	Operating
1982	Krakatau	Kota Baja	Indonesia	HyL I	2	Gas	1.15	Operating
1983	Hadeed	Al-Jubail	Saudi Arabia	Midrex	1	Gas	0.40	Operating
1983	OEMK	Kursk	USSR	Midrex	1	Gas	0.42	Operating
1983	HYLSA 3M5	Monterrey	Mexico	HyL III	1	Gas	0.50	Operating
1983	OSIL	Keonjhar	India	Accar	1	Coal	0.15	Operating
1983	Scaw Metals	Germiston	S Africa	DRC	1	Coal	0.08	Operating
1984	SGI	Labuan	Malaysia	Midrex	1	Gas	0.72	Operating
1984	ISCOR	Vanderbijlpark	S Africa	SL/RN	4	Coal	0.60	Operating
1984	SIIL	Paloncha	India	SL/RN	1	Coal	0.03	Operating
1984	Mining Corp	Maymo	Burma	K-M	1	Coal	0.02	Operating
1985	OEMK	Kursk	USSR	Midrex	1	Gas	0.41	Operating
1985	NISCO	Ahwaz	Iran	Midrex	1	Gas	0.40	Idle
1985	Perwaja	Chukai	Malaysia	NSC	1	Gas	0.60	Closed
1985	Davsteel	Vanderbijlpark	S Africa	DAV	1	Coal	0.03	Operating
1985	USCO	Vereenging	S Africa	USCO	1	Gas	0.25	Closed
1986	OEMK	Kursk	USSR	Midrex	1	Gas	0.42	Operating
1986	ANSDK	El Dikheila	Egypt	Midrex	1	Gas	0.72	Operating
1986	NZS 2	Glenbrook	New Zealand	SL/RN	4	Coal	0.70	Operating
1986	Ipitata	Joda	India	Tisco	1	Coal	0.09	Operating
1987	OEMK	Kursk	USSR	Midrex	1	Gas	0.41	Start 3QTR
1987	BSIL	Chandil	India	SL/RN	1	Coal	0.15	Under Cons
1988	Sunflag	Bhandara	India	Codir	1	Coal	0.15	Under Cons
1988	Sicartsa	Las Truchas	Mexico	HyL III	4	Gas	2.00	Delayed
1988	NISCO	Mobarakeh	Iran	Midrex	5	Gas	3.20	Under Cons
1988	I&S Complex	Misurata	Libya	Midrex	2	Gas	1.10	Delayed
1989	NISCO	Ahwaz	Iran	Midrex	2	Gas	0.80	Delayed
1989	NISCO	Ahwaz	Iran	HyL I	3	Gas	1.00	Delayed
1989	Soidac	Knor Al-Zubair	Iraq	HyL I	2	Gas	1.00	Delayed

SOURCE: DIRECT FROM MIDREX - 3RD QUARTER - VOL. 12 - NR. 4

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TABLE 8

ANALYSIS OF COALS USED IN LURGI DIRECT REDUCTION KILNS

COMPANY	COAL	% MOIST	% DRY F.C.	V.M.	ASH	S
AÇOS FINOS PIRATINI	CHARQUEADAS / BRAZIL	9	40	25	35	0,4
AÇOS FINOS PIRATINI (*)	LEÃO / BRAZIL	15	51	34	15	0,6
AÇOS FINOS PIRATINI (*)	BROWN COAL BRIQU./GERM.	17	45	51	4	0,3
STEEL COMP. OF CANADA	FORESTBURG/ALBERTA/CAN.	20	51	40	9	0,5
NIPPON KOKAN	GROSE VALLEY/AUSTRALIA	8	58	26	16	0,5
HIGHVELD S.AFRICA	GREENSIDE/S.AFRICA	3	54	31	15	0,6
WESTERN TI CORP. AUSTRALIA	COLLIE/AUSTRALIA	22	56	40	4	0,5
N.Z.STEEL LTD.	HUNTLY/NEW ZEALAND	16	49	42	9	0,3
SIDERPERU	COKE BREEZE/PERU	1	81	3	18	0,7
SPONGE IRON INDIA LTD.	SINGARENI/INDIA	8	44	31	25	0,3
ISCOR VANDERBIJLPARK	VAN DYKSDMFT/S.AFRICA	8	59	26	14	0,6

SOURCE: LURGI - W. SCHNABEL PAPER "FLEXIBILITY OF SL/RN COAL BASED DIRECT REDUCTION IN RESPECT OF RAW MATERIALS AND FUELS".

(*) INDUSTRIAL TEST.

TABLE 9

ANALYSES OF IRON ORE USED IN LURGI DIRECT REDUCTION KILNS

Company	Iron Ore	% Dry			
		Fe	SiO_2	CaO	Others
Aços Finos Piratini	Itabira Pellets / Brazil	67	2,4	1,6	
Aços Finos Piratini (*)	Urucum Lump Ore / Brazil	69,4	0,58	0,03	
Nippon Kokan	Waste Oxide Pellets	55	4,9	3,3	0,7 Zn
Nippon Kokan (*)	Sishen Lump Ore /S.Africa	66	2,5	0,2	
Steel Comp. of Canada	Griffith Pellets/Canada	67	3,4	0,6	
Hecla Mining Corp.	Leach Residue Pellets	47	19,0	2,0	1,5 Cu
Western TI Corp./Australia	Hmenite Conc./Australia	30	0,8	-	55 T_1O_2
					13,2 T_1O_2
Highveld South Africa	Titaniferous Magnetite Lump Ore	54	2,1	-	1,7 V_2O_5
Highveld South Africa (*)	Sishen Lump Ore/S.Africa	66	2,5	0,2	
NZ Steel Ltd.	Iron Sand Conc./N.Zealand	58	1,1	0,2	8 T_1O_2
Siderperu	Marcona Pellets/Peru	66	2,2	1,0	
Sponge Iron India Ltd.	Bayaram Lump Ore/India	63	4,5	0,1	
Iscor Vanderbijlpark	Sishen Lump Ore/S.Africa	66	2,5	0,2	

(*) Large Scale Test

TABLE 10

COALS USED IN THE COREX®. – PILOT PLANT UNTIL 1987 (21)

TYPE	Consumpt. (t)	Fixed carb. (dry) %	Volatiles (daf) %	MOISTURE %	S %	ASH %	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	CaO %	MgO %
ANTHRACITE I	5,000	86.1	9.2	7.5	0.8	5.1	43.5	24.3	17.0	7.6	2.1
ANTHRACITE II	1,400	90.9	5.9	5.0	0.7	3.4	45.4	32.6	9.3	2.8	1.2
AUSTRALIAN COAL	1,100	65.6	22.5	5.0	0.4	15.4	55.0	36.0	4.0	1.0	0.7
BELGIAN COAL	500	64.1	32.4	4.5	1.0	5.2	46.0	34.0	11.0	2.0	1.0
INDIAN COAL	1,500	45.1	41.6	7.9	0.8	22.8	50.0	28.2	10.6	8.1	1.0
US COAL I	1,200	57.4	38.2	5.9	1.0	7.1	34.2	22.1	17.2	8.8	4.4
US COAL II	1,000	51.7	39.0	8.0	[illegible]	15.3	55.3	30.9	8.3	0.9	0.9
US COAL III	2,700	75.9	16.4	3.5	0.6	9.2	56.0	30.0	6.1	1.2	0.9
SOUTH AFR. I	1,000	57.4	30.7	6.8	0.6	17.2	42.8	36.9	2.5	7.0	0.9
SOUTH AFR. II	550	55.8	32.2	7.4	1.3	17.7	40.6	26.8	7.9	10.7	1.0
SOUTH AFR. III	700	53.4	32.3	8.3	0.9	21.1	49.6	24.4	2.8	9.6	1.5
SOUTH AFR. IV	2,000	56.9	36.2	9.0	0.6	10.9	49.3	31.6	3.1	6.1	1.5
SOUTH AFR. V	1,900	58.3	31.2	7.5	0.6	15.3	37.9	30.2	4.9	11.8	2.1
BIT. COAL EASTERN EUR.	500	63.0	33.0	4.8	0.6	5.9	41.4	24.8	8.6	7.8	3.4
BIT. COAL, FRG	2,000	57.0	38.5	9.0	0.9	7.3	35.9	27.3	16.1	6.4	3.7
LIGNITE COKE GOR	3,200	82.5	2.0	7.5	1.3	15.5	27.4	5.1	21.5	17.5	6.5
LIGNITE BRI-QUETTES, GOR	600	42.9	53.8	13.0	2.0	7.1	36.6	4.2	19.9	14.5	5.1
BRASILIAN COAL	1,500	52.6	36.6	18.0	1.5	17.0	54.0	23.5	8.3	1.5	0.3
BRASILIAN COAL	500	47.0	40.3	19.2	0.7	21.2	59.0	21.5	4.2	2.9	0.4

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SHEET OF

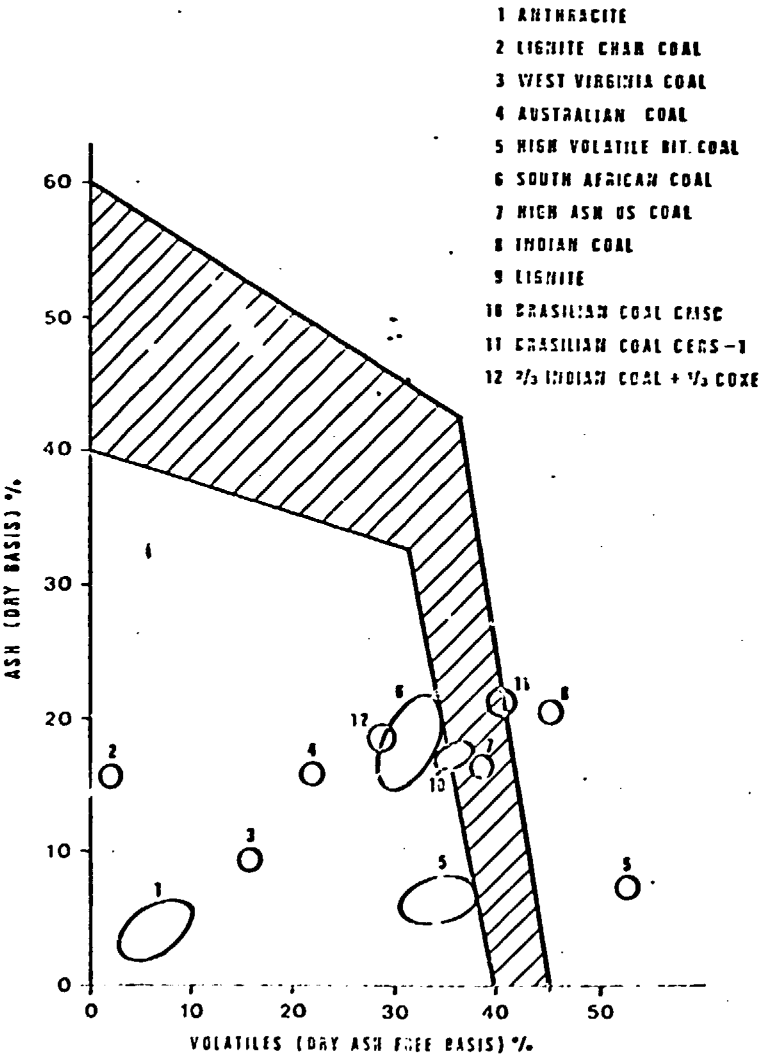
TITLE
COMPARATIVE EVALUATION OF NEWLY DEVELOP TECHNOLOGIES FOR APPLICATION IN MINI STEEL PLANTS

TABLE 11

IRON ORE USED IN THE COREX® – PILOT PLANT UNTIL 1987 (21)

TYPE	Fe %	SiO_2 %	Al_2O_3 %	CaO %	MgO %	P %	S %	Mn %
CVRD PELLETS	65.1	4.70	0.60	1.00	0.66	0.009	0.040	0.02
ITABIRA PELLETS	65.5	2.22	0.52	2.33	0.30	0.024	0.009	0.05
MINNTAC PELLETS	65.3	5.68	0.23	0.35	0.32	0.005	0.040	0.14
MPRC PELLETS	67.1	1.20	0.40	1.10	0.80	0.015	0.008	0.04
SAMARCO PELLETS	65.2	3.00	1.09	2.16	0.20	0.028	0.008	0.03
MT. NEWMAN LUMP ORE	65.4	3.17	1.14	0.35	0.13	0.034	0.005	0.25
SISHEN LUMP ORE	66.3	3.26	1.20	0.09	0.06	0.030	0.019	0.05
CARAJAS LUMP ORE	66.9	0.60	1.31	0.02	0.13	0.010	0.005	0.28
AUSTRIAN LUMP ORE (Carbonate, CO_2: 26.8%)	29.6	5.77	1.23	10.56	4.76	0.029	0.054	1.91
SINTER (GDR)	50.0	11.12	2.10	12.04	2.80	0.140	0.048	0.51
SINTER (AUSTRIAN)	47.3	11.18	2.24	11.40	5.20	0.048	0.034	2.40

TABLE 12 (20)



Classification of coals
for COREX--the KR process

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rr. CLT 87/047 July 29th, 1987

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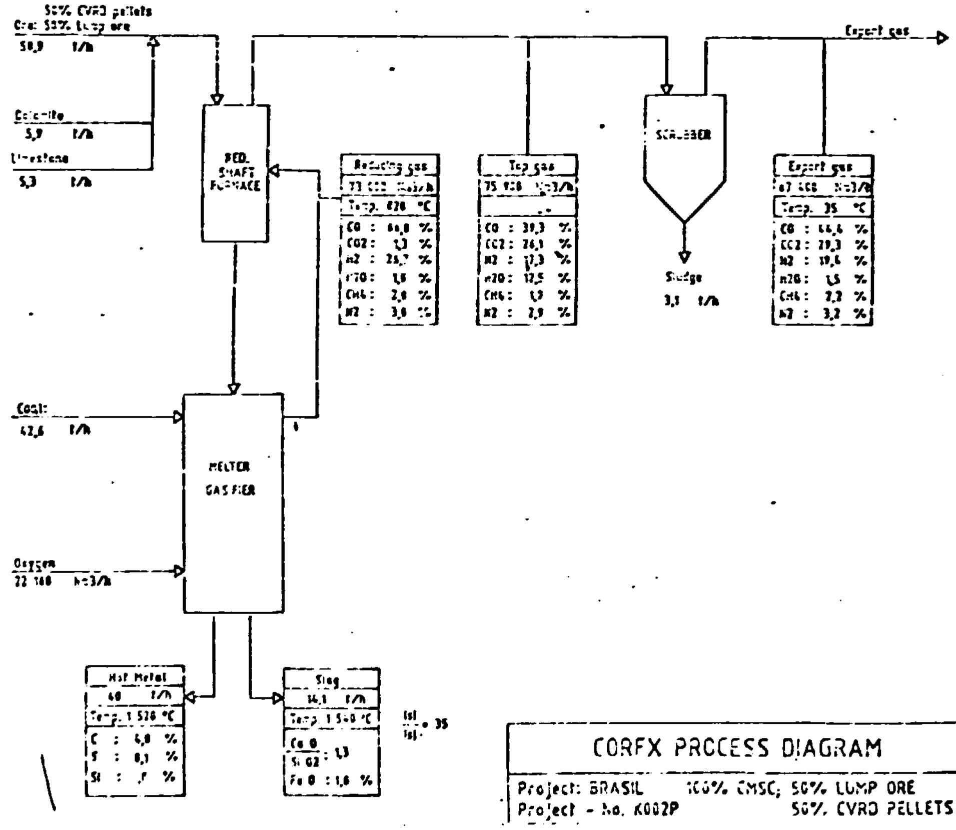
ISSUE DATE
Jan 26th, 1988

SHEET OF

TITLE
COMPARATIVE EVALUATION OF NEWLY DEVELOP TECHNOLOGIES FOR APPLICATION IN MINI STEEL PLATNS

TABLE 13



COREX PROCESS DIAGRAM

Project: BRASIL 100% CMSC; 50% LUMP ORE
Project - No. K002P 50% CVRD PELLETS

KE
JULY,07,1986

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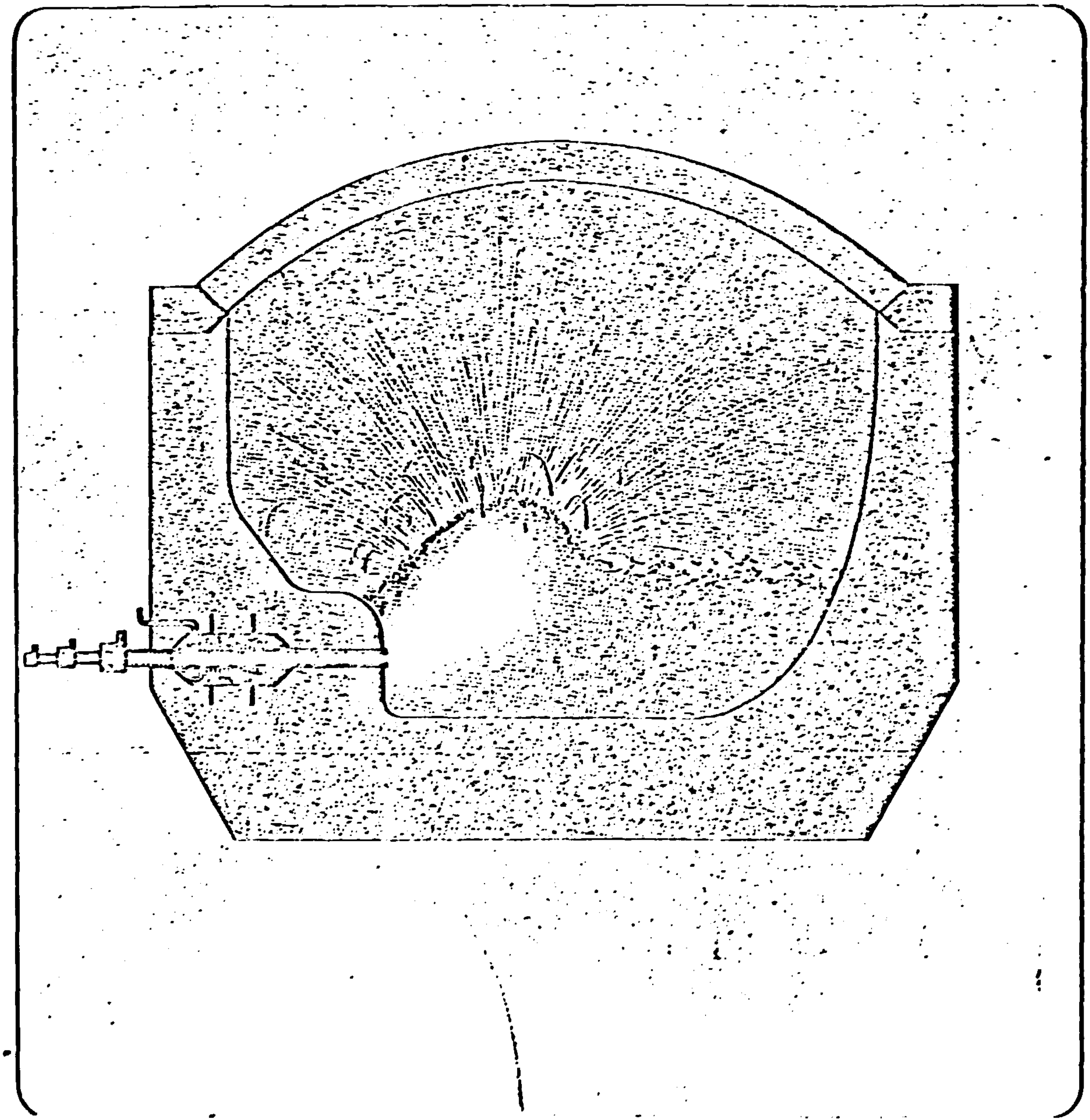
TITLE

COMPARATIVE EVALUATION OF NEWLY DEVELOP TECHNOLOGIES FOR APPLICATION IN MINI STEEL PLANTS

TABLE 14

KORTEC

SUBMERGED BLOWING PROCESS



K.O.R.F.

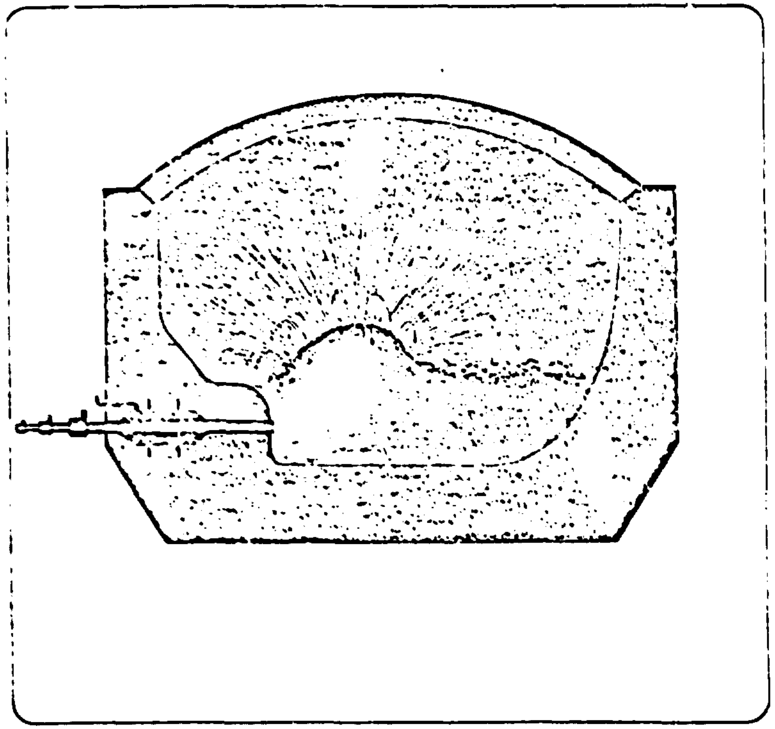
KORF OXY-REFINING FUEL SYSTEM FOR OPEN HEARTH FURNACES AND OTHER METALLURGICAL VESSELS

TABLE 14 A

SUBMERGED OXYGEN BLOWING FOR LOWER ENERGY CONSUMPTION AND HIGHER PRODUCTIVITY

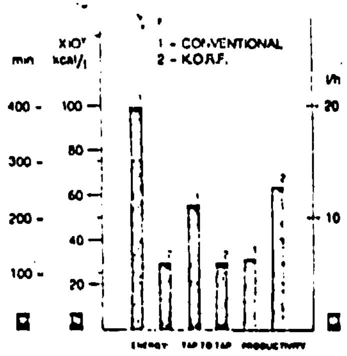
ADVANTAGES OF THE K.O.R.F. SYSTEM

- 50–75% decrease in energy consumption
- Up to 100% increase in productivity
- Up to 50% decrease in O_2 consumption as compared with lancing
- Increase in metallic yield
- Better temperature control
- Improved coordination with continuous casting



RESULTS ACHIEVED BY THE K.O.R.F. SYSTEM IN OPEN HEARTH FURNACES

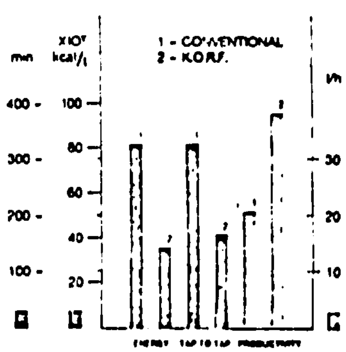
Furnace size (t)	30	60	100	250
Tap to tap time (min)	120	150	165	250
Energy consumption (kcal/t)	280,000	240,000	365,000	430,000
Total O_2 consumption (Nm^3/t)	30	35	35	35
Hot metal (%)	70	85	60	40



→ results – PAINS

28 t OH furnace

- over 35,000 heats
- approx. 1,000,000 t of steel made by the K.O.R.F. process



→ results – OKÜ

100 t OH furnace

- 3 100 t OH furnaces in operation with K.O.R.F. process

PAINS BRAZIL
The first installation
in the world

OKÜ HUNGARY
The first installation in Europe

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UNIDO S.S. AGREEMENT
nr. CLT 87/047 July 29th, 1987

S.W.G. Scherer

Jan 26th, 1988

COMPARATIVE EVALUATION OF NEWLY DEVELOP TECHNOLOGIES FOR APPLICATION IN MINI STEEL PLANTS

SHEET

OF

TABLE 15

LICENSOR: KORTEC AG

YOUR PARTNER FOR BETTER STEELMAKING

with many years experience
from its own steel and rolling mills.

Technical description of the K.O.R.F. system

The system uses a unique concept for introducing oxygen under the metal surface and thereby improving oxidation rates and energy transfer. The improvements arise from the stirring of the metal bath and the increased exposure of metal to slag and to the furnace atmosphere.

The installation of the necessary control system and piping can be done in 3 months without affecting normal furnace operation. The burners can be installed within 12 hours during a normal furnace repair. The furnace need not be modified.

The capital cost of the system is low and its components are usually available locally.

After undergoing basic training in the system under the guidance of IKOSA's experts, furnace operators are capable within a short period of making all the grades of steel included in their production program.

TABLE 16

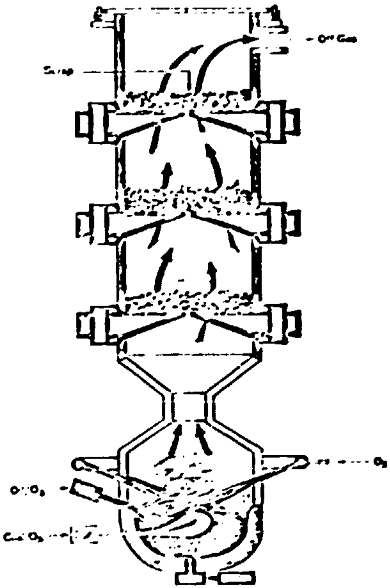
The Energy Optimizing Furnace – EOF – is the new way to make low cost, high quality steel. The EOF handles solid, liquid or mixed charges with equal ease and efficiency – – and it does not need expensive electric energy for melting.

Process Description

The EOF is a hearth furnace for the production of liquid steel with coal and oxygen from varying ratios of hot metal and scrap, combining the principles of oxygen blowing and scrap preheating.

The main process principle underlying the EOF is to introduce oxygen into the bath to react with carbon, creating CO gas which is subsequently burned to CO_2 above the bath within the furnace vessel. The heat generated by the oxygen reactions is efficiently used to melt scrap that has been previously preheated. The carbon required for the reaction is introduced into the bath either as a constituent of molten pig-iron or in the form of solid carbon which is injected into the bath and reacted with liquid steel to create an artificial pig-iron.

Sensible heat in the waste gases is utilized for stepwise preheating of the scrap in a refractory-lined scrap preheater consisting of several preheating sections located above the furnace roof.



Main Advantages of the EOF

- Submerged horizontal oxygen blowing trough special tuyeres;
- Use of a circular shaped, compact furnace in which heat losses are reduced;
- 95% afterburning of CO to CO_2 in the furnace, transferring energy to the steel bath by radiation;
- Scrap preheating with the EOF's hot off-gases up to 850 °C and quick charging of scrap;
- Extreme flexibility with regard to the metallic charge mix;
- Proven high plant availability; commercially proven technology
- Minimum amount of auxiliary equipment, no high power electricity distribution system, no furnace tilting resulting from a special tapping device;
- Utilization of water-cooled elements for walls and roof.

TABLE 17

History

The development started in April 1978 with the first installation for submerged blowing in open hearth furnaces.

May 1982 – Start-up of the EOF pilot plant at Companhia Siderúrgica Pains (CSP), Brazil.

January 1983 – Start-up of the first commercial EOF plant with 30 t tapping weight at CSP.

January 1984 – Introduction of water-cooled roof.

August 1984 – Introduction of removable bottom car for quick bottom change.

May 1986 – Start-up of multi layer counterflow scrap preheater.

July 1986 – First commercial demonstration with 50% scrap operation.

July 1987 – Start of "high-scrap" operation with coal injection.

First EOF Steel Plant at Companhia Siderurgica Pains

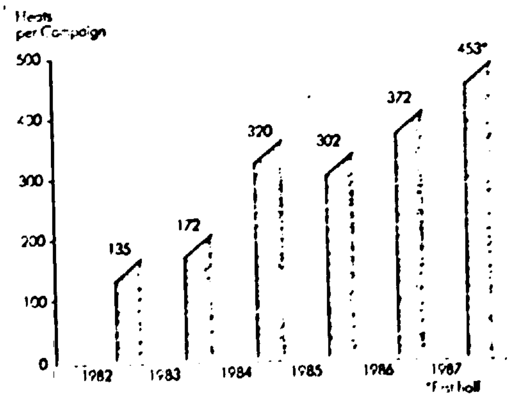
Plant Design Data

Fixed Furnace	
Heat Size	30 t/Heat
Capacity	200,000 t/year
Scrap Preheater	max. 30 t
Heats/Day	23
Quick Bottom Change	24 h

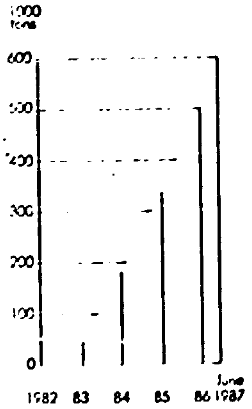
Typical Operating Results for the 30 t EOF

Hot Metal	550	-	900 kg/t
Cold Charge	580	-	230 kg/t
Tap-to-Tap Time	55	-	70 min.
Energy Consumption	200,000	-	50,000 Kcal/t
O_2 Consumption	60	-	75 Nm³/t
Refractory Consumption	5	-	10 kg/t
Campaign Length	400	-	550 heats

CSP: Average Number of Heats per Campaign



Cumulative Production 10³ tons



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UNIDO S.S. AGREEMENT
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Jan 26th, 1988

SHEET OF

TITLE
COMPARATIVE EVALUATION OF NEWLY DEVELOP TECHNOLOGIES FOR APPLICATION IN MINI STEEL PLANTS

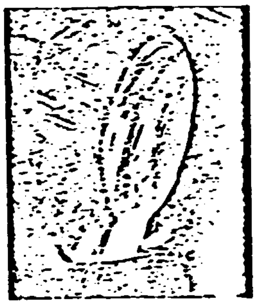
TABLE 18

Operating Facts & Figures

Operating Procedure of the EOF.
0 – 50% Scrap in Charge Mix.

The EOF taps all liquid steel contained in the vessel after each heat.

Preheated scrap is charged together with lime and some coke on the bottom, subsequently liquid pig-iron is introduced through a runner. No coal injection is required, only oxygen is introduced through submerged tuyeres.



Comparison of Production Data at CSP with different Charge Mixes

	I*		II		III**		IV***	
Charge material	kg/t	%	kg/t	%	kg/t	%	kg/t	%
Liquid pig-iron	675,0	59,5	575,7	50,5	326,0	30,0		
Solid pig iron	329,0	29,0						
Scrap	131,0	11,5	563,0	49,5	761,0	70,0	1087,0	100,0
	1135,0	100,0	1138,7	100,0	1037,0	100,0	1087,0	100,0
Fuel oil (kg/t)	6,0		13,8		13,2		12,0	
Coke breeze (kg/t)	1,0		14,5		66,5		140,0	
Oxygen (Nm³/t)	77,7		83,0		98,0		148,0	
Tap-to-tap time (min)	63,0		68,0		79,0		100,0	
Blowing time (min)	37,9		36,0		60,0		85,0	

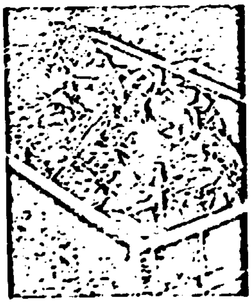
* Normal operating method at CSP ** Test Heats *** Calculated values

Scrap ratio over 50%
"Liquid heel practice"

A constant liquid heel equivalent to between 30 and 50 per cent of the heat weight is maintained in the furnace after tapping.
All required energy is introduced by coal injection through submerged tuyeres together with oxygen.
The preheated scrap is charged stepwise into the liquid heel.

Alternative Cupola – EOF

In certain cases it is economically attractive to operate a Cupola – EOF combination with 100% cold charge material. The Cupola pig iron represents 50% of the charge mix for the EOF in liquid form.



Furnace Sizes available:

Tapping Weight	30 t to 100 t
Annual Capacity	200,000 tpy to 650,000 tpy

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UNIDO S.S. AGREEMENT
nr. CLT 87/047 July 29th, 1988

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ISSUE DATE
Jan 26th, 1988

SHEET OF

TITLE
COMPARATIVE EVALUATION OF NEWLY DEVELOP TECHNOLOGIES FOR APPLICATION IN MINI STEEL PLANTS

TABLE 19

Steel Quality Aspects

The EOF is a fast melting unit for all steel qualities, tapping steel with a chemistry typical for combined blowing oxygen vessels.

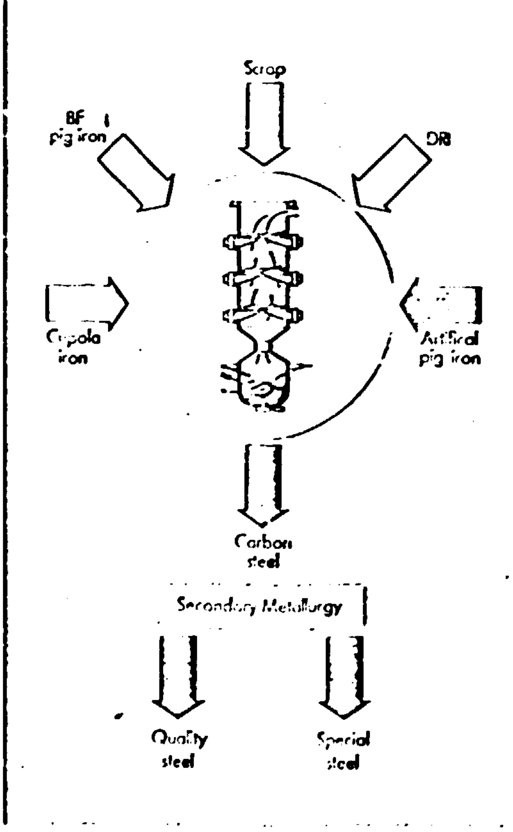
Metallurgical control of phosphorus and sulphur is excellent, desired carbon levels can be adjusted by submerged coal injection.

For high quality and special steel making secondary metallurgy, e.g. ladle refining, vacuum degassing etc. is required.

The following gas contents of EOF steel have been measured:

$O_2 < 300$ ppm at 0,1% C; $N_2 < 15$ ppm; H_2 5-7 ppm (without purging)

The EOF – an economical process for all routes of steelmaking



Benefits

■ for Integrated Steelmakers

The EOF can easily operate with 50% or more scrap, benefiting steelmakers with

- ☐ Reduced Operating Costs – by increasing the scrap-to-hot metal ratio
- ☐ Increased Production – by stretching the hot metal usage
- ☐ Low Investment Costs

■ for Minimill Steelmakers

An EOF meltshop can be operated with 100% scrap, resulting in

- ☐ Reduced Operating Costs – by eliminating use of expensive electricity and electrodes, and by preheating scrap to 850 °C
- ☐ Improved Environment – by lowering noise levels, reducing fugitive dust emissions and lowering off-gas quantities
- ☐ Low Investment Costs

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nr. CLT 87/047 July 29th, 1987

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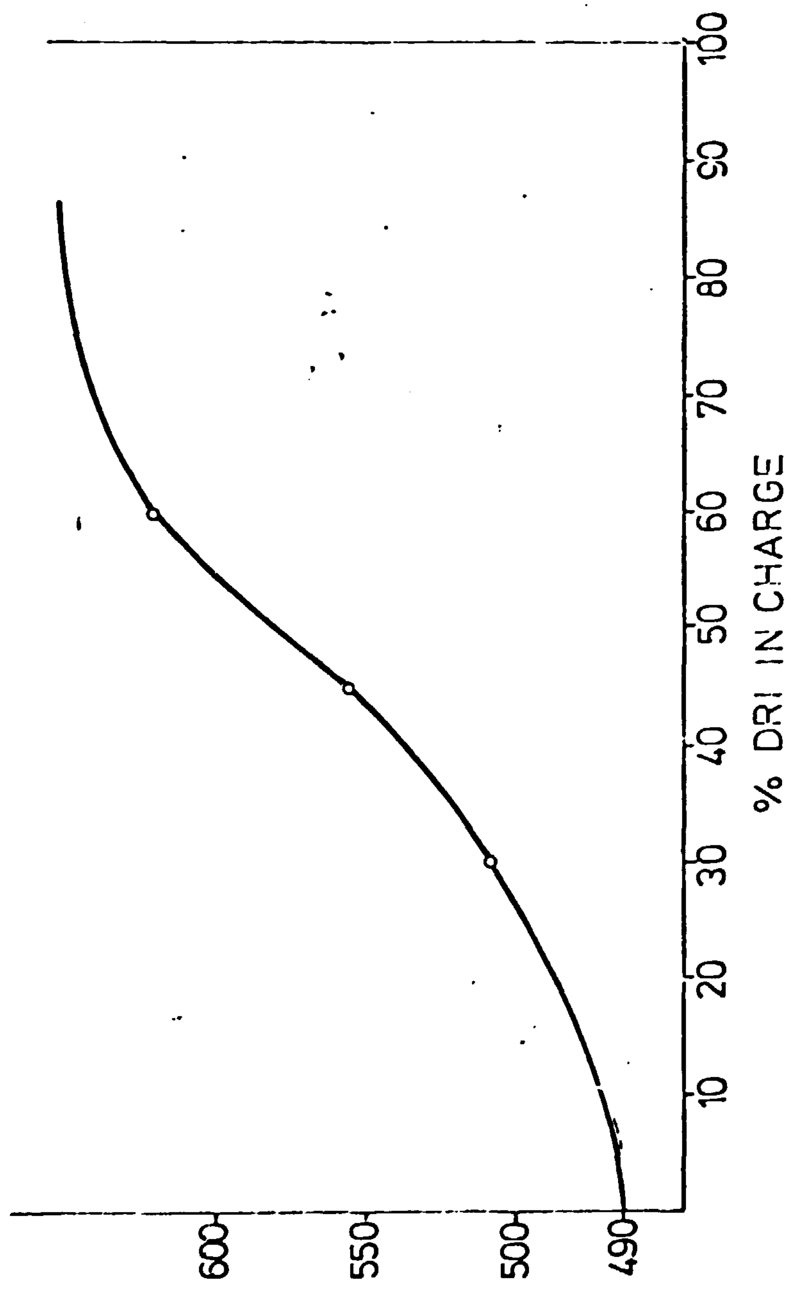
S.W.G. Scherer	Jan 26th, 1988		

TITLE
COMPARATIVE EVALUATION OF NEWLY DEVELOP TECHNOLOGIES FOR APPLICATION IN MINI STEEL PLANTS

TABLE 20



POWER CONSUMPTION WITH DRI CHARGING

KORF ENGINEERING GMBH

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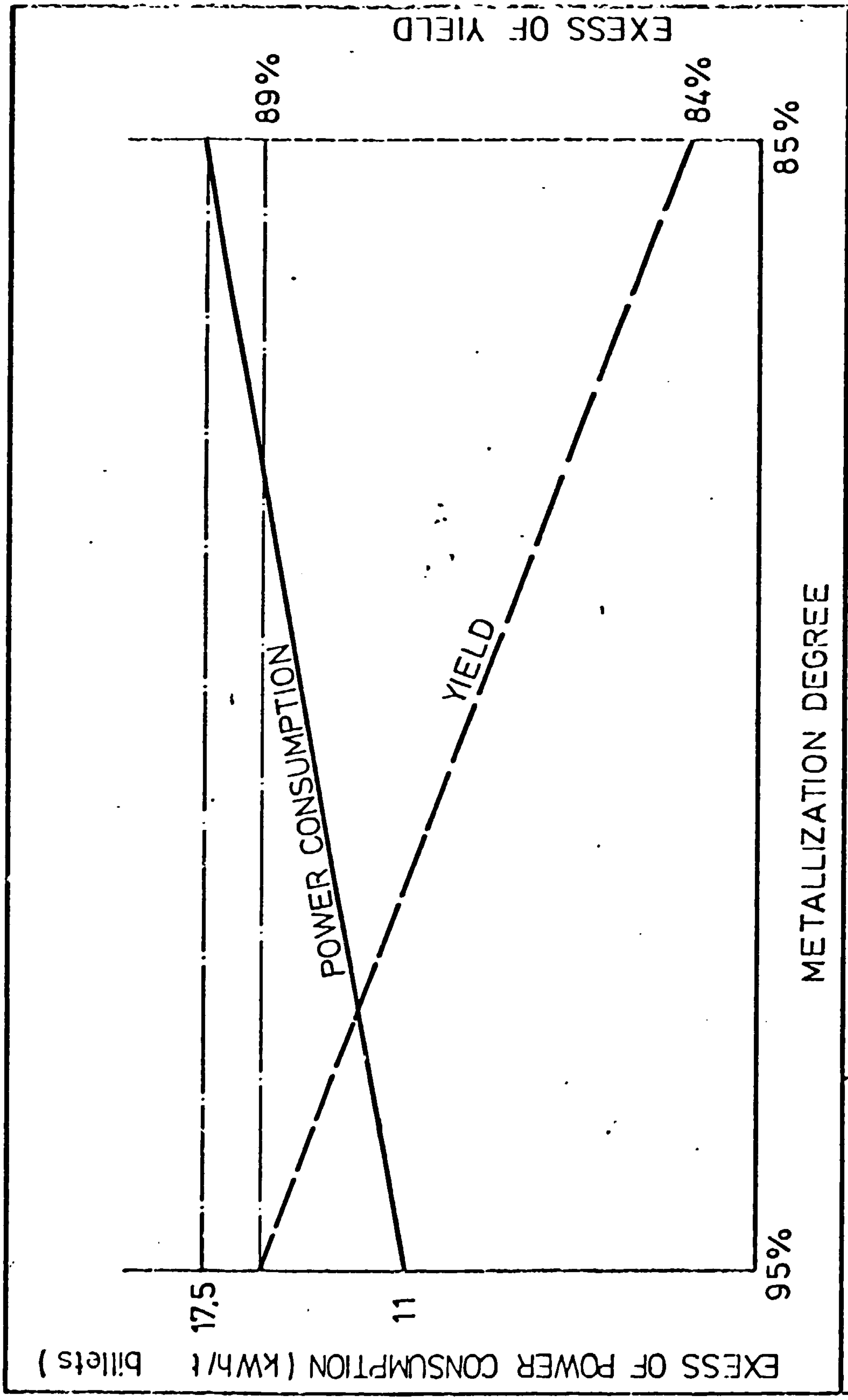
TABLE 21

INFLUENCE OF METALLIZATION



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nr. CLT 87/047 July 29th, 1987

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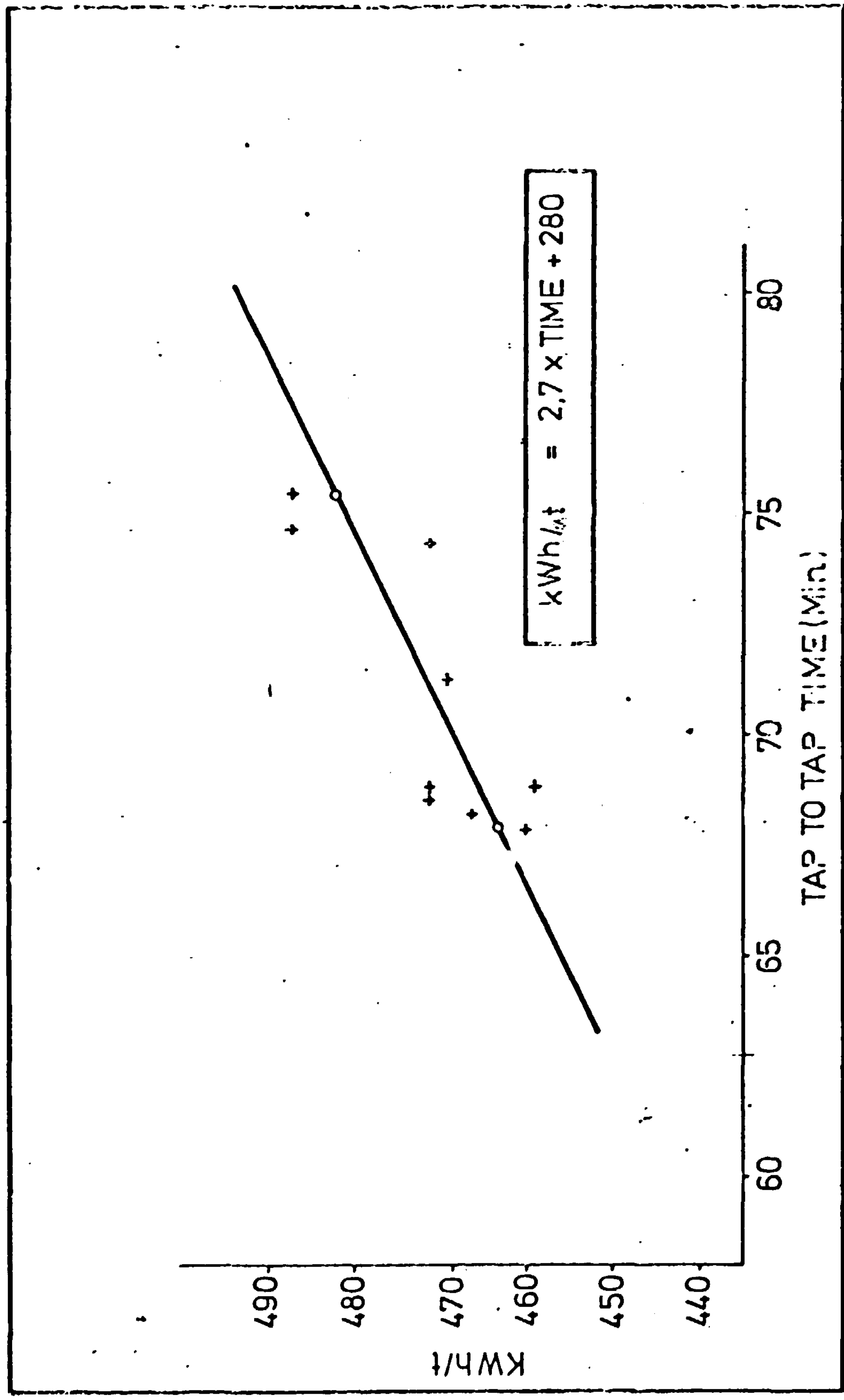
ISSUE DATE Jan 26th, 1988

SHEET OF

TITLE COMPARATIVE EVALUATION OF NEWLY DEVELOP TECHNOLOGIES FOR APPLICATION IN MINI STEEL PLANTS

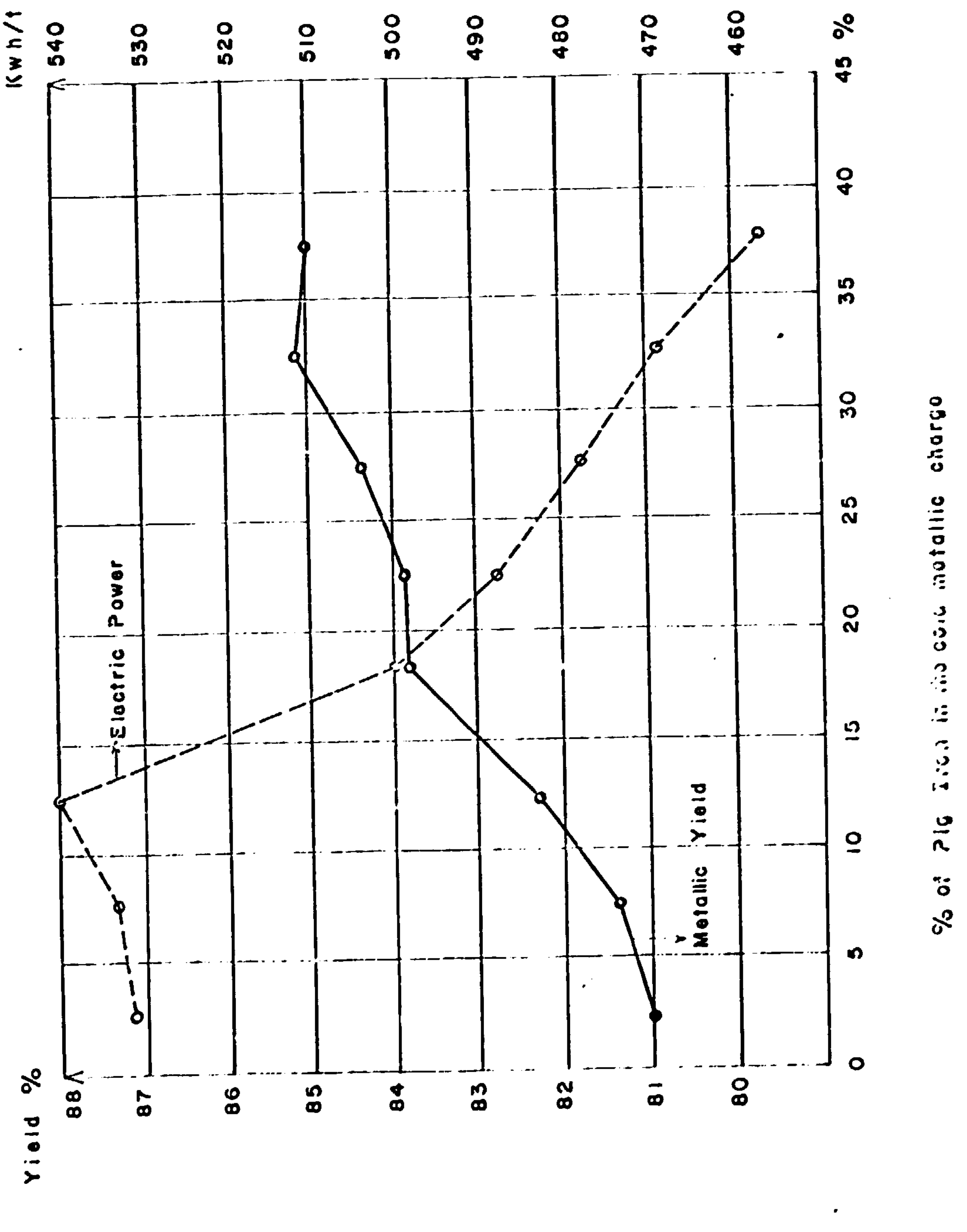
TABLE 22

INFLUENCE OF THE TAP TO TAP TIME ON POWER CONSUMPTION



KORF ENGINEERING GMBH

Table 23 - Pig iron in the Electric Arc Furnace
Metallic charge: Electric Energy Consumption
and Metallic yield (27)



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Nr. CLT 87/047 July 29th, 1987

S.W.G.Scherer | Jan 26th, 1988 | SHEET OF

COMPARATIVE EVALUATION OF NEWLY DEVELOPED TECHNOLOGIES FOR APPLICATION IN MINI STEEL PLANTS

Table 24 - C & F Steel Plant Prices for the Raw Materials and Main Supplies

INDUSTRIAL PLANT

Data =

Exchange Rate=

Domestic currency/U$
Domestic currency/DM
Domestic currency/Yen

- Price C & F for the Raw Materials and main Supplies:

Supplies	Unit U	Source	Price FOB U$/U	Transport System and Distances	Transport Price U $/U	Price C I F U $/U	Remarks

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Nr. CLT 87/047 July, 29th, 1987
S.W.G. Scherer
Jan, 26th, 1988
SHEET OF

COMPARATIVE EVALUATION OF NEWLY DEVELOPED TECHNOLOGIES FOR APPLICATION IN MINI STEEL PLANTS

TABLE 25 - ESTIMATED FEASIBILITY FOR THE INRONMAKING PLANT

Site Location :

Process :

Annual Capacity:

INVESTMENT

Fix (FI): US$ x 10^6 Fix per unit (UFI): US$ /t

Total (TI): US$ x 10^6 Total per unit (UTI): US$ /t

ITEM	Unit U	Consump. U/t	Price US$/U	Cost US$ / t	Per U x 10^3	Year US$ x 10^3
1. VARIABLE COSTS						
1.1 Ores	t					
1.2 Reductant	m^3					
1.3 Electric Energy	kWh					
1.5 Others (1.1 + 1.2 + 1.3)						
2. FIXED COSTS						
2.1 Maintenance&Met. 4 % U F I						
2.2 Labour 0,10 x Variable Cost						
2.3 Capital - 18 % UTI						
3. CREDITS Gas Coal Fines						
4. OPERATIONAL COSTS 1 + (2 - 2,3) - 3						
5. TOTAL COSTS (1 + 2 - 3)						
6. SALES						
7. $\frac{6 - 4}{UTI}$						

Remarks:

Date :
Exchange Rate:

Domestic Currency/US$
Domestic Currency/DM
Domestic Currency/Yen

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S.W.G.Scherer | Jan 26th, 1988 | SHEET OF

COMPARATIVE EVALUATION OF NEWLY DEVELOPED TECHNOLOGIES FOR APPLICATION IN MINI STEEL PLANTS

TABLE 26 - ESTIMATED FEASIBILITY FOR THE STEELMAKING PLANT

Site Location :

Process :

Annual Capacity :

INVESTMENT

Fix (FI): US$ x 10^6 Fix per unit (UFI): US$ /t

Total (TI): US$ x 10^6 Total per unit (UTI): US$ /t

ITEM	Unit U	Consump. U/t	Price US$/t	Cost US$ / t	Per U x 10^3	Year US$ x 10^3
1. VARIABLE COSTS						
1.1 Liquid Metal	t					
1.2 Solid Pig Iron	t					
1.3 Sponge Iron	-					
1.4 Scrap	t					
1.5 Ferro Alloys	t					
1.6 Electric Energy	kWh					
1.7 Oxygen	Nm^3					
1.8 Electrodes						
1.9 Others 5 % (1.1 +1.2+...1.8)						
2. FIXED COSTS						
2.1 Maintenance &Mat. 4 % UFI						
2.2 Labour 0,10 x Variable Cost						
2.3 Capital 18 % UTI						
3. CREDITS						
4. OPERATIONAL COSTS 1 + (2 - 2,3) - 3						
5. TOTAL COSTS (1 + 2 - 3)						
6. SALES						
7. $\frac{6 - 4}{UTI}$						

Remarks:

Date :

Exchange Rate:

Domestic Currency/US$

Domestic Currency/DM

Domestic Currency/Yen

Table 27 - C & F Steel Plant Prices for the Raw Materials and Main Supplies

INDUSTRIAL PLANT Mato Grosso do Sul State
(Southwest of Brazil)

- Price C & F for the Raw Materials and main Supplies :

Date = October 1987

Exchange Rate=

Domestic currency/U$	53,64
Domestic currency/DM	29,76
Domestic currency/Yen	0,3727

Supplies	Unit U	Source	Price FOB U$/U	Transport System and Distances	Transport Price U $/U	Price C I F U $/U	Remarks
Charcoal	m³	own production	10,00	Highway up to 100.km	1,00	11,00	
Iron ore	t	Corumbá	6,82	Railway - 500 km	6,70	13,52	minimum 65 % Fe
Manganese Ore	t	Corumbá	25,00	Railway - 500 km	6,70	31,70	
Limestone	t	--	6,82	Highway - 300 km	8,18	15,00	
Quartzite	t	--	6,50	Highway - 200 km	5,00	11,50	
Electric Energy	kWh	Distribution net work				0,035	

TABLE 28 - ESTIMATED FEASIBILITY FOR THE IRONMAKING PLANT

Site Location : Mato Grosso do Sul State (Southwest of Brazil)

Process : Charcoal Blast Furnace

Annual Capacity: 62.000 tpy

INVESTMENT

Fix (FI): US\$ 3,72 x 10^6 Fix per unit (UFI): US\$ 60,00/t
Total (TI): US\$ 4,95 x 10^6 Total per unit (UTI): US\$ 80,00/t

I T E M	Unit U	Consump. U/t	Price US\$/U	Cost US\$ / t	Per U x 10^3	Year US\$ x 10^3
1. VARIABLE COSTS				66,06		4.095,72
1.1 Ores	t	1,52	13,76	20,91	94,24	1.296,42
1.2 Reductant	m^3	3,50	11,00	38,50	217,00	2.387,00
1.3 Electric Energy	kWh	100	0,035	3,50	6.200,00	217,00
1.5 Others (1.1 + 1.2 + 1.3)				3,15		195,30
2. FIXED COSTS				23,41		1.451,42
2.1 Maintenance&Mat. 4 % U F I				2,40		148,80
2.2 Labour 0,10 x Variable Cost				6,61		409,82
2.3 Capital - 18 % UTI				14,40		892,80
3. CREDITS						
Gas	Gcal	0,90	3,60	3,24	55,80	200,88
Coal Fines	m^3	0,35	5,50	1,93	21,70	119,66
4. OPERATIONAL COSTS 1 + (2 - 2,3) - 3				69,90		4.333,80
5. TOTAL COSTS (1 + 2 - 3)				84,30		5.226,60
6. SALES				89,00		5.518,00
7. $\frac{6 - 4}{UTI}$				0,238		

Remarks:

Date : October 1987
Exchange Rate:

Domestic Currency/US\$	53,64
Domestic Currency/DM	29,76
Domestic Currency/Yen	0,3727

TABLE 29 – ESTIMATED FEASIBILITY FOR THE STEELMAKING PLANT

Site Location : Mato Grosso do Sul State (Southwest of Brazil)
Process : EOF + Continuous Casting
Annual Capacity : 100.000 tpy

INVESTMENT

Fix (FI): US\$ 9,00 x 10^6 Fix per unit (UFI): US\$ 90,00 /t
Total (TI): US\$ 11,70 x 10^6 Total per unit (UTI): US\$ 117,00 /t

ITEM	Unit U	Consump. U/t	Price US\$/t	Cost US\$ / t	Per U x 10^3	Year US\$ x 10^3
1. VARIABLE COSTS				124,17		12.417,00
1.1 Liquid Metal	t	0,56	89,00	49,84	56,00	4.984,00
1.2 Solid Pig Iron	t	0,54	89,00	48,06	54,00	4.806,00
1.3 Sponge Iron	–	–	–	–	–	–
1.4 Scrap	t	0,02	89,00	1,78	2,00	178,00
1.5 Ferro Alloys	t	0,021	400,00	8,50	2,10	850,00
1.6 Electric Energy	kWh	45,00	0,035	1,58	4.500,00	158,00
1.7 Oxygen	Nm^3	85,00	0,100	8,50	8.500,00	850,00
1.8 Electrodes		–	–	–	–	–
1.9 Others 5 % (1.1 +1.2+...1.8)				5,91		591,00
2. FIXED COSTS				37,08		3.708,00
2.1 Maintenance &Mat. 4 % UFI				3,60		360,00
2.2 Labour 0,10 x Variable Cost				12,42		1.242,00
2.3 Capital 18 % UTI				21,06		2.106,00
3. CREDITS				-		-
4. OPERATIONAL COSTS 1 + (2 – 2,3) – 3				140,19		14.019,00
5. TOTAL COSTS (1 + 2 – 3)				161,25		16.125,00
6. SALES				170,00		17.000,00
7. $\frac{6-4}{UTI}$				0,255		

Remarks:

Date : October 1987
Exchange Rate:

Domestic Currency/US\$ 53,64
Domestic Currency/DM 29,76
Domestic Currency/Yen 0,3727

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(2 of 2)

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COMPARATIVE EVALUATION OF NEWLY DEVELOPED TECHNOLOGIES FOR APPLICATION IN MINI STEEL PLANTS

ANNEXES

January 1988

Written by Eng. SERGIO W. G. SCHERER

10. LIST OF ANNEXES

ANNEX 1 - The Charcoal Blast Furnace in Brazil - H.C.Pfeifer - International Metallurgy - Brazilian Society for Metals - Vol. 1 Nr. 1 Oct 1987

ANNEX 2 - Operating Experience with Charcoal Blast Furnace and EOF Steelmaking in Brazil - H.C. Pfeifer and Orlando E. Simões - International Conference on Alternatives Routes to Iron and Steel under Indian Conditions - 8 - 10th Feb 1988 - Jamshedpur - India.

ANNEX 3 - Smelting Reduction Processes for Iron and Steelmaking - O. Nyquist - IISI Rio de Janeiro - October 1986.

ANNEX 4 - COREX - The Coal Based Smelting Reduction Process - G. Papst and J. Flickenschild - May 1987.

ANNEX 5 - The EOF Process: Performance and Outlock - R.Weber and H.C.Pfeifer - International Conference of Iron and Steel Industry - Brazilian Society for Metals - Sao Paulo, Brazil, November 1986.

ANNEX 6 - Preliminary Proposal for a Steel Plant Based on Scrap - Cupola Furnace - EOF.

ANNEX 7 - A Brief Summary of the Reducing Gas Generation Schemes (2 - Section 3).

ANNEX 8 - Rotary Kiln Process Description (2 - Section 4).

ANNEX 9 - Kinglor Metor Process Description (2 - Section 4) and Table 7.

ANNEX 10- MIDREX Process Description (2 - Section 3).

ANNEX 1

THE CHARCOAL BLAST FURNACE IN BRAZIL

The charcoal blast furnace in Brazil

Henrique Carlos Pfeifer

1. INTRODUCTION

The abundant, high grade iron ore deposits as well as the huge extention of its territory, widely covered by tropical and subtropical forests, are too well known characteristics of Brazil.

These features, combined with the growing demand for iron and steel and with entrepreneurial abilities of the population, led to the development of an important charcoal based iron production capacity. Total output 1985 was 6.8 million tons, 2.5 of which were exported.

Although this branch of the Brazilian iron and steel industry originated and developed in the Minas Gerais iron ore district, up to now responsible for 85% of total production, the recent development of the eastern Amazon region (Carajás) and of southwestern Brazil (Mato Grosso do Sul) offers all conditions for a new upsurge of charcoal pig iron production, which is likely to double the present output within the next six years.

The high grade iron produced in charcoal blast furnaces, combined with its lower operation cost and capital investment, in contrast with that of coke blast furnaces, has resulted in an increasing demand in Brazil and abroad for this raw material. This demand has come specifically from electric arc furnace plants, which have to cope with scarce, expensive and contaminated scrap. In these plants a technique has been developed for charging up to 30% charcoal pig iron with the metallic burden. As a result, there have been achieved remarkably good economic results in respect to energy, quality and costs.

On the export market, the new demand is explained by the need of high quality, non contaminated metallics, easy to handle and to store, both to complement the scrap supply as well as to substitute the hot metal of blast furnaces which have shut down.

Pig iron is an ideal product in this connection, pointing to an increasing potential market for Brazilian charcoal pig iron.

These features explain the growing importance given in Brazil not only to the charcoal blast furnaces but also to the related activities of reforestation and charcoal manufacture.

2. THE IMPORTANCE OF THE CHARCOAL BLAST FURNACE FOR BRAZILIAN ECONOMY

Table I summarizes the development of Brazilian iron production during the last few years. As may be seen, charcoal blast furnaces are responsible for about 38% of total iron production. Output of independent plants comes to the domestic market, where it covers the demand of foundries and, on a growing scale, arc furnace based non-integrated steel plants, or it is exported.

The growth of charcoal pig iron sales both on the domestic market and abroad seems to signalize a stable and long term tendency, supported by three main factors: the low cost of this product; its quality; and its energy content. This last factor is assuming growing importance, since the energy represented by the 4% C and 0.6 Si may be fully used adequately equipped electric arc furnaces, leading to corresponding savings of electric energy. Monetary expression of these savings is somewhere between US$ 10.00 and US$ 25.00 per ton of pig, depending on the price for electric energy, when adding between 20 and 30% pig to the EAF charge (1) (2).

Table I – Brazilian Iron Production 1.000 t

		Iron Production			Charcoal Pig Iron Sales	
			Charcoal Blast Furnace			
Year	Total	Coke Blast Furnace	Integrated Plants	Independent Producers	Domestic Market	Export
1986	8,170	4,141	1,895	2,133	544	775
1980	12,685	7,744	2,494	2,447	949	841
1984	17,230	10,744	3,002	3,484	952	2,484
1985	18,961	12,132	3,000	3,829	1,219	2,478

Source: IBS – Statistical Yearbook 1986.

Importance of charcoal pig iron for Brazilian economy, however, goes far beyond the substitution of scarce scrap and the growing exports. The related reforestation and charcoal production activities are an important source of jobs in the rural area, generating a safe and steady income for tens of thousands of families. The social and economic importance of these activities is underlined by the following figures, showing total labor employed (3):

in reforestation : 106,000
in charcoal manufacture: 210,000

These activities are spread over far more than 250,000 square kilometers retaining people on the country, in undisrupted social and family binding.

It is our opinion that one or the other developing country offers conditions which are sufficiently similar to those in Brazil, thus allowing for the installation of a charcoal-based iron and steel industry.

3. DIFFERENCES BETWEEN THE CHARCOAL AND THE COKE BLAST FURNACE

The charcoal blast furnace presents some basic differences as to the coke blast furnace, which arise from the character of charcoal when compared to normal coke (4) (5) (6):

Temperature:

Temperature in the reserve zone is about 150 °C lower (800 °C as against 950 °C) in the charcoal than in the coke

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Technical paper presented to the International Conference of Iron and Steel Technology in Developing Countries, November 1986, São Paulo/Brazil.

blast furnace.

Residence Time:

Residence time of the ore in the reserve zone in the charcoal furnace is about half that of the coke blast furnace.

Ore in Burden:

Since charcoal has a much lower apparent density (230kg/m^3) than that of coke (540kg/m^3), the volume taken by the ore in the charcoal blast furnace (15%) is about half that in the coke blast furnace (30%). This factor, together with the differences between charcoal and coke, account for the following particularities:

- The charcoal blast furnace demands a highly reducible ore or agglomerate.
- The charcoal blast furnace is less demanding in regard to the size and crepitation properties of the ore, since the gas flow is more affected by the reductant than by the ore.

Blast Temperature:

The blast temperature in charcoal blast furnace is limited to around 850 °C.

Higher temperatures lead to a richer top gas, with no further decrease in the "coal rate".

Slag:

Charcoal blast furnace iron is known to be of higher grade than that of coke blast furnace, because of its lower sulphur content. This is particularly true in Brazil, where low phosphorous iron ore produces an iron which is low in both sulphur and phosphorous. Furthermore, the low ash content (abt. 3%) reduces the charcoal blast furnace slag volume up to 120 kg/t, with low basicity (usually 0,9), allowing additional energy savings.

Refractory:

The lower blast temperature means a lower flame temperature and lower strain regarding the lining, which may be of cheaper quality (50% and, in very special cases, 70% Al_2O_3). As a further consequence, cooling is limited to shell cooling with no need of boxes and other cooling devices.

Top Gas Temperature:

Also the top gas temperature is lower in the case of the charcoal blast furnace: 90 °C to 120 °C, as against 150 to 200 °C for the conventional coke blast furnace.

Use of Sinter:

As shown by (4), the replacement of screened ore by sinter does not result in any charcoal savings unless the furnace is operating in the so called "critical" productivity range (27 to 33 t/m^2-day). Even in this range, the saving is small.

Size:

The charcoal blast furnace has an upper limit as to its size, mainly due to low mechanical resistance of the charcoal. There are only three such furnaces in the range of 800 to 1200 tpd, which is the top size. Another four or five furnaces have a capacity of 400 to 500 tpd, one of them being the new furnace started up in early 1986 with several improvements. All others, totalling over 100 furnaces, have a capacity between 60 and 200 tpd.

Blast Preheating:

The small size of the charcoal blast furnace and its lower blast temperature make it possible to eliminate the conventional stoves for blast preheating, substituting them by metallic heat exchangers called "glendons", which cost substancially less. The few already mentioned furnaces bigger than 400 tpd, however are outfitted with stoves, with the exception of the most modern one, already mentioned, which operates with glendons giving 850 °C in the blast.

Fans:

Because of the lower density of the charcoal, the permeability of the burden is better and consequently the pressure drop through the furnace is low (3 to 5 m of water column). Simple fans in series may therefore be used to provide the blast air, in lieu of heavy blowers.

Investment:

The small size and simplicity of the charcoal blast furnace, with its simple air blowing and heating devices, unexpensive instrumentation and gas washing, almost manual pig caster, simple raw material handling and storing and low-cost refractory lining demands very low investment.

This is in the range of about US$ 50.00 to 60.00 per ton to yearly capacity, as against US$ 120.00 to 150.00 in the case of the conventional coke blast furnace.

4. THE CHARCOAL BLAST FURNACE

Concept

The basic concept of a charcoal blast furnace plant is shown on Fig.1, in plan view and section, and on Fig. 2, as a flow sheet.

Typical parameters for two furnaces of different sizes are as follows:

		1	2
Nominal capacity	t/day	180	(*) 400
Yearly production (liquid)	tpy	63,000	140,000
Operating days per year	days/y	350	350
Length of campaingn	years	3 to 4	4 to 5
Refining time (tap to tap)	days	20	20

(*) Real production is as high as 460 tpd, with a 515 tpd record..

These are the main dimensions of the furnaces:

		1	2
Hearth diameter	m	2.75	4.20
Parallel section Ø	m	3.82	5.20
Working height	m	14.45	16.00
Working volume	m^3	110	250
Number of tuyeres		6	10
Tuyere diameter	mm	95	100
Top pressure	m WC	1.8	3.4

Blast conditions:

		1	2
Maximum flow	Nm^3/h	10,500	28,000
Blowers in series		5	6
Power of each blower	HP	150	250
Blast pressure	m WC	8.0	9.5
Blast temperature	°C	780	850

Top gas pressure shall be sufficient to overcome the pressure drop of the venturi-type gas cleaning plant. About 30% of this gas are demanded by the glendon blast preheater, whereas the balance is available for use by anyheat demanding industry which may settle in the neighbourhood. Top gas analysys is as follows, by volume and on a dry basis:

	%
CO	23 to 26
H_2	5 to 7
CH_4	1
CO_2	16 to 18
N_2	balance

Lower heating value remains between 950 and 1.000 kcal/Nm^3. Since the gas is the fuel for the "glendon" preheater it has to be cleaned to about 30 mg/Nm³ of solids in suspension.

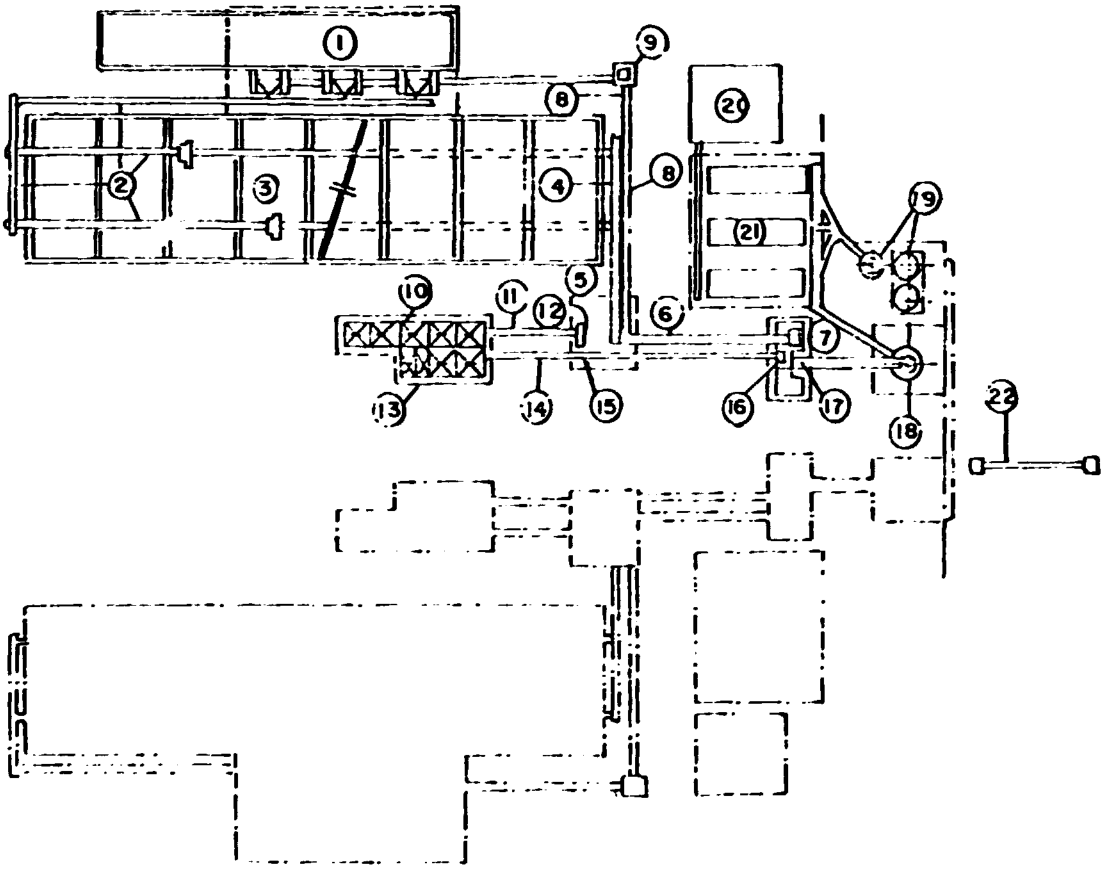
In case the excess gas is used by more demanding constumers it will have to be cleaned more thoroughly, up to a level of 5 to 8 mg/Nm³, as in the case of the 400 tpd furnace mentioned as an example. The pressure of the clean gas made available is between 300 and 500 mm of water column.

The Furnace

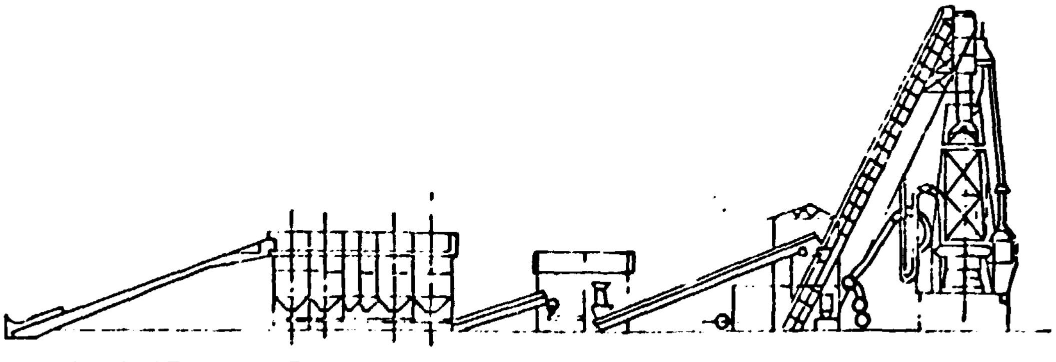
The furnace (Fig.3) is of the self-supporting type, with double bell closing, fitted with material receiving hopper; intermediate chamber pressure equalizing system; stock level indicator; downcomer leading straight into the dust catcher. Cooling is external by water sprays distributed round the shell, whereas the tuyere cooling is conventional.

The "Glendon" Type Blast Preheater

The counter-flow metallic heat exchanger called glendon is shown in plan view and section on Fig. 4. Fueled with top gas, the modern glendon delivers the blast at 800 to 850 °C, with a thermal efficiency of about 60%. In order to reach such a performance the glendon has undergone some improvements in design and materials (e.g. centrifugally cast refractory steel pipes in the hottest zone), but there are still many oldfashioned units with cast iron piping, delivering the blast with only 400 to 600 °C, at an efficiency of not more than



CHARCOAL BLAST FURNACE
Plan View



CHARCOAL BLAST FURNACE
Section

1 - Charcoal Unloading System; 2 – Charcoal Storage Conveyors; 3 - Charcoal Storage; 4 – Charcoal Extracting Conveyors; 5 – Charcoal Screening; 6 – Screened Charcoal Conveyors; 7 – Charcoal Measuring Bin; 8 - Charcoal Fines Conveyors; 9 – Charcoal Fines Bin; 10 - Iron Ore Bins; 11 Iron Ore Conveyor, 12 – Iron Ore Screening; 13 – Additive bins; 14 - Additive Conveyor; 15 - Iron Ore & Additive Weighing Bin; 16 - Iron Ore Additive Charge Bin; 17 - Skip Charging Bucket; 18 - Blast Furnace; 19 – Gas Cleaning; 20 – Blowers House, 21 Air Preheaters (Glendons); 22 – Pig Iron Casting Machine.

Fig. 1 – Plan View and Section – Charcoal Blast Furnace Plant

40%.

Pig Casting System

Older furnaces use to tap continuously, through a forehearth, directly onto a manually driven casting wheel. The normal procedure is to tap into a ladle, conveyed by hoist to the casting machine, which is either of the wheel or of the moving belt type. The newest trend goes to piglets of about 2 kg weight, with rounded-off edges, allowing to be handled as a bulk material, conveyed on belts and dropped directly into the ship's hold. Granulation may also be considered, as an alternative.

Other Aspects

For further details refer to papers (5), (7) and (8).

5. REFORESTATION

Since 1966 reforestation is mandatory for all wood consumers be it for charcoal, pulp, fuel or whatsoever, in such a proportion that 50% of their demand will be supplied by own forests. This obligation, fulfilled with rather varying zeal and backed by a program of fiscal incentives, led to the implantation of a total of 4.5 million hectars of forests, from which 1.0 million is for charcoal production. Due to several factors, one of which is the low yield of the older reforestation projects developed with incipient technology (average yearly increment of 10 to 15 steres per hectar and year, instead of the planned 25), the present share of charcoal from reforestation in overall consumption is only 17%, although there are some individual companies where this rate reaches 50%. For this reason and due to the ongoing extinction of the native forests around the iron producing regions (Minas Gerais and Espírito Santo), a change in present regulation is anticipated, in the sense of increasing from 50 to 100% the compulsory reforestation. Such an extension would have a considerable influence on capital demand, both for already existing and specially for new plants as will be seen later, in the chapter on Investment.

Maintenance and even expansion of the fiscal incentives program, which carries resources from other investors to the reforestation activity, will be imperative in such case.

Reforestation for charcoal is made with different species of the genus "eucalyptus", developed from seeds or, more recently, by vegetative production("cloning"). After 8 years a first cut is made, followed by a second and third cuts in successive intervals of 6 to 7 years, closing one cycle of 20 to 22 years. The average yearly increment expected for the full cycle falls between 20 and 25 st/ha-year but, as already mentioned, in several older projects the yield upon the first cut was far less. Therefore there is a growing tendency to reform the forests, i.e., to substitute low yield forests without waiting for the second and third cuts.

The cost of reforestation is presented on Table II, being mainly a function of the quality of soil and of the interest rate,

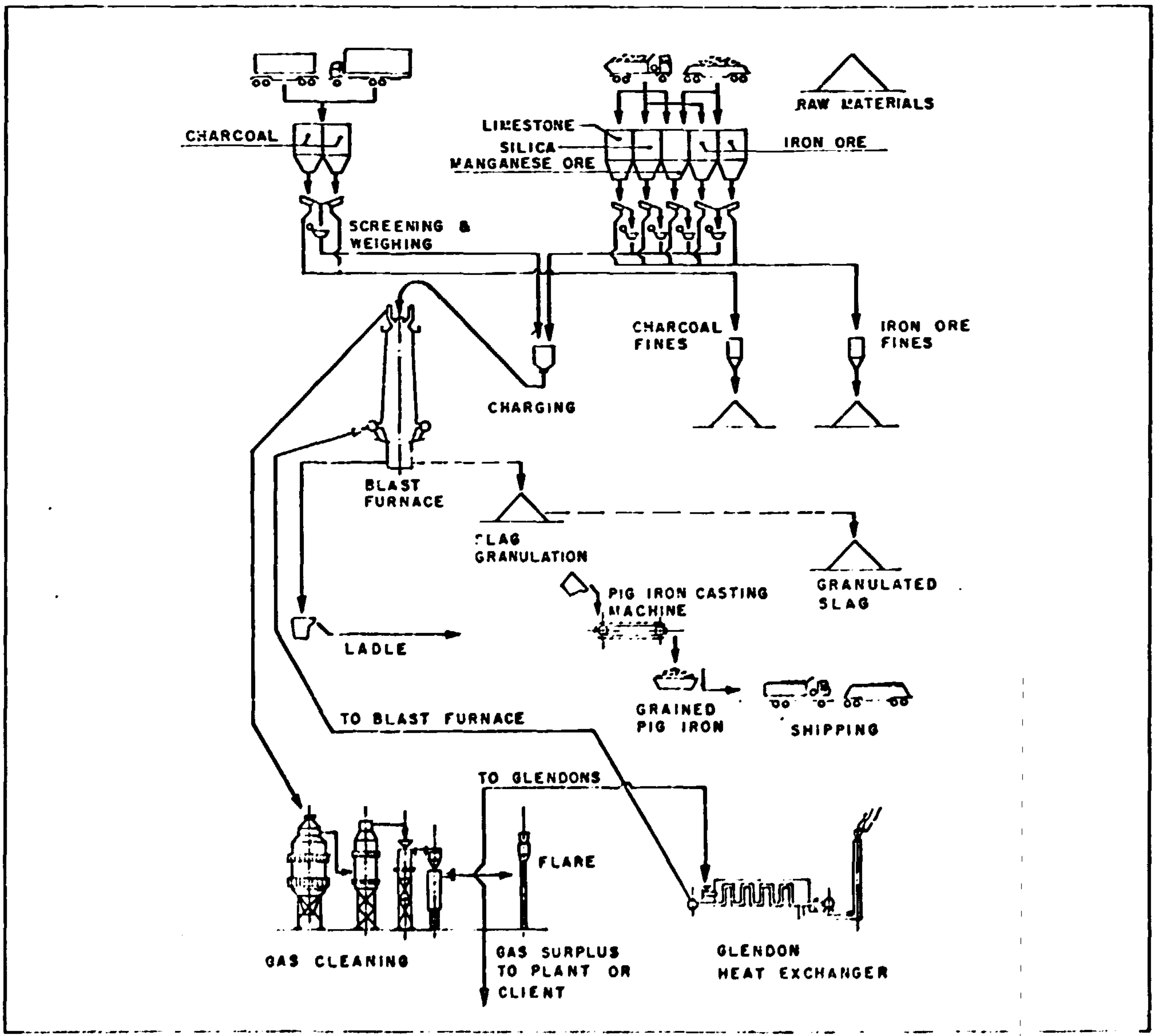


Fig. 2 - Flow Diagram of a Charcoal Blast Furnace Plant

besides the planting techniques, fertiziling etc (9). US$ 2,00/st may be taken as an average price for standing wood. Since specific consumption of eucapyptus wood is 2,0 st/m³ of charcoal, the resulting cost of wood is US$ 4.00/m³ of charcoal.

Table II – Cost of Reforestation (US$/st of standing wood) US$/st

		Three cut cycle (22 years)		One cut cycle (8 years)	
		Weak Soil	Average Soil	Weak Soil	Avge. Soil
Total Production Increment	st/ha st/ha-y	260 11.8	520 23.6	100 12.5	200 25.0
Interest rate pct/year	0 6 10	1.92 3.66 6.06	0.96 1.83 3.03	4.00 5.92 7.60	2.00 2.96 3.80

NOTE: without remuneration of land

6. CHARCOAL

Charcoal is a heterogeneous material for which there are no standard specifications. Its quality and characteristics depend on the kind of wood employed and on the carbonization process parameters, specially in regard to temperature and time. Production and consumption are growing in Brazil, as shown on Table III.

Table III – Charcoal Consumption in Brazil 1.000m³

Year	From Native Forests	From Reforestation	Total	% from Reforestation
1976	14,044	1,456	15,500	9.4
1980	16,866	2,788	19,644	14.1
1984	24,597	5,010	29,607	16.9
1985	26,636	5,501	32,137	17.1

Source: IBS Statistical Yearbook - 1986

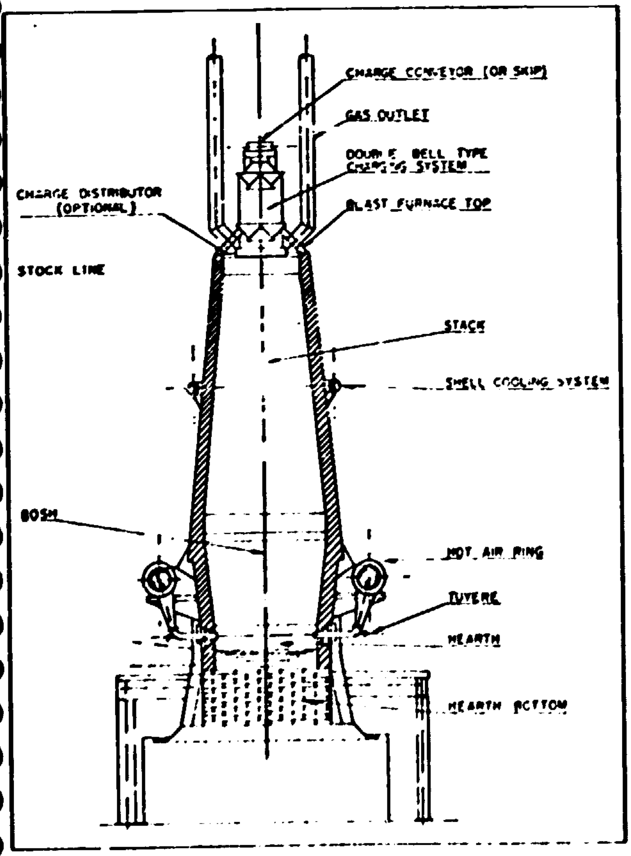


Fig. 3 – The Charcoal Blast Furnace – Section

The immediate analysis of charcoal obtained in well operated beehive kilns is the following:

	%
Fixed C	70 – 75
Volatile Matter	20 – 25
Ash	3 – 5
P (as P_2O_5)	0.06 – 0.08

Moisture content is around 8%, going up to 20% in the rainy season. Other characteristics:

Bulk density (dry basis) : 200 – 280 kg/m³
Size: 0 – 10 mm : 10 – 15%
10 – 50 mm : 60 – 80%
50 – 200 mm : 10 – 20%

Lower heating value
(dry Basis) : 6800 – 7200 kcal/kg
Ash analysis (%): SiO_2 : 15 – 25
CaO : 25 – 45
MgO : 6 – 7
Al_2O_3 : 2 – 4
Fe_2O_3 : 3 – 5
K_2O : 10 – 15
Na_2O : 1 – 2
S : 0.05 – 0.06
P : 1 – 3

Volatile matter analysis (vol.%):
H_2 : 64
C_nH_m : 7
CO : 20
CO_2 : 9

Consumption per ton of pig iron: In the case of well-built furnaces, with 800 °C blast temperature and adequate raw material preparation, the following data are representative for the yearly average consumption, as referred to one ton of basic iron produced:

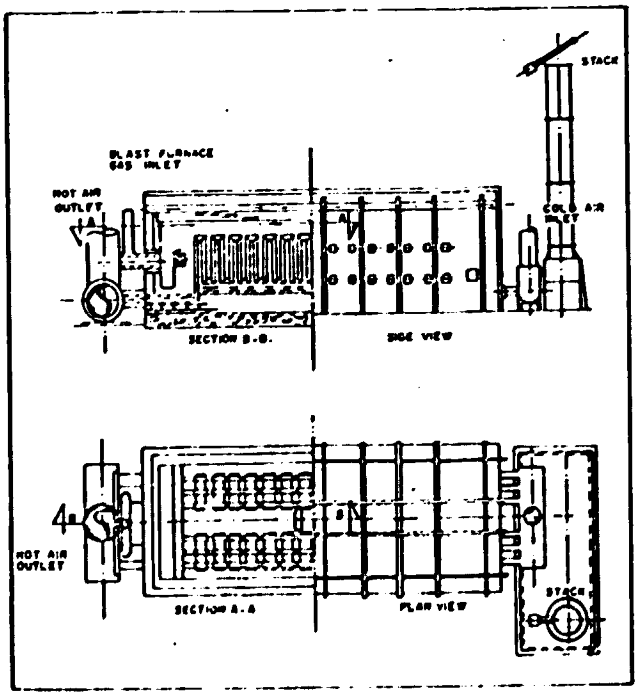


Fig. 4 – "Glendon" Type Blast Preheater

	m³	kg/t (dry Basis)
Net quantity charged to furnace	2.90	640.0
Fines recovered	0.35	123.0
Losses	0.25	35.0
Gross quantity purchased	3.50	798.0

Charcoal is normally produced in brick kilns, built in groups close to the forests and are periodically dismantled and rebuilt in the neighborhood of the next forest ready to be cut.

The increasing proportion of planted forests makes it worthwhile to centralize charcoal production, building larger kilns or employing metallic kilns, even continuous ones, with tar recovery. Investment in this case will be considerably, higher, raising doubts on the return on investment, besides the rise of some problems relating to charcoal quality, regarding mainly its size and friability.

The cost [illegible] tree felling, wood transportation and piling, charcoal manufacture including kiln depreciation, loading of charcoal on trucks and general administration amounts to between US$ 6.00 and 9.00 per cubic meter.

Transportation-usually by truck-between charcoal manufacture and iron plant costs between US$ 2.00 and 5.00/m³, according to distance (basis: US$ 0.01/m³-km).

Total cost of the cubics meter of charcoal therefore comes to:

	US$/m³
Wood, standing	4.00 – 6.00
Felling, charcoal making etc.	6.00 – 9.00
Freight to iron plant	2.00 – 5.00
Total C&F iron plant	12.00 – 20.00

At an average bulk density of 238 kg/m³ this is equivalent to US$ 50.00 to 84.00 per ton of charcoal, a range were the market price has established itself for many years, with strong fluctuations.

The trend, however, is towards the higher limit, as it is being observed along the current year of 1986.

Summing it up, the technical indices are the following:

	Range	Average
Steres of wood per hectar and year (st/ha-y)	12 to 25	22
Steres of wood per m³ of charcoal (st/m³)	1.8 to 2.2	2.0
Gross charcoal consumption per t of pig (m³/t)	3.2 to 3.8	3.5
Tons of pig per hectar and year (t/ha-y)	4.3 to 1.4	3.1

This means that the production of 100,000 tpy of iron, for instance, at a basis of 100% own reforestation, demands a reforested area of 32,000 ha. This results in a total demand of land of the order of 44,000 ha for the sustained production of 100,000 t/y of pig iron, since the reforested area may only cover up to 75% of the total available land, being the remainder assigned for reserves of native forest, roads etc.

7. INVESTMENT

Total investment in a charcoal iron plant is composed of three well identified parcels: investment in the industrial plant; investment demanded by reforestation; investment to be made for cutting and handling the wood and for charcoal manufacture.

The first parcel – investment in the industrial plant – amounts to US$ 50.00 to 60.00 per yearly ton of capacity, under Brazilian conditions, and has to be disbursed in a one-year interval, which is the normal installation period. It has to be accrued by the necessary working capital.

The second parcel – investment in reforestation – has to be expected in a linear distribution over a period covering the year of construction and the first 7 operating years of the plant. There are two cases to consider:

i . Reforestation on a basis of 50% of the consumption, as per the present regulation. In this case, total investment will be equivalent to (1 : 3.1) : 2 = 0.16 ha/t-y, demanding the purchase of 0.44 : 2 = 0.22 ha/t-y. Assuming that land will cost US$ 300.00/ha and total cost of reforestation is US$ 400.00/ha, there results a total investment of US$ 130.00/t-y, to be paid out in 8 successive annual parcels of US$ 16.25 each, starting from the year of installation of the plant.
Practice has shown that in terms of cash the industrial operation itself generates these resources, right from the first year on, even admitting that no tax incentives are available.

ii. Reforestation on a 100% basis:
In this case, which sooner or later will become reality, at least in regions where native woods approach exhaustion, investment will be twice that of case (i): total investment in reforestation and land will be of US$ 260.00/t-year, to be paid out in 8 successive and almost equal parcels of US$ 32.50. This amount will not be generated any more by industrial operation, which will cover at best US$ 20.00, leaving the remainder to be covered in the form of new resources from shareholders or from incentives, or else by long-term financing. Whith a view on this there are efforts being made to develop credit lines in foreign currency with compatible interest rates and grace period (up to 8 years). A further possibility is to rent the land on a long-term basis, such reducing own investment.

The third parcel, finally, corresponding to the equipment for tree felling and handling, charcoal making and related activities, amounts to a total between US$ 12.00 to 16.00/t-year for the case of 50% selfsufficiency, or US$ 24.00 to 32.00 for 100% own charcoal production. In both cases this investment has to be paid out in the seventh year of operation of the plant, and in terms of cash it will be paid back in one year, with the first harvest of charcoal.

Therefore there is no problem in funding this parcel. Besides, the whole of these operations may be subcontracted with third parties, thus avoiding the commitment of own resources.

From the foregoing the following conclusions made be drawn:

- Investment in the industrial unit is the least parcel of overall investment in a pig iron plant; however, it has to be paid out at once, in the year of installation of the plant.
- At present, where only 50% of own reforestation are required, the investment in reforestation, including land, spread over 8 successive years, is generated by industrial operation itself, in terms of cash, with the exception of the year of installation of the plant.
- In the case of 100% own reforestation, likely to occur in the future, industrial operation will not be able to generate all the cash necessary to cover investment in reforestation. The investor will have to be prepared to commit an additional annual sum of the order of US$ 10.00 to 15.00 per yearly ton of pig iron, up to the seventh year of operation.
- From the eight year of operation onwards, when the plant starts to be supplied by its own charcoal, the return on investment starts to be very high.

8. CHARCOAL BLAST FURNACE OPERATION

Theoretical Aspects

Since charcoal is much more reactive than coke, the reaction $C + CO_2 \rightarrow 2\,CO$ begins around 750 to 800 °C in the charcoal blast furnace, as against 900 to 950 °C in the case of coke. This fact is responsible for the lower temperature of the thermal reserve zone in the charcoal blast furnace.

For the same reason, the indirect reduction is more intense than in the coke blast furnace. Thus the lower stack height, which is a condition imposed by the lower mechanical resistance of the charcoal, becomes admissible. On the other hand, the lower reaction kinetics related to the lower temperature demand a highly reductible ore.

The low bulk density of charcoal (240 kg/m^3 as against 550 for coke) makes that about 75% of the furnace volume is occupied by the reductant. So, the permeability of the burden is widely determined by the charcoal, which has to be carefully screened (at least at 3/8"), charged in separate layers and should be uniform in size, which in practice is an impossible condition.

Since ash content of charcoal is very low (abt. 3%), sulphur is nonexistent and iron ore is of high grade, charcoal blast furnaces usually work with a low slag volume, in the range between 100 and 160 kg/t of iron (as against 300 kg for coke). Since no sulphur has to be removed the slag may be acid, with a basicity (Ca O+Mg O to Si O_2 ratio) between 0.8 and 0.9, as against 1.3 to 1.4 in the coke blast furnace.

Due to all the foregoing considerations, the travel time of burden through the furnace is lower (4 to 6 hours) than in the coke blast furnace. This makes the charcoal blast furnace very sensitive and quickly reacting to burden changes, a fact which has to be born in mind when operating it.

Raw Materials

The Materials Flow Chart (Fig. 5) shows a representative example of materials balance for a charcoal blast furnace.

The balance is based on Brazilian raw materials of the usual characteristics, specially the iron ore with about 65% Fe, in the size of 1/4" to 3/4". Charcoal, which is the weightiest raw material both for the cost and for the operating parameters of the blast furnace, has already been thoroughly examined. The other raw materials do without more detailed analysis.

Operation. Labor

Provided the peculiarities of the charcoal blast furnace as listed above are borne in mind, the operation of such a furnace is easy and does not demand highly skilled labor, although a thorough experience is required. Main activity areas are charcoal unloading; raw material preparation and charging; tapping and casting; maintenance and utilities; administration and supervision.

In the case of the 63,000 tpy plant given as an example, the following labor would be required for continuous 4 shift operation:

Charcoal unloading	:	14
Raw materials handling and charging	:	16
Tapping and casting	:	22
Maintenance and utilities, lab.	:	15
Miscelaneous	:	8
Administration and supervision	:	10
Total		85

With the above crew, total labor amounts to about 3,3 man-hours per ton of pig iron, at a cost of about US$ 5.00 per ton under brazilian conditions. Productivity is in the range of 730 t per man-year.

Products and Waste Products

Pig Iron:

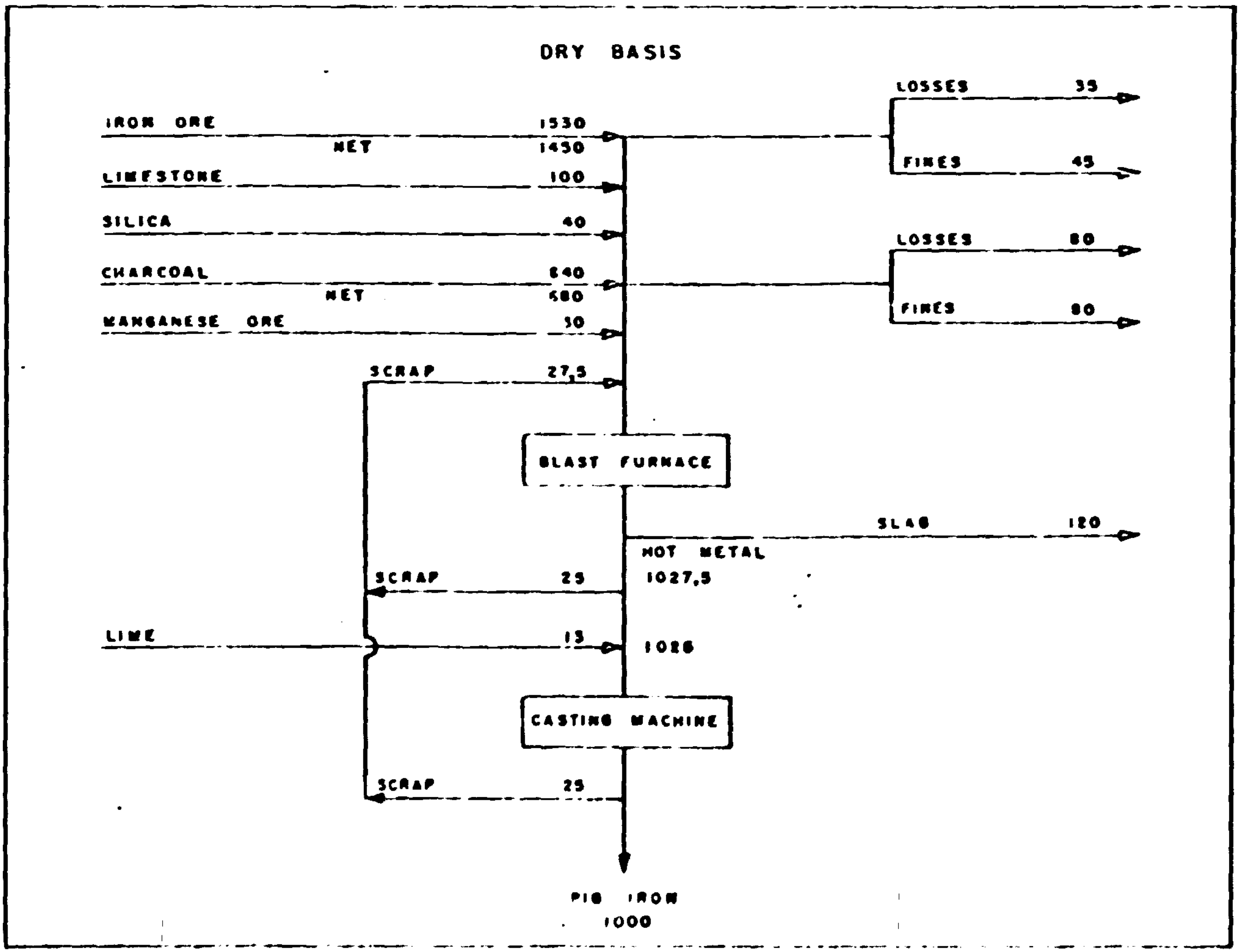


Fig. 5 – Materials Flow

Although pig iron specifications present minor variations from one market to the other, the normal analysis of basic charcoal pig iron is as follows:

C	3.8 – 4,2%
Si	0.4 – 0,5%
Mn	0.2 – 0,5%
P	0.10 – 0,15%
S	0.05 maximum.

Foundry iron differs mainly in Si analysis (up to 3.0%) and P (down to 0.08). Its production leads to a decrease in productivity of the furnace (up to 20%) and an increase (10%) in specific charcoal consumption.

The usual specification asks for pigs of 10 to 30 kg, clean and convenient for handling, with adequate marking. Such pigs, however, cannot be handled by bucket wheel reclaimers nor conveyed by normal belt conveyors. Furthermore, due to their weight they may not be dropped directly into an unprepared ship hold. For this reason the trend is towards the production of "piglets" of 1.5 to 3.0 kg weight and rounded-off corners, which improve the handling operations also at buyers end, leading to a substancial freight reduction. Another alternative may be the "granulation" of pig iron as shown by operational tests already performed in the country, corroborated by extensive foreign experience.

At present the FOB price for basic pig iron is about US$105.00/t, whereas foundry pig iron costs US$ 6.00 to 10.00 more. Domestic price corresponds to the FOB price plus taxes.

Gas:

The surplus gas generated by the charcoal blast furnace, after covering the glendons' consumption, amounts to about 1,200 Nm^3 per ton of iron. With a lower heating value between 950 and 1,050 kcal/Nm^3, this surplus gas totals about 1.2 Gcal/t, a considerable amount of energy, equivalent to 120 kg fuel oil.

The gas is fully used in integrated plants, mainly in the reheating furnaces of rolling mills. It is usually wasted, however, in the case of independent blast furnaces, offering a remarkable energy potential for heat demanding industries.

Operating Cost

Under usual Brazilian conditions, as described above, production cost of basic charcoal pig iron may be illustrated as shown on Table IV(6,10). If depreciation is added, at a rate of 10% on fixed investment, the total cost comes to be about US$ 90,00 per ton of pig iron FOT plant.

In those cases where the surplus gas is fully used, a credit of up to US$ 8.00 to 10.00 per ton of pig iron has to be accounted for ,bringing the total cost to about US$ 80.00 per ton of pig.

9. NEW DEVELOPMENTS

The new upsurge of the charcoal blast furnace which is taking place in Brazil during the last years is giving way to a search for improvements, both in process and equipment, aiming mainly at improving energy balance and cutting wastes.

One big waste is still the surplus gas of single blast furnaces, which is lost to atmosphere in an amount of about 1.2 Gcal per ton of pig iron. Since the gas is a lean gas, however, the only way of economic utilization is the installation of heat-demanding industries right aside the blast furnace, or vice-versa. Lime calcining plants, ceramic industries, cement and pelletizing plants are examples of such industries. The generation of electric energy is still expensive under present price conditions, but may become a solution in the future.

Successful efforts are being made to improve the glendon blast preheater, in order to increase its thermal efficiency and lower the investment. Careful redimensioning, utilization of centrifugally cast steel pipes and combustion control are some measures which present success.

Mention should also be made of improvements developed on the blast furnace itself, such as a keener control of the charge, automation of the raw materials handling and charging system, improved monitoring etc, which all together help to improve efficiency and reduce costs.

The proper utilization of charcoal fines is another way of cutting wastes.

Table IV – Production Cost for Basic Hot Metal

		Specific Consumption un/t	Unit Price US$/t	Cost per t of pig US$/t
A. Raw Materials				72.81
Charcoal	m^3	3.50	16.00	56.00
Iron ore	t	1.63	9.40	15.32
Lime and Dolomite	t	0.10	8.00	0.80
Silica	t	0.04	6.00	0.24
Manganese Ore	t	0.03	15.00	0.45
		z		
B. Labor		2.90		5.00
Direct	Mh	0.40	1.40	4.06
Indirect and Administrative	Mh		2.35	0.94
C. Miscelaneous		0.10		3.60
Electric Energy	MWh		25.00	2.50
Water (1)	m^3			–
Others	–			1.10
D. Services (2)				4.00
E. Credits (3)		0.35		(2.80)
Charcoal Fines	m^3		8.00	(2.80)
F. Provisions				0.50
Provision for new lining				0.50
TOTAL – Production Cost				83.11

(1) Cost included in labor and electric energy
(2) Services under contract and/or materials for maintenance, internal transport etc.
(3) Gas surplus is not being credited

As already pointed out, these fines under 3/8" are being sold at low prices as fuel. Their use in the process itself or in new reduction processes in being the aim of many efforts. One already proven technology is that of injecting charcoal fines through the tuyeres(11,12). ACESITA, a Brazilian charcoal based integrated special steel plant, got excellent results with the process they developed(13,14), translated into charcoal savings by eliminating the waste of fines. No data have yet been published, however, about the investment and the overall economy of fines injection, comparing the savings against the injection costs, such as energy for drying and grinding, inert gas consumption, maintenance etc.

The development or adaptation of new reduction processes capable of using charcoal fines is another possible way for the economic utilization of this waste product. An example is the KR Process(15), which is able to use directly the available fraction of – 3/8".

The addition of charcoal to the burden of coke blast furnaces, under certain special conditions(16) has already been tried with success.

A further important area for new improvements are the charcoal making techniques. Tar recovery is becoming a standard practice(17), allowing the recovery of about 80 kg of tar per ton of charcoal in brick kilns (against up to 200 kg in continuous metallic kilns). The use of tar as a substitute of fuel oil is a proven practice, once some corrosion problems in the fuel and burner system have been overcome. The substitution rate is of 3 kg of tar for 2 kg of oil.

New charcoal furnace designs also allow extensive heat recovery[18], with considerable improvement in the efficiency of the carbonization process. The substitution of brick kilns by metallic ones offers a great potential for yield and cost improvement, although for the time being the investment still does not seem to be compensating.

Last but not least, important improvements are under way in the reforestation activity. Some of these improvements, which are bringing remarkable increases in yield[19] are the following:

- Genetic improvement of species
- Reproduction by clones rather than by seeds
- Larger mechanization
- Training of labor and supervision
- Energetic use of the waste biomass (branches, leaves)

Altogether, these developments show the vitality of the Brazilian charcoal iron industry, an example of a successful industrial activity based on renewable energetic resources.

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ANNEX 2

OPERATING EXPERIENCE WITH CHARCOAL BLAST FURNACE AND EOF STEELMAKING IN BRASIL

OPERATING EXPERIENCE WITH CHARCOAL BLAST FURNACE AND EOF STEELMAKING IN BRAZIL

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The main features of the charcoal blast furnace and the EOF process are recalled. The brazilian PAINS plant is described, with their successful combination of charcoal blast furnaces and EOF steelmaking. An account is given on operational practice, production costs and investment figures. Several alternative concepts for combining the EOF with reduction processes are mentioned, showing the versatility of the EOF in regard to solid charge and hot metal.

INTRODUCTION

In previous papers (1) (2) the important role of the charcoal blast furnace in Brazil has been pointed out. Low cost of charcoal pig iron, due to low priced raw materials and the simplicity and ease of operation of the furnace, together with its purity and energy content render this metallic source into a favorite charging material for the electric melt shop, in proportions up to 30 %.

The EOF (Energy Optimizing Furnace") on the other hand, developed by the KORF Group at its brazilian Companhia Siderúrgica PAINS plant, is a combined blow refining process originally based on a 60 % hot metal and 40 % scrap charge.

Although the EOF is being developed into a 100 % cold charge melting and refining device, it is ideally suited for plants which have an availability of hot metal.

Since in Brazil, as well as in most developing countries, scrap is scarce, expensive and increasingly contaminated, whereas some sort of coal is usually available, the combination of a blast furnace with an EOF presents a handy solution for new plants as well as for increasing capacity of existing ones.

This paper presents in detail the latest operating data for this very successfull route to steel, in a plant which evolved from 200 to 400.000 tpy in a few years. It also mentions further examples of reduction processes which favorably combine with the EOF for the production of low cost billets. Such are the small coke blast furnace, with combination blast furnace / MIDREX DR plant, the COREX process, among others.

The great flexibility of the EOF in regard to solid and liquid charge as well as to plant size make the prospects for this process look bright.

THE CHARCOAL BLAST FURNACE

Due to the low investment demanded, its simplicity of operation and the low-cost, high quality iron produced, charcoal blast furnaces are getting growing importance in Brazil.

As shown in Table 1, total output of charcoal iron in 1986 reached 7,5 million tons, accounting for more than 37 % of total iron production in Brazil. From this production a considerable share goes to the export market, as shown in Table 2. But also the domestic market reveals a trend of growing demand for pig iron.

Three main factors support such growth: the low cost of this product; its purity; and its energy content. This last factor is acquiring growing importance, since the energy represented by the 4 % C and 0,6 % Si may be fully used by adequately equipped electric arc furnaces, leading to proportional savings of electric energy. When adding between 20 and 30 % pig to the EAF charge, such savings amount to somewhere between US$ 15,00 and US$ 25,00 per ton of pig, depending on the price for electric energy (4) (5). This tends precisely to be the overprice any plant will be willing to pay for charcoal pig in comparison to scrap.

As pointed out by Tables 1 and 2, between 42 and 48 % of all charcoal pig iron is produced by so called integrated plants, which immediately convert the hot metal into steel. This is the case of some well-known brazilian steel plants, which are listed in Table 3.

Domestic sales of charcoal pig iron, on the other hand, cover the demand of foundries and, on a growing scale, that of arc furnace based non-integrated steel plants, making up for scrap shortages and supplementing energy demands as already mentioned.

It is worthwhile mentioning that one important non-integrated arc furnace steel plant of 1 million tpy capacity is presently installing a charcoal blast furnace in order to benefit both from the chemical energy and the enthalpy of the hot metal, not to mention the top gas surplus which is a welcome fuel supplement for reheating furnaces and ladle heating stations.

As regards the charcoal blast furnace itself, its main features and investment cost, as well as reforestation and charcoal manufacture, references (1) and (2) give a general picture. Figure 1 illustrates the charcoal blast furnace flow diagram.

THE EOF PROCESS

The EOF ("Energy Optimizing FURNACE") process (3) is essentially an oxygen steelmaking process using combined side blowing.

Oxygen is injected horizontally through special tuyeres into the bath, and oxygen is blown into the furnace atmosphere by water-cooled injectors, as shown in Figure 2.

The process was developed by the KORF Group at its brazilian PAINS plant, in Divinópolis, state of Minas Gerais, with the idea of ultimate rationalization of the open hearth furnace. Although preserving the great flexibility of the OH as to the proportion of hot metal and solids in the charge, the EOF has dramatically increased productivity and reduced cost, thanks mainly to its thermal efficiency. This is a result of the optimized use of energy derived from the following three sources:

I . Chemical energy released in the bath and on its greatly extended surface by the reactions between injected oxygen and oxidizable elements, including added carbon.

II . Chemical energy derived from the burning of CO released from the bath, within the furnace atmosphere.

III. Sensible heat conveyed by the hot gases from the furnace to the cold scrap charged into the preheater.

Starting operation at the end of 1982 and having undergone some important changes ever since, the first 28 t EOF of PAINS today has the following performance:

22 heats per day
29 days per campaign
1 day of maintenance between campaigns
12 campaigns per year
28 t of good billets per heat
210.000 tpy of good billets.

These figures are the result of some important features of process and equipment, namely:

- Large use of watercooled elements, which are a specialty of the KORF Group.
- Ingenious design of the scrap preheater, warranting a long life for all construction elements, in spite of a 850 °C preheating temperature and of an admitted maximum weight of 500 kg per single piece of scrap.
- Removable furnace bottom, supported by the bottom car which allows quick exchange at the

end of each campaign.

- Special submerged oxygen tuyeres, warranting long campaigns.

Figure 3 shows the 60 t EOF unit scheduled to start operation in April 1988 at the ALIPERTI plant in São Paulo, Brazil. Figure 4 presents some of the operational results achieved in the 28 t EOF at PAINS.

Some of the relevant consumption and production indices are the following, at present (referred to steel in ladle):

Oxygen consumption	: 78 Nm^3/t
Oil consumption	: 4,6 kg/t
Refractory consumption	: 9,0 kg/t, from which 4,5 kg/t correspond to formed pieces, the rest being fetling material.
Productivity	: 25,8 t/h
Tap-to-tap time	: 65 min.

It has to be emphasized that the above indices are average values over long operational periods, including all normal waiting and down-times of an industrial plant. Also included are test heats and campaigns, which are regularly performed for the sake of further improvements of the process, specially with the aim of achieving an operating mode with 100 % cold charge.

THE PLANT COMBINING CHARCOAL BLAST FURNACE AND EOF

The PAINS plant in Divinópolis, Minas Gerais state, Brazil, is so far the only one combining the two processes, a condition which will soon be lost, because of the start-up in April 1988 of the new 60 t EOF of ALIPERTI in São Paulo, Brazil. All the following, therefore, relates to the PAINS plant which, by the way, is well known to over one hundred Indian engineers and plant operators, who have been visiting the plant and/or practicing the KORF submerged blowing process at the open hearth furnaces, over the last one and a half years.

Relevant Features of the Plant:

The following are the relevant features of the plant:

Blast Furnaces: Number: 3
Inner volume: 110, 192 and 125 m^3.
Production capacity: 760 t per day
270.000 tpy
Individual tapping weight : 18 to 40 t
Tap-to-tap : 2,5 hours

Hot Metal Mixer: Holding capacity: 300 t max.

EOF : Number: 1
Tapping capacity: 28 t
Production capacity: 616 t per day
210.000 tpy

Open Hearth : Number: 3 (2 operating, 1 stand-by)
Tapping weight: 28 t
Production capacity: 560 t per day
176.000 tpy

Remark: In May 1987 one of the OH furnaces was dismantled. In its place the EOF Nr. 2 is being erected, scheduled to get on stream in February 1988.

Continuous Casting: Number of machines: 2

Machine Nr. 1: Strands: 2
Radius : 4 m
Billet : 120 x 120 mm

Machine Nr. 2: Strands: 2 (place for a 3rd)
Radius : 5 m
Billet : 120 x 120 mm.

Evolution of Plant Equipment:

It should be pointed out that the plant has undergone the following evolution:

Prior to 1982: 4 blast furnaces
3 OH furnaces with KORF submerged blowing
1 continuous casting machine
Capacity: 200.000 t per year

From 1982 through 1987: 3 blast furnaces
2 OH furnaces
1 EOF (28 t)

2CCmachines (2 x 2 strands)
Capacity: 400.000 tpy

From 1988 up to 1992 : 3 blast furnaces
2 EOF (28 - 50 t)
2CCmachines (2 x 3 strands)
Capacity: 600.000 tpy

The installation of 2 ladle furnace unit is foreseen.

Charge Composition

The following was the yearly charge composition of the melt shop, in 1987:

	1.000 t	%
Hot metal	241	65
Return scrap	26	7
Purchased pig iron/iron scrap	103	28
Total metallic charge	370	100
Total production (steel in ladle)	330	
Average metallic yield	89 %	

The low total production is due to market reasons.

From 1988 on the charge will present the following pattern:

	%
Hot metal	50
Return scrap	7
Purchased pig iron/iron and steel scrap	43
Total metallic charge	100

Due to FAINS location, in an iron producing region and far away from steel scrap sources, all purchased metallics are either iron scrap or pig iron from nearby blast furnaces.

This will be quite different in the case of the already mentioned ALIPERTI plant, with its 60 t EOF, where the charge will be composed of:

	1.000 t	%
Hot metal	270	60
Return scrap	38	8
Purchased steel scrap	144	32
Total metallic charge	452	100
Total production (steel in ladle)	400	

It should be recalled (3) that 50 % cold steel scrap is the limit at which carbon injection has to start in order to supplement the heat balance.

Operational Practice:

Blast furnaces are operated aiming at the following analysis:

C : 4,20
Si : 0,60
Mn : 0,30
P : 0,14 max.
S : 0,02 max.

There are occasional fluctuations in Si, down to 0,30 and up to 1,2 %, which are handled by controlling the lime addition in the EOF. P and S suffer almost no fluctuations.

Blast furnaces are tapped at periods of two and a half hours, into ladles supported by trucks, which convey the hot metal to the melt shop, about 1.000 m apart - see Fig. 5. Blast furnace Nr.2, with its 40 t tapping weight, needs two ladles, each on one truck.

Hot metal is not weighed but level in the ladle gives an indication within + -0,5 t limit.

As often as possible the hot metal is directly charged into the EOF or OH, after temperature determination, since bypassing the mixer saves about 80 °C in hot metal temperature. Precise weight is given by weighing cells in crane crossbeam and indicated at the crane display. In case of excess or insufficiency of hot metal in ladle, the mixer is used for correction. If no melting furnace is ready to take the charge it goes to the mixer. As evident, some coordination is demanded in order to minimize mixer operation.

The EOF on its turn is tapped every 65 minutes, as an average, and the ladle is conveyed to a rinsing station (Ar or N_2) and then to the casting machine. After cleaning and closing of the taphole the hearth and slag line are fettled, which altogether takes around 10 minutes. The preheated scrap is then dropped and scrap for the next heat is charged (4 minutes). The furnace is now ready to receive hot metal and start blowing. Usually at PAINS there is a 8 to 12 min delay, due to lack of overhead crane availability. During this time oil is being fired into the EOF. After 38 to 42 minutes blowing time the heat is tapped, which takes another 3 minutes, totalling the average 65 minutes tap-to-tap time.

Production Cost

Tables 4 and 5 show average unit consumption figures and production cost for hot metal and steel in ladle, according to present industrial operation at PAINS. Some points should be remarked:

. The weight of charcoal upon pig iron cost.
. The importance of gas and charcoal fine credits on pig iron cost.
. The low overall cost of steel produced according to this route.

But there are still some improvements to make:

I . In the blast furnace area:

- Coal fines injection through the tuyeres
- Full use of top gas, up to the available 1.200 Nm^3/t.
- Dehumidifying of the blast.
- Increase of blast temperature (from present 600 °C to 950 °C).
- Improvements in blast furnace design, specially regarding the top.

PAINS is working on all these aspects, which will finally lead to a further cost reduction of about US$ 10,00 for the pig iron.

II. In the EOF:

- Slag free tapping system.
- Lime injection system.

Such improvements, on which PAINS is working, together with a ladle metallurgy unit which will soon be installed, will further improve productivity and cost, which may be reduced by about US$ 3,00 to 5,00.

Some information in order to complete the picture: yield in continuous casting is slightly over 98 % and cost of transformation, including overhead and depreciation, amounts to US$ 11,40 per t of billet, bringing final cost of good billets to US$ 145,80/t.

Investment:

Papers (2) and (3) give some information about investment demanded by charcoal blast furnaces and EOF's, namely about US$ 60,00 per ton of yearly capacity for the former and US$ 40,00 to 50,00 for the latter, under brazilian conditions. Adding the necessary infrastructure, as well as ladle furnace and continuous casting machine, and assuming 65 % own hot metal, an investment of about US$ 130,00 to 150,00 per ton of annual billet capacity accounts for a complete plant, in the range between 100.000 and 600.000 tpy of billets.

Should there be no oxygen available on the market, an oxygen plant has to be included, which means another US$ 30,00 to 40,00 per annual ton of billet.

Mention has to be made also to the investment demanded by reforestation (2), which in Brazil amounts to US$ 130,00 per ton of hot metal, to be paid out in 8 successive annual parcels of US$ 16,25 each, starting from the year of installation of the plant. At the rate of 65 % own hot metal this would add a further US$ 85,00 to the specific investment per ton of billet, bringing the grand total to about US$ 240,00 per annual ton of billet, an investment, however, which includes the oxygen plant and, in a figurative way, the own coal mine.

ALTERNATIVE CONCEPTS

In the forgoing the basic combination of charcoal blast furnaces and EOF has been analysed, taking the real case of the PAINS plant, where the charge is composed of 62 % hot metal. This will develop into a charge pattern of only 50 % hot metal between 1988 and 1992.

Another case mentioned was the ALIPERTI plant, with the start-up scheduled for April 1988, where the charge is made up of 60 % hot metal and 40 % steel scrap.

Plants with a 100 % hot metal, in sites where no solid charge is available - as in western and northern Brazil - are of course a neat solution, in spite of the considerable waste of energy inevitably associated (there is a surplus of chemical heat in the EOF and all the sensible heat in the off-gases is lost).

i . Small Coke Blast Furnace / EOF

In countries which have no availability of charcoal nor scrap, but which have iron ore and/or mineral coal at their disposal - example: India -, ministeel plants may be conceived based on a small coke blast furnace and an EOF. Paper (2) mentions the main differences between the charcoal and the coke blast furnace, which have to be properly taken into account and which render the small coke furnace somewhat more expensive than the charcoal blast furnace, but still within the same range of investment. The combination will be to a great deal similar to the charcoal blast furnace case, besides the question of sulfur in the hot metal, introduced with the coke. The need of an iron desulfurizing station will be defined by the S content of the coke, the final product envisaged and the availability of a ladle furnace.

ii . Blast Furnace and Gas Based Direct Reduction / EOF

In the case of availability of both natural gas and charcoal (or coke), a combination of a DR plant (MIDREX) and blast furnace(s) may prove very economical: by overdimensioning the reformer a surplus amount of reducing gas may be directed to the blast furnace and injected into the stack, thus reducing specific coal consumption to about 65 %, whereas the blast furnace top gas may be used as fuel in the reformer, with corresponding savings of natural gas. The EOF will then be fed by 30 % hot metal and 70 % HBI (hot briketted iron). Such a combination, which is likely to turn out extremely economical, asks for a scale of at least 0,6 million tons per year.

iii. Other Hot Metal Producing Reduction Processes / EOF

Several hot metal producing reduction processes have been mentioned over the last years and anyone may well be combined with an EOF. The best known of such processes is certainly the COREX (KR) process, with one plant being started-up at ISCOR by the end of 1987 and another one being erected in the United States. This is a process suited for countries which have availability of non-coking coals and are looking for plants in the range of 300 to 600.000 tpy of billets. Attention has to be given to the availability of oxygen, a basic raw material for the COREX process.

The EOF will be fed by the hot metal together with either scrap or hot briquetted iron, produced with the big surplus of COREX top gas, which is suited for DR.

iv . Cupola / EOF

For very small plants in the range from 50 to 150.000 tpy of billets, in countries with good scrap availability and high priced electric energy, the installation of a hot blast cupola together with an EOF is certainly a good and economical solution. But there is one implicit risk: as soon as the EOF masters the 100 % cold charge operating mode - and the solution seems to be fairly close - the investment in the hot blast cupola will have been wasted.

OUTLOOK

The very successfull operation of the charcoal blast furnace/EOF combination at the PAINS plant already led to a second company, ALIPERTI, to decide for an EOF. Several other steel plants in Brazil are also looking at the advantages of installing the process.

A group of independent charcoal blast furnace operators, with furnaces located in a radius of 2 kilometers apart from each other, is presently considering the installation of an EOF melt shop in the range of 500.000 t/year, in order to sell billets instead of pig iron.

Also several local or regional microsteel plants, in the range of 100.000 to 200.000 tpy, are being analysed, based on charcoal blast furnaces and EOF melt shops.

But the EOF makes a good combination with any hot metal producing process, as seen from the alternative concepts presented above. Thanks to its flexibility in regard to liquid and solid charge even a combination of blast furnace and a gas based DR unit, with the induced mutual advantages, is being examined.

Thanks to this wide spectrum of interests and possibilities, the EOF may be looked at as the most versatile and attractive refining process to be combined with both classical and non conventional reduction processes.

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TABLE 1 - BRAZILIAN IRON PRODUCTION

Year	Total	Coke BF	Charcoal BF Total	Charcoal BF Integrated Plants	Charcoal BF Independent Producers	Charcoal Iron / Total Iron %
1976	8.170	4.141	4.029	1.895	2.134	49,3
1980	12.685	7.744	4.941	2.494	2.447	39,0
1984	17.230	10.230	6.486	3.002	3.484	37,6
1986	20.268	12.618	7.650	3.229	4.421	37,7

Source: IBS - Statistical Yearbook 1987

TABLE 2 - CHARCOAL IRON SALES

1.000 t

Year	Total	Domestic Market	Export
1976	1.319	544	775
1980	1.790	949	.841
1984	3.425	952	2.473
1986	3.726	1.356	2.370

TABLE 3 - INTEGRATED STEEL PLANTS IN BRAZIL BASED ON CHARCOAL BLAST FURNACES (1986)

Name	BF Capacity (1000 tpy)	Crude Steel Capacity (1000 tpy)	Melt Shop	Final Products	Remarks
ACESITA	600	750	LD/AOD/EAF	Special steels including stainless and silicon sheet	
ALIPERTI	200	320	OH/EAF	Rebar. Carbon steels Spring steels - Sections	(1)
BARRA MANSA	170	230	LD/EAF	Rebar. Wire Rod. Sections	
BELGO MINEIRA	860	900	LD	Wire Rod. Drawn Wires.	
CIMETAL	200	200	LD	Rebar. Light Section	
LAFERSA	50	40	OH	Rebar	
MANNESMANN	700	850	LD/EAF	Seamless Pipes. Special steel	
PAINS	250	360	OH/EOF	Rebar. Carbon Steels;W.Rod	(2)

Remark: (1) 60 t EOF under construction. Start-up April 1988.
(2) Second 28 t EOF scheduled to start-up February 1988.

Table 4 - Hot Metal / Pig Iron Cost
Production of 20.000 tpm, in 3 furnaces

	Unit Un	Specific Consumption Un/t	Specific Cost US$/t	%
RAW MATERIALS			71,32	86,2
Charcoal	m^3	3,54		
I.Ore: Natural	t	1,13		
Pellets	t	0,56		
Limestone	t	0,09		
Manganese Ore	t	0,02		
Silica	t	0,05		
LABOR			2,96	3,6
Direct	Mh	2,00		
Indirect	Mh	0,05		
OTHER			1,97	2,4
Oxygen	Nm^3	6,80		
Miscellaneous	US$			
Services:				
Maintenance	US$			
Support	US$			
Int.Transport	US$			
Quality Contr.	US$			
Electr.Energy	kWh	0,08		
Prov.Revamping	US$			
Others	US$			
Credit top gas	1000 Nm^3	0,75		
Credit Charcoal Fines	m^3	0,35		
SUB-TOTAL Production Cost			76,25	92,2
GENERAL			6,45	7,8
Plant Overhead	US$			
Depreciation	US$			
Services - Indir.	US$			
TOTAL Industrial Cost			82,70	100,0

Table 5 - EOF: Cost of Steel in Ladle
Production of 17.000 tpm

	Unit Un	Specific Consumption Un/t	Specific Cost US$/t	%
RAW MATERIALS			101,06	76,0
Hot Metal	t	0,704		
Steel Scrap	t	0,091		
Iron Scrap	t	0,148		
Pig Iron	t	0,193		
Lime	t	0,050		
FerroManganese	t	0,014		
Ferro Silicon	t	0,004		
Others	t	0,012		
LABOR		-	1,58	1,2
Direct		0,74		
Indirect		0,05		
OTHER			23,70	17,8
Fuel Oil	kg	4,50		
Oxygen	Nm^3	78,00		
N_2/CO_2	Nm^3	13,50		
Refractory *	kg	4,50		
Refractory **	kg	4,50		
Miscellaneous	US$			
Services:				
Maintenance	US$			
Support	US$			
Int.Transport	US$			
Quality Contr.	US$			
Electr.Energy	kWh	0,025		
Others	US$			
SUB-TOTAL Production Cost			126,34	95,1
GENERAL			6,56	4,9
Plant Overhead	US$			
Depreciation	US$			
Services - Indir.	US$			
TOTAL Industrial Cost			132,90	100,0

* fettling ** relining

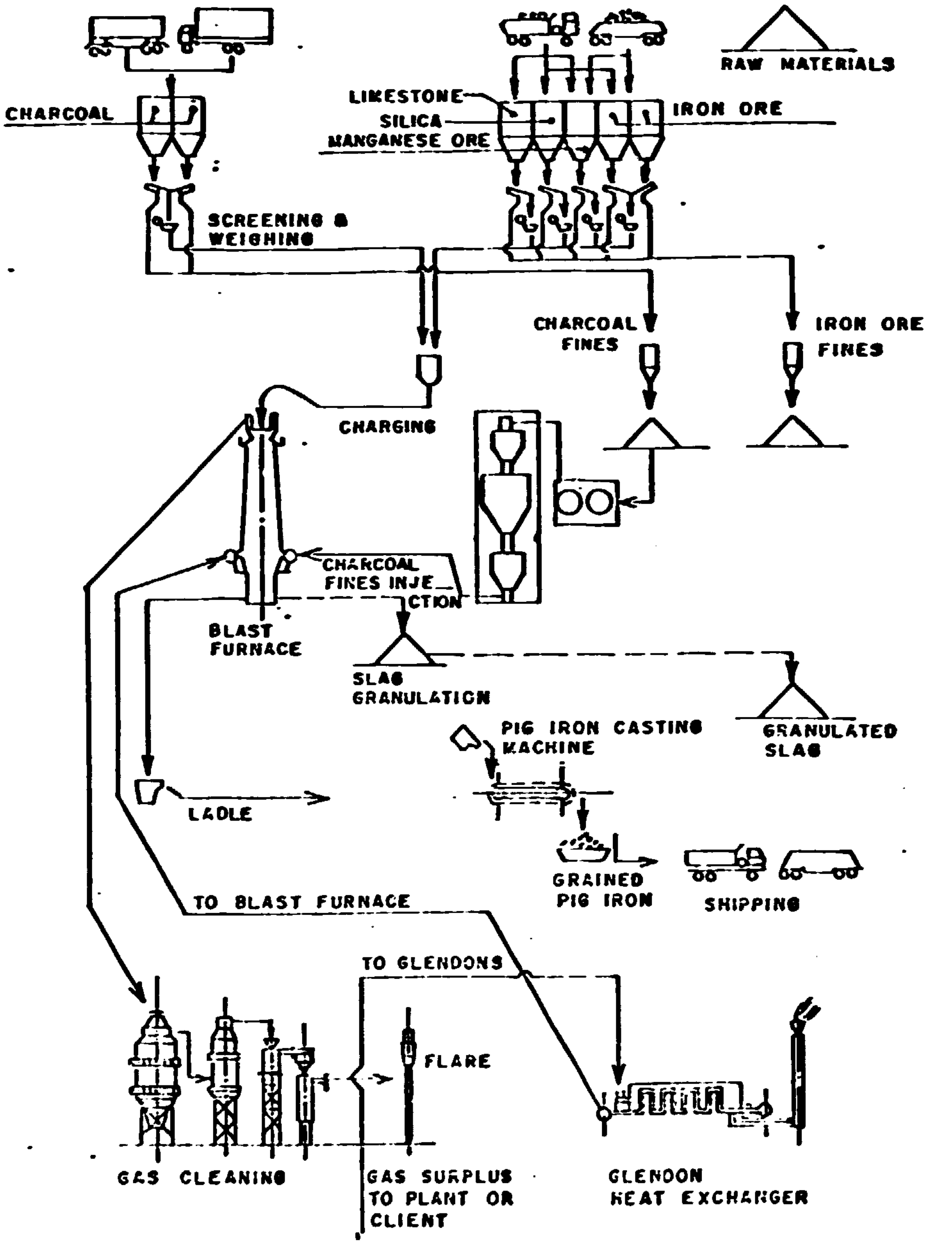

Fig.1: Flow diagram of a Charcoal Blast Furnace Plant

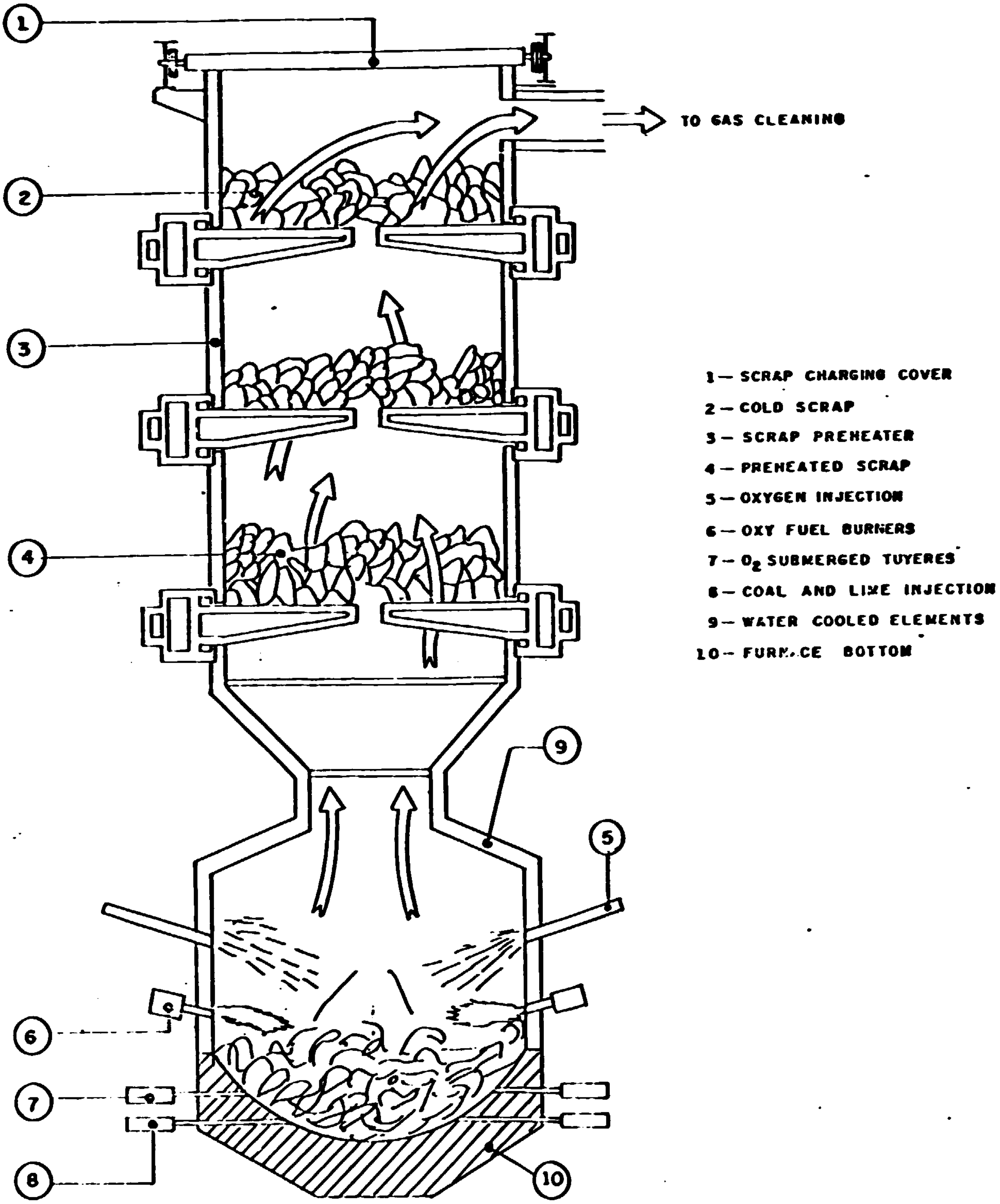

Fig. 2 – EOF (Energy Optimizing Furnace) Schematic

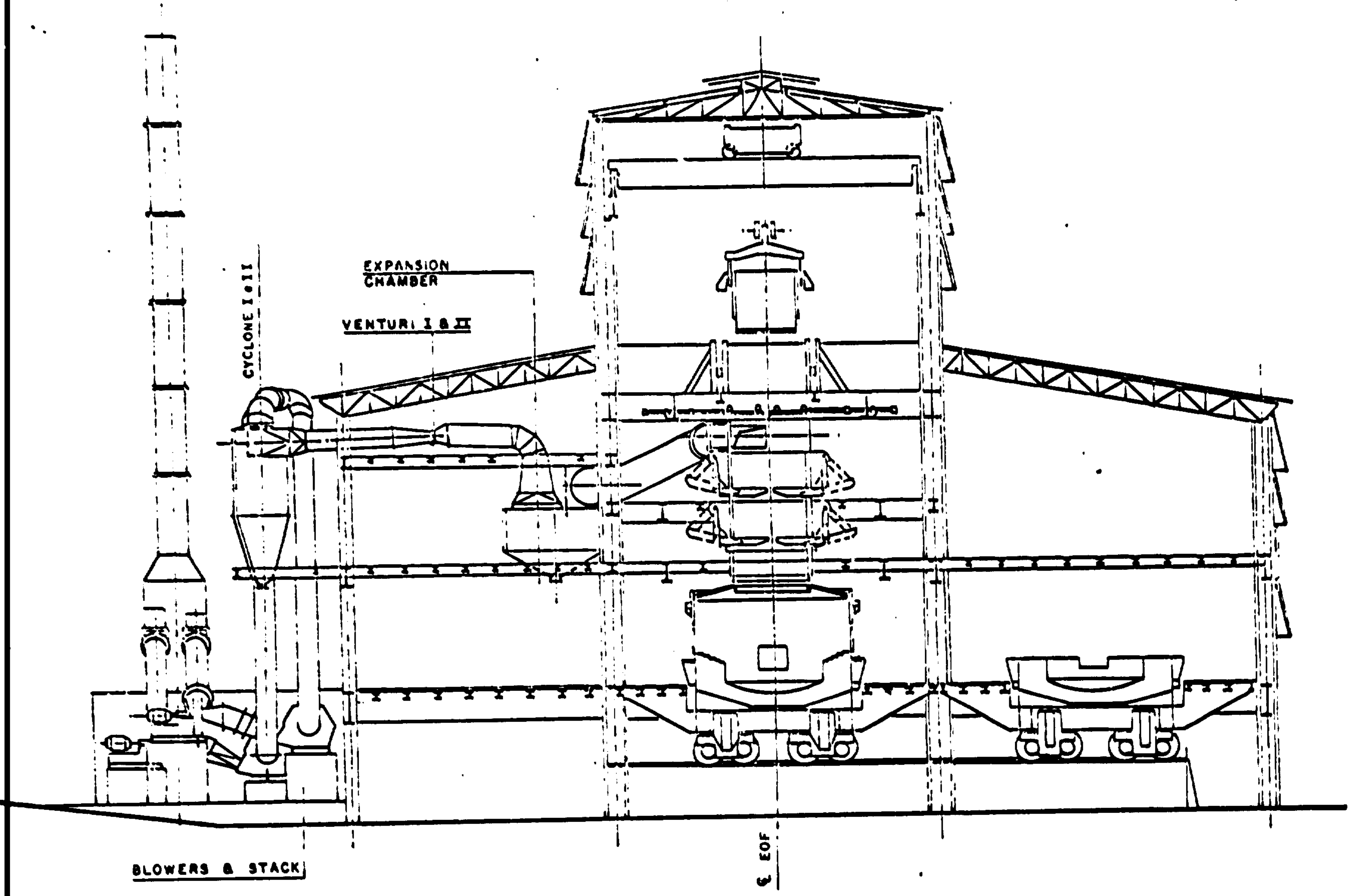

Fig. 3-60t. EOF
Section

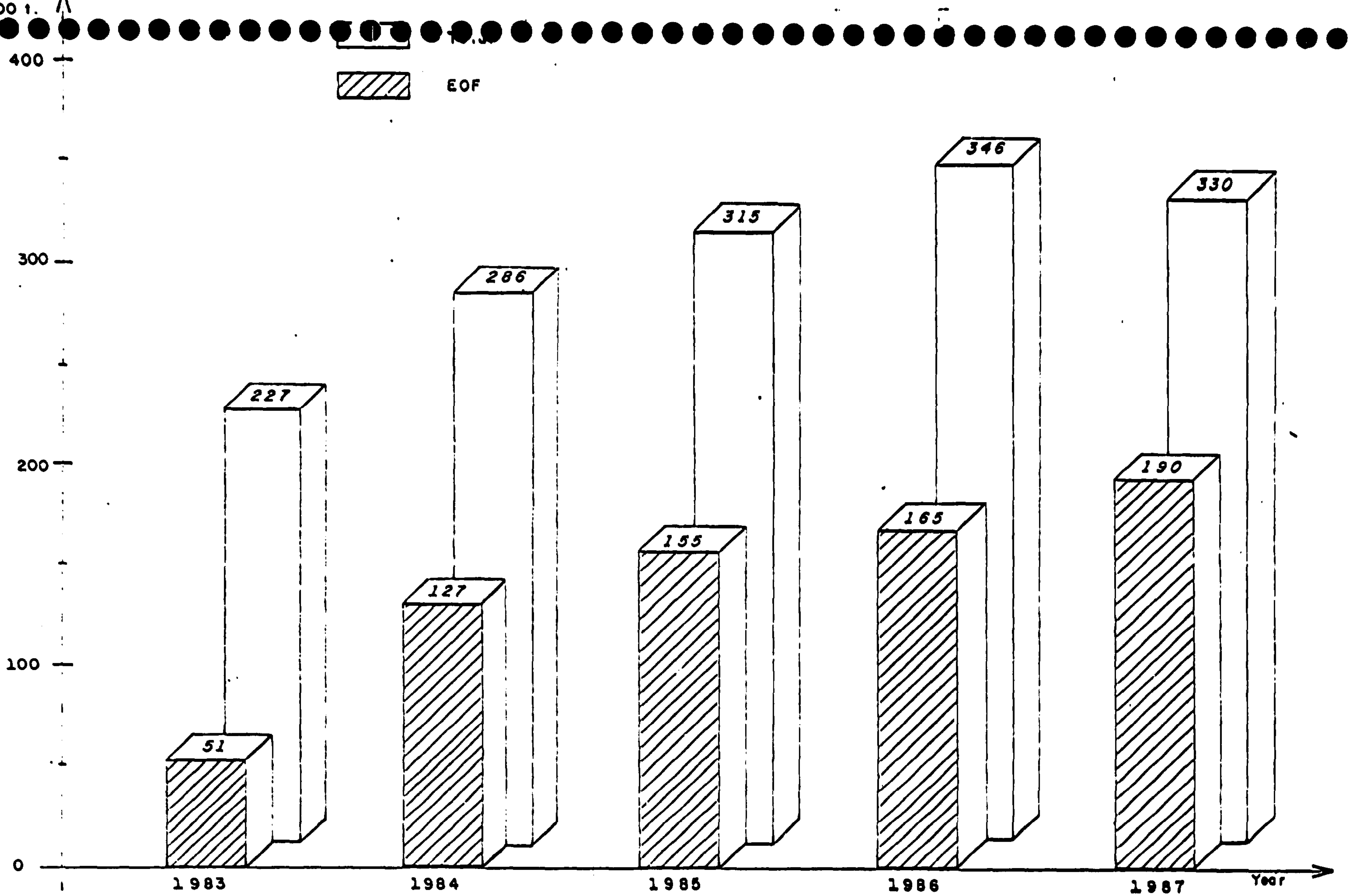

Fig. 4 – PAINS: Annual Steel Production(1000t. of good billets)

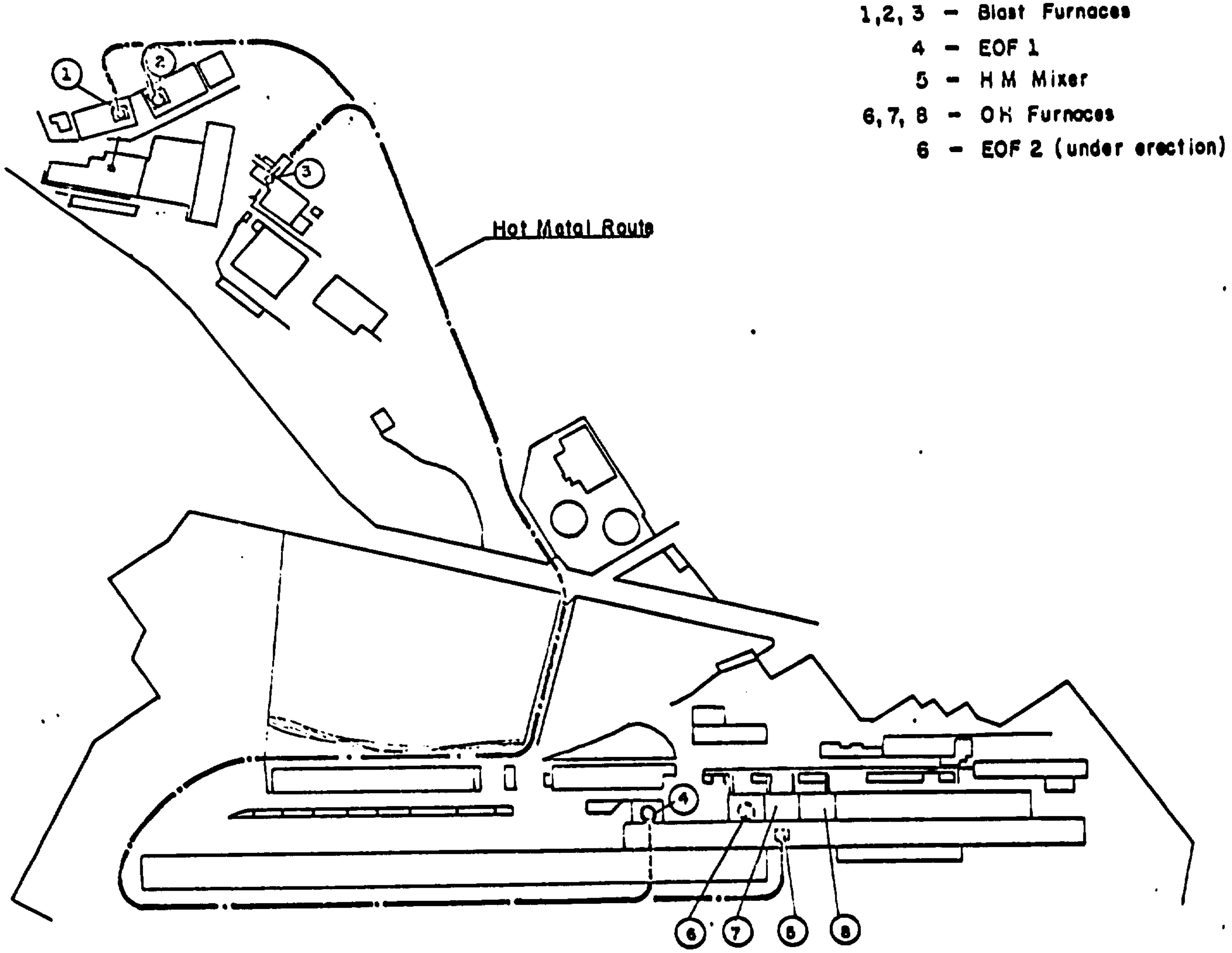

Fig. 5 – PAINS Plant: General Layout

ANNEX 3

SMELTING REDUCTION PROCESS FOR IRON AND STEELMARKING

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PANEL DISCUSSION: ALTERNATIVE ROUTES FOR IRON AND STEELMAKING

SMELTING REDUCTION PROCESSES FOR IRON AND STEELMAKING

Orvar Nyquist

Executive Vice President

SSAB Svenskt Stål AB

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1. INTRODUCTION

The dominant method to make iron and steel today is the blast furnace basic oxygen furnace route. In this route a well prepared burden of agglomerated iron ores is reduced with high quality coke in a big blast furnace to make well defined hot metal which after desulphurising treatment is blown to steel in a BOF converter.

In spite of its age the blast furnace process has successfully withstood all attacks from alternative processes mainly due to the considerable development which has taken part during the last decades. Today a modern blast furnace is an extremely efficient computer controlled unit.

To ensure trouble free operation of a modern blast furnace the iron ore concentrate has to be agglomerated. Coal cannot be used as the main fuel of the blast furnace but has to be converted into high grade coke. The agglomeration of the ore concentrate and the coking of the coal are costly processes, representing about 20 percent of the cost of the hot metal produced. Furthermore to be competitive a production system based on the blast furnace has to work on a rather large scale, above 1 to 1.5 Mt/year of crude iron.

Since the 1950s considerable efforts have been made in many countries to produce iron on a small scale at low cost by avoiding agglomeration and coking. The very competitive blast furnace and the general decline in the production of steel in the industrial world have contributed to the fact that none of the proposed methods has yet been realised on a commercial scale.

Despite earlier failure to achieve an economic process several processes are now under way and close to a commercial stage.

The economic incentives to find methods other than that of the blast furnace can be summarised as follows:

- to avoid agglomeration of the iron ore concentrate;
- to replace the costly blast furnace coke with cheaper fuels;
- to create a process that can be economic in a relatively small scale;
- to have less environmental problems and costs.

Earlier in this century the sponge iron processes were developed as an alternative to the blast furnace route. However, in the sponge iron processes the reaction rate is slow and no separation of metal and slag takes place. Therefore great interest was focused to develop a smelting reduction process where a substantial part of the reduction should take place in the liquid state.

Historically methods have been proposed and tried in the 1920s by Basset in a cement kiln for production of clinkers and iron for iron making in rotating furnaces and in the 1930s by Stürzelberg for iron production and of pyrite ash.

A true smelting reduction process was the DORED process developed in Sweden during the 1960s, where iron ore concentrates were added on the top of a coke bed floating on molten iron and slag bath in a fast rotating converter. The carbon monoxide from the reduction was completely burnt to carbon dioxide with oxygen over the bath. In spite of low consumption of coke the process failed due to the heavy lining attack from aggressive iron oxides in the very hot oxidising atmosphere. At the same time the flame smelting method for iron making was tried at BISRA which also failed due to refractory problems. Both these processes have influenced the further development of ELRED and INRED processes.

Development of the new generation of processes that will be described below started during the 1970s and 1980s. So far none of these processes has yet come into commercial production.

2. SOME BASIC PRINCIPLES

In the blast furnace system coke from the coking plant and sinter from the sintering plant are charged at the top of the furnace in such a way that good permeability of gas is ensured. In the blast furnace shaft the reduction and melting of the reduced iron is carried out more or less simultaneously, in different parts of a single reactor, Figure 1.

In most of the smelting reduction processes these reactions have been divided into two stages in separate reactors, Figure 1. In the first step iron ore oxide is preheated and prereduced and in the second step the final reduction and smelting takes place. In this way it is possible to maintain a balance between the quantity of gas evolved in the final reduction, e.g. smelting reduction at 1,400 to 1,500°C, and that required for the prereduction of the iron oxides. Furthermore it is possible in this way to optimise the utilisation of the reduction agent, coal.

Since the iron oxides only need to be reduced to about 50 percent, the reduction process is fast and the sticking phenomena normally encountered in reduction to sponge iron can be avoided. Thus the prereduction can be carried out in a fluidised bed. In this way fine grained iron oxides can be used directly and the sintering or pelletising operation can be avoided. The prereduction process can naturally also be carried out in the classical and well proven shaft furnace. However, in this case lump ore must be used or iron ore concentrate has to be sintered or pelletised before reduction.

The final smelting reduction operation can be carried out in an electric arc furnace, a shaft furnace or a converter. In the following description, the different smelting reduction processes have been classified in the following groups:

- Methods using electric energy for final smelting
- Methods using oxygen injection for final smelting

3. ELECTRIC MELTING OF PREREDUCED IRON ORES

The ELRED process

The ELRED process was developed jointly by the Swedish companies Stora Kopparberg and ASEA. The work started already in 1971. The basic idea was to use the carbon monoxide gas formed during reduction for electric power generation. The process is divided into three main operations, Figure 2. In the first step the iron ore concentrate is prereduced to 60 to 70 percent. In the second operation the final reduction takes place in a DC arc furnace and in the third operation electric power is generated from the off gases from the prereduction and final reduction. The off gases can alternatively be utilised for heating purposes in the steel plant, thus avoiding investment in a small power plant.

The prereduction takes place in a circulating fluidised bed which operates under a pressure up to 5 bars and at a temperature of 950 to 1,000°C. Air and coal powder are blown in to generate the heat and reducing gas necessary for the ore reduction. The high velocity of the gas together with excess of coke particles in the bed contribute to a uniform temperature and to avoid the sticking of the reduced particles. The prereduced ore is discharged from the bottom of the reactor to the electric arc furnace.

The DC arc furnace, Figure 2, has the central electrode connected to the negative pole of the rectifier. The positive pole is connected to the bottom electrode in direct contact with the bath. The hot prereduced ore from the reactor is charged together with suitable fluxes through the bore in the electrode. The hot material at 600 to 700°C is fed into the arc submerged in the slag and rapidly smelted and reduced. The foaming slag is continuously tapped. The hot metal is intermittently tapped leaving about 20 percent of metal in the furnace.

The hot metal contains approximately 4 percent carbon and very low silicon and manganese content, around 0.05 percent, but a relatively high sulphur content. After tapping, the hot metal is treated in a conventional way for removal of sulphur before steelmaking.

Full scale tests of the final reduction stage were carried out at the SSAB Domnarvet steel plant in 1977/1978 in a 30 t furnace. Tests of the prereduction stage were performed by ASEA in Sweden.

The INRED process

The development of the INRED process started in 1972 at Boliden AB in Sweden with the first aim to produce hot metal out of pyrite cinder.

The method has been developed in several stages and tested and adjusted in pilot plant trials (3 t/h) in 1978 and in a demonstration plant 1982/1984 with a capacity of 8 t/h at the MEFOS research plant in Lulea, Sweden.

The reduction of the ore in the process occurs in two stages which both take place in one single reactor. This is schematically shown in Figure 3. The main raw materials are iron ore concentrate, bituminous coal and limestone. Heat and gases are generated with oxygen and electricity. The products are hot metal, slag and the electricity needed for the process. Iron ore concentrate is prereduced to wustite (FeO) during the flash smelting of the concentrate using coal and oxygen in the upper section of the reactor. In this first stage up to 90 percent of the process energy may be supplied. The final reduction is made in an electric furnace, which forms the lower part of the reactor where the balance of the required energy is supplied by electricity.

Hot metal and slag are tapped from the bottom of the reactor. The waste gases are completely burnt with oxygen and from the heat of these gases steam is produced in the cooling system of the reactor which is connected to a waste heat boiler. Superheated steam from this boiler is used to drive a steam turbine generator producing electric power for the oxygen plant, the electric furnace and auxiliaries.

The construction of an INRED iron plant appears in Figure 3. The walls of the flash smelting chamber consists of panels of boiler tubes. Boiler tubes are also used in the central gas take off in the roof of the chamber. Into this chamber jets of the raw materials and oxygen are tangentially blown to create a vortex. A temperature of 1,900°C is maintained in the gas atmosphere of the chamber, where oxide materials in the feed rapidly become molten and fall down together with some formed coke on the bed of reacting materials floating on the top of the molten slag and iron.

During the final reduction the temperature drops rapidly to the temperature of the bath about 1,450°C. Due to the high temperature of descending material (1,600 to 1,650°C) the need for heat for the final reduction of iron oxide in the bed is in the order of 300 kWh/ton, which is added in form of electricity in a submerged arc furnace where final reduction takes place. Consumption figures appear in Table I.

The Plasmasmelt process

The development of metallurgical processes based on plasma technology started in 1972 at SKF Hofors in Sweden. The main principle of these processes is that electric energy is converted into heat energy in a plasma gas, independent of the gas generation.

Also this smelting reduction process, Plasmasmelt, is a two stage process, Figure 4, where fine grained iron ore concentrate in the first stage is prereduced in fluidised beds and transferred with reducing gas to the final reduction stage. This takes place by injection of this prereduced material together with coal and slag formers into the bottom of a shaft furnace which is filled with coke and provided with plasma burners.

The process has been tested since 1981 in pilot plants with 1.5 MW burner and a capacity of 0.5 to 1 t/hour. In 1984 a plant was erected for upgrading of dust from steelworks. This plant is equipped with three 6 MW plasma generators and has an annual capacity of 70,000 t/year. This autumn another plasma plant for production of ferrochromium will be taken into operation in Sweden. This plant will produce 80,000 t/year.

The independent heating by the plasma burners makes it possible to control the generation of gas in the final stage of reduction and optimise the utilisation of the generated reducing gases and avoid recirculation of big gas volumes.

In the extremely hot gas temperature of 3,000 to 5,000°C in the plasma generator the prereduced ore concentrate is rapidly reduced and smelted and recarburised to a hot metal of conventional blast furnace quality. Slag and metal are tapped in the same way as from the blast furnace.

The generated carbon monoxide and hydrogen gases from the final reduction leave the shaft at temperatures of 1,000 to 1,200°C. About 20 percent of the gas is generated from the coke in the shaft and the rest from the injected coal.

After cleaning and cooling the gas is fed to the prereduction stage at a temperature of about 800°C. The off gases from the prereduction contain 10 to 15 percent carbon monoxide and hydrogen and are used for drying and preheating the ore concentrate.

When electricity is expensive compared to coal it can be preferable to replace electric heating by burning coal with oxygen in the final reduction stage. In the tables and figures this method is called "Plasmasmelt OXYGEN". Consumption figures for the process appear in Table I.

4. FINAL SMELTING THROUGH OXYGEN INJECTION

The COREX process

Contrary to the previously described smelting reduction processes where electric energy is used more or less for final reduction the COREX process uses heat from carbon combustion with oxygen injected in the coke bed on the bath. The development of this process earlier called KR, was started in 1977 at Kehl in West Germany by Korf Stahl AG.

The concept of the process is also based on the two stages of reduction, Figure 5. Pelletised iron ore is prereduced in the first step using generated reducing gas from the final second step. The separating of the reducing stages makes it possible to use cheap coal for recarburisation, gasification and heating.

Unlike the earlier described Swedish processes for smelting reduction the COREX process uses the agglomerated iron ores or lump ores of uniform grain size. Requirements on the properties of the ore are somewhat less stringent than for direct reduction both physically and chemically due to the successive smelting, which can tolerate higher contents of small particles and gangue than normal sponge iron. A wide range of coals has been tested from lignite to anthracite. It is preferred to use a low sulphur coal in order to avoid extensive desulphurisation of the hot metal. Slag analysis is controlled by additives of limestone, dolomite and sand depending on the composition of the gangue.

The gas generation takes place by partial oxidation of coal in a fluidised bed over the bath as is schematically seen in Figure 5 showing the COREX process system. To the so-called melter gasifier the hot (800 to 900°C) prereduced iron ore from stage 1 is fed as well as the coal and the fluxes. The reactor consists of two zones, a lower gasification zone where the coal is gasified and the prereduced material melted to hot metal and an upper zone called the calming zone where entrained dust particles settle and recirculate in the fluidised bed. The gas is leaving at a temperature 1,000 to 1,200°C, mixed with cooling gas to 850°C, cleaned and led to the prereduction furnace. The other products from the reactor, hot metal and slag, is tapped from the bottom.

The prereduction furnace is a shaft furnace of a well known design within the DRI technique. The gas ascends counter currently through the burden, which descends by gravity and is transferred to the melting reactor by a controllable transport system. Metallisation is supposed to be at least 92 percent.

The top gas is cleaned, cooled and often mixed with surplus gas from the gasifier. The energy in the gas can be used for various energy demands as generation of electricity, oxygen etc. Consumption figures appear in Table I.

The COREX process seems to be the first of the modern existing smelting reduction processes to be applied commercially on iron ores. ISCOR in South Africa has thus decided to erect a 300,000 t/year plant at Pretoria Works which will start operation next year.

The COIN process

This process is an example of a series of processes for gasification of coal, which also can be used for production of hot metal through smelting reduction.

In the COIN (Coal Oxygen Injection) process the development work started by Krupp in West Germany in the late 1970s. The concept of the process is to inject fine grained coal and oxygen through nozzles in the bottom of a converter melting prereduced iron ore or scrap using the heat of the partial combustion of the coal, Figure 6.

The simplest possible way to combine a prereduction stage with final smelting in the converter is shown in Figure 6 where the gases leaving the converter consisting of carbon monoxide and hydrogen are used untreated in a conventional direct reduction process. Recently the main activities have been directed towards the combination of COIN with prereduction in a circulating bed. The calculated consumption figures appear in Table I.

Extensive research work is going on today in many countries to use the principles of this process as a general way of coal gasification. For the moment two different groups Klöckner-Humboldt-Deutz-Sumitomo (MIP) and Inter Project Service-Nippon Steel (CIG) are, independently of each other, carrying out such development work at the MEFOS research plant in Luleå, Sweden. In West Germany a third group Klöckner Maxhütte CRA (KSG) has also been working along these lines.

The SC process

The SC process is a smelting reduction process invented by Sumitomo Metal Industries in Japan, which started their development research in 1981. The SC process is divided into two stages, Figure 7, the first of which is a conventional reduction of pelletised ore in a shaft furnace using the reducing gases coming from the second melting gasifying stage. This final step takes place in a shaft furnace to which coke and the prereduced hot material from the first step are added at the top and oxygen and pulverised coal at the bottom.

The SC process can use low quality coke and has coal as the main reductant. Compared to the blast furnace the productivity of the final shaft is increased. This is mainly due to reduced gas volumes because no direct reduction seems to take place during melting.

The process has been tested by Sumitomo in a pilot plant, where the reduction shaft furnace and the melter gasifier were installed side by side. The consumption figures appear in Table I.

Kawasaki Steel has also developed a similar two stage process, Figure 8, which has been tested at a pilot plant facility at Chiba Works in Japan.

5. TECHNICAL AND PROCESS COMPARISONS OF THE DIFFERENT METHODS

Table II is a summary of the various characteristics of the different processes. As has been mentioned earlier one main objective for the development of the new processes was to find ways to avoid sintering or coking and also to create flexibility to use a wide range of iron ores and inexpensive low grade non coking coal.

As has been summarised in Table III the INRED, ELRED, Plasmasmelt, COIN and Kawasaki processes can all use fine grained iron ore concentrates directly. In the COREX and SC processes on the other hand pellets or screened lump ore have to be used as the prereduction takes place in a shaft. This is also necessary in one of the COIN concepts.

All processes can utilise non metallurgical coal, but Plasmasmelt, Kawasaki and SC also need coke as a filler of the final reduction and smelting shaft. In these cases the consumption of coke should be rather small.

The electric arc furnace is used in the ELRED and the INRED processes for the final smelting. The necessary electric power is generated internally from the off gases in a power station close to the plant.

A shaft furnace design is utilised in the Kawasaki, SC and the Plasmasmelt processes. In these cases the shaft is filled with coke. In Plasmasmelt and Kawasaki the prereduced iron ore concentrate is injected through tuyeres at the bottom of the furnace where it is melted and carburised to form hot metal. In the SC process all the prereduced iron ore is charged at the top of the shaft. In the Plasmasmelt process the energy is supplied through the plasma unit whereas in the Kawasaki and SC the energy is created by burning coal with oxygen. In the Plasmasmelt Oxygen part of the electricity is replaced by burning coal with oxygen.

The COIN process uses a converter type furnace where energy is supplied by burning oxygen with coal. Oxygen is supplied either by blowing it on to the bath or through the bottom of the furnace. In the COREX process the smelting and gasification takes place in a reactor that has similarities to the bottom part of a blast furnace.

In order to compete, the necessary downstream processes must not be more expensive than those in the blast furnace basic oxygen furnace route. This is also the case for all the described methods. The necessary treatments of the hot metal depend solely on the qualities of ore and coal, as in the blast furnace route. Thus desulphurisation is necessary in most cases.

In the ELRED and COIN processes the produced hot metal has a very low silicon content, thus a slagless steelmaking practice will follow, which will have some cost and quality advantages.

In the COREX process on the other hand the hot metal produced seems according to published data, to have a high silicon content around 2 percent which means somewhat higher cost for conversion into steel.

Energy requirements

Table IV shows the energy consumption in the different processes. As can be seen all the processes have the same order of magnitude of energy requirements as that of the blast furnace.

Most of the processes produce excess gas with high calorific value. To get the process economic this excess gas has to be utilised. The excess gas can be used for such applications as oxygen generation, heating of steel mill furnaces, or as in the case of ELRED, for generation of electricity. In the INRED case all the excess gas i utilised internally in the process.

It should be pointed out that, with the exception of Plasmasmelt, even in the processes where electricity is used for final smelting, coal is the primary source of energy.

Capital requirements and scale factors for process equipment

As the new smelting reduction processes are independent of coke oven plant and in most cases also of sintering plant, they can be built on a much smaller scale than would be feasible for a system based upon a blast furnace, where the minimum economic size generally is considered to be around to 1 to 1.5 Mt annual capacity. However the smelting reduction processes can be scaled up, even though with the present knowledge it is hard to envisage a one unit plant above 1 Mt. For capacities above that one has to calculate with more than one unit. Some scale up problems may be connected with the INRED, COREX and COIN processes above 0.5 Mt annual capacity.

In the analysis below, the capital expenditures needed for the smelting reduction processes are based upon information from the equipment suppliers. Strictly the costs are valid for the country of process origin only. It is reasonable to assume that these costs are more reliable for the processes which have been extensively tried in pilot or demonstration stages than for those who have not yet reached these development stages.

It should be pointed out however that, in general, suppliers are known to underestimate when quoting for capital budget figures as compared to the figures they give as firm quotations. Also there is a tendency to underestimate the cost for services and anti-pollution measures.

Assumptions about equipment productivity is another important factor and only full scale operation can give reliable data. The capital expenditure for the conventional blast furnace route as well as equipment needed for BOF steelmaking are based upon latest experience.

The capital expenditure needed to build a 1 Mt integrated steel plant in the Antwerp, Rotterdam, Amsterdam area (ARA) is shown for the various processes in Figure 9. The Plasmasmelt route has lower investment costs than the other processes mainly because no equipment for electric power generation is included and because the low consumption of fossil fuel means that there are only small volumes of gas to be cleaned. Also the COIN process claims low investment cost. This is due to a simplified steelmaking plant, which can be built because of the low carbon content in the hot metal. The COREX process has investment cost for agglomeration but needs no external desulphurisation unit.

It is clearly shown in Figure 9 that the disadvantage from the investment point of view with the blast furnace-BOF route is the cost for agglomeration and cokemaking plant. The smelting reductions units on the other hand, with the exception of the Plasmasmelt route, have high cost for oxygen plants.

However it is interesting to note that the investment cost for the reduction unit itself is lowest in the blast furnace-BOF route. Thus a blast furnace costs less to build than the smelting reduction units.

The total investment cost for the integrated blast furnace basic oxygen furnace system is about 340 to 360 US$/annual tonne of steel as compared with 240 to 330 US$/annual tonne of steel for the smelting reduction routes. These costs refer to a unit size around 1 Mt/year.

To obtain investment values of equipment sizes which differ from the normal size, the 2/3 rule has been used. The estimated cost of investment (I_1), at a selected capacity (V_1) is then calculated by the known investment cost (I_2) at a given capacity (V_2) according to the formula:

$$I_1 = I_2 (V_1/V_2)^{2/3}$$

The calculated capital cost per tonne of liquid steel for the various processes as a function of scale is shown in Figures 10 and 11 for ARA location. The discontinuities in the curves indicate that an additional smelting reduction unit has been added to the system. In the blast furnace-BOF route it has been assumed that a second blast furnace is added when the capacity increases above approximately 2 Mt/year.

Figures 10 and 11 show that when the scale increases the capital cost per tonne of liquid steel becomes lower for the blast furnace BOF route than for the smelting reduction routes. An exception to this is the COIN process, where the low capital investment yields a low capital cost per tonne.

For capacities below 1.5 M annual tonnes all the smelting reduction routes have somewhat lower capital costs than the corresponding blast furnace-basic oxygen furnace route. It has to be stressed at this point however that most investment data for the smelting reduction processes are based on estimates only.

6. MANUFACTURING COST COMPARISONS

In Figure 12 a total manufacturing cost comparison for the production of liquid steel has been made between the different smelting reduction processes and the blast furnace basic oxygen furnace route. The calculated manufacturing cost is the sum of raw material costs, operating costs and capital costs, including depreciation and interest. In each case the calculations have started at the stage of iron ore concentrate and coal and finished at the liquid steel stage. That means that the cost of agglomeration as well as coking, desulphurisation, etc. are all included when it is necessary for the process route. In the case of the Plasmasmelt and SC process the limited amount of necessary coke is supposed to be bought at a price which equals the cost of manufacturing coke in a 700,000 t/year coke plant. Consumption figures for raw materials, labour, etc. for the different processes are given in Table I. The corresponding data for the blast furnace are mainly taken from operational data at Nippon Steel Oita plant for a sinter charged furnace and from SSAB Svenskt Stål, Luleå plant for a pellet charged furnace. The unit costs for raw materials, labour and other cost elements, which are listed in the appendix are based upon price and dollar exchange rate at April 1, 1986.

The calculations are made for locations in ARA, Tubarão and Tokyo Bay. Costs for repair and maintenance have been assumed to be 4 percent of the investment cost for the equipment. Cost for overhead, research and development have been assumed to be 65 percent of direct labour. In ARA and Japan the capital charges are based upon discount + 5 percent as shown in the appendix. That means an interest of 9.5 percent in ARA and 9 percent in Japan. In Brazil an average rate of interest is estimated to be 15 percent, 9 percent from the World Bank and 21 percent from the international capital market. The depreciation of fixed assets is 12 years. Capital charge for current assets are based upon necessary raw materials and other inventories for two months of operation. Investment costs are calculated for the volume needed in each step of the different routes.

As has been pointed out earlier, besides the price of ore and coal the credit value for the off gases has a dominant role in the calculations. Local conditions for how to utilise the excess gas can vary greatly. In the calculations the excess gas has been priced according to local credit value per GJ for BOF gas.

As can be seen in Figure 12 at the ARA location the total cost of production in a 1 Mt plant varies very little between the various routes and are within the limits of uncertainties in the calculations. At the present stage of development and knowledge it thus is impossible to differ between the various routes based upon economic calculations only. However, as expected when the plant size decreases as shown in Figures 13 and 14 the smelting reduction process will give a lower manufacturing cost. In the most favourable position, that is at a low annual tonnage around 500 kt, the INRED route which has the lowest cost, give a manufacturing cost which is 15 percent below the cost for the blast furnace route.

Also for location at Tubarão, Figure 12, the various routes give, in a 1 Mt plant, manufacturing costs which are close to each other.

On the other hand in the Tokyo Bay location, Figure 12, with very high cost of electricity (almost double that of ARA and Tubarão) and high local value of credit gas, the Plasmasmelt and COIN give significantly higher costs for liquid steel than the other processes. The present situation in this location is such that the generated excess gas can be utilised in production of electricity in a way which is favourable from the economic point of view.

It is interesting to note that Figure 12 also shows that for the classical blast furnace-basic oxygen furnace route the calculated costs of steel production are approximately the same in Tokyo Bay as in the ARA location, 175 US$/t of liquid steel. In Tubarão on the other hand the cost are significantly lower, 165 US$/t or 6 percent. This difference will be 19 percent if capital cost for investment is excluded. Cost of raw material and manpower are the most important factors explaining this difference between Tubarão (FOB location) and ARA/Tokyo Bay (CIF location).

When the different smelting reduction methods are compared to each other, consumption of raw material, labour, etc. are approximately the same for all the different methods. Of greater influence are local factors like availability of and price of coal and electricity. Figure 15 shows that when cheap electricity from hydroelectric power or atomic energy is available, Plasmasmelt, which has an optimal use of energy within the process, should have good prospects of success. In a country where cheap coal or other fossil fuels are available but the price of electricity is high, ELRED, which yields electricity as a by-product should be competitive. INRED and COREX, which are also coal based in this respect occupy intermediate positions.

If a situation of over capacity exists the introduction of a new iron and steelmaking process has to meet very tough economic criteria. Thus the cost of production including capital cost for the new process, has to be lower than the cost of production excluding capital cost for the existing process. Figure 16 clearly shows that if this factor is taken into account it is, in the present situation, impossible for the new smelting reduction processes to compete with the classical blast furnace basic oxygen furnace route in the locations investigated.

If any of these new methods are going to be introduced there must be other local reasons. Such a reason could be availability of local non coking coals, cheap electricity, desirable increase of marginal tonnage of liquid hot metal, gas generation, etc. Building a new coke plant in an existing steel plant, for instance, requires much capital and gives pollution problems. Here a smelting reduction unit can be a solution if hot metal can also be used.

For instance the decision to build a COREX unit of 300,000 t/year in South Africa was due to several factors, like the availability and cost of coking coal as opposed to the ready availability of low cost non coking coal with a high ash content, the need for a substantial supply of fuel gas at the particular works, pollution control requirements and the need to augment the scrap charge with a virgin Fe source.

7. SMELTING REDUCTION IN COMBINATION WITH SCRAP MELTING IN THE ELECTRIC ARC FURNACE

It should also be mentioned that one field of application for the new smelting reduction processes could be in combination with an electric arc furnace to produce steel from scrap to liquid metal. Such a mixed process where the arc furnace is fed with liquid metal low in sulphur and silicon could be economic even on a small scale. By comparison with cold scrap charging only, this offers a substantial increase in productivity of the electric arc furnace and hence lower power and electrode costs.

Many electric arc operators are facing increasing tramp element problems and a source of liquid iron will assist them in diluting these elements.

The mixed processes also have quality advantages due to the heavy boil that occurs during decarburisation. Thus the manufactured steel can be used for a wider variety of products.

Such a plant built for utilising cheap purchased scrap and liquid metal will probably be very economical on a scale much below 0.5 Mt a year. It could be a strong proposition in an area with shortage of quality scrap. By changing the ratios between hot metal and scrap the mixed process also gives an interesting economic way to out balance the frequent fluctuations in scrap prices.

8. FINAL REMARKS

A number of smelting reduction processes exist today as pilot and demonstration plants i.e. ELRED, Plasmasmelt, INRED and COREX processes. Besides these there are also processes that exist at concept or pilot stage, for instance COIN, SC, CIG, MIP, KSG and Kawasaki processes. So far none of these projects have yet reached the commercial stage for iron ore reduction. One of the processes, COREX, will be in operation next year with a rated capacity of 300,000 t/year. A Plasmasmelt unit of 70,000 t/year is in operation for upgrading of steel furnace dust to metals and another Plasmasmelt plant for production of 80,000 t/year ferrochromium will be in operation this fall.

One of the main objectives with these processes is to bypass the coke oven and mainly utilise cheap non coking coal and also to have a high degree of flexibility towards iron ore and other raw materials. Thus, in most cases iron ore concentrate can be used without agglomeration. The concept of the smelting reduction process is to produce a liquid product, hot metal, which then can be processed downstream to steel by existing steelmaking technology, for instance in a basic oxygen furnace.

As the consumption of ore and manpower are approximately the same in all processes, the economic result of the new processes depends mainly upon the ability to utilise cheap energy as completely as possible within the process or in such a manner that surplus energy in the form of gas or electricity can be entirely used for other purposes.

Economical calculations which are based upon data given by the equipment suppliers indicate that at locations like ARA, Tokyo Bay and Tubarão in Brazil the cost of manufacturing liquid steel by the smelting reduction route is somewhat lower than for the classical blast furnace basic oxygen furnace route, when the plant size is smaller than 1 to 1.5 Mt/year steel. It must be pointed out however that the difference is small and considering the uncertainties in the basic data regarding equipment productivity, refractory and fuel consumption and capital expenditure in the new processes, the difference is probably within the error of the calculations.

However, the difference will increase for small plant sizes. At a plant size of 500,000 t/year and in the ARA location this difference to the blast furnace route for the smelting reduction process yielding the lowest calculated manufacturing cost, is calculated to be approximately 15 percent.

Within the various smelting reduction processes themselves the difference is small in the ARA and Tubarão locations. In the Tokyo Bay area greater difference exists due to high cost of electricity.

Local conditions may vary substantially and thus favour one or other of the processes. In countries with cheap electricity Plasmasmelt should give the lowest manufacturing cost. On the other hand coal based ELRED should have good prospects in countries with cheap coal and high electricity prices. The INRED and COREX processes which also are coal based hold, in this comparison, intermediate positions.

The economic calculations clearly show that it is not possible for the new smelting reduction processes to compete with the already existing modern blast furnace-basic oxygen furnace system, as in this case the capital cost for the existing furnace can be disregarded (sunk cost). On a short term basis in the present situation of over capacity it is therefore hardly expected that any of the new processes will be built in the industrialised western world.

However, when new investment in steelmaking capacity are planned the new processes will have a possibility to be realised when plants of low capacity are built. One example could be a coal and iron ore based mini mill. Also in combination with electric arc furnace steelmaking, hot metal from a smelting reduction unit could replace part of the scrap. It is also possible that when old capacity is going to be replaced local conditions in an existing steel plant could favour the building of a smelting reduction unit.

Today pilot plant and demonstration plant data exists for some of the processes. Only full scale plant operation however can definitely show whether the smelting reduction processes in the long perspective will be a successful competitor to the blast furnace route.

ACKNOWLEDGEMENTS

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APPENDIX
GENERAL CONDITIONS FOR THE CALCULATIONS

Exchange rates of some currencies April 1, 1986:	1 NLG = 2.7955 SEK 1 US$ = 7.355 SEK 1 US$ = 2.631 NLG 1 SEK = 0.3577 NLG 1 NLG = 0.381 US$ 1 SEK = 0.136 US$
Depreciation period:	12 years
Stock turnover:	2 months
Official discount rate April 1, 1986:	Netherlands 4.5 % Japan 4.0 %
Interest rate for the calculation:	Netherlands Discount + 5 % = 9.5 % Japan Discount + 5 % = 9.0 % Brazil World Bank 9 %, International currency market 21 %. 50/50 financing => 15 %

Raw materials (All figures in metric tonne units)

Pellet feed (ton)	Assumed price of Samarco pellet feed 21.01 ct/u FOB (67.56 % Fe). For Tokyo additional freight 6 US$/ton and ARA 5 US$/ton. For the latter location, the cost of ore handling is added. ARA 21.01 x 0.6756 + 5 + 2.7 = 21.89 US$ Tokyo 21.01 x 0.6756 + 6 + 2.7 = 22.89 US$ Tubarão 21.01 x 0.6756 = 14.19 US$
Micro pelletized concentrate	As concentrate above + 5 SEK/ton (0.68 US$/ton) ARA 21.89 + 0.68 = 22.57 US$ Tokyo 22.89 + 0.68 = 23.57 US$ Tubarão 14.19 + 0.68 = 14.87 US$
Sinter fines (ton)	Carajas sinter feed assumed price 27.5 ct/u FOB (67.5 % Fe). Freight and handling as for pellet feed. ARA 27.5 x 0.675 + 5 + 2.7 = 26.26 US$ Tokyo 27.5 x 0.675 + 6 + 2.7 = 27.26 US$ Tubarão 27.5 x 0.675 = 18.56 US$
Pellets (ton)	Calculated as Samarco pellets, price 34 ct/u (65.18% Fe), for the process routes without internal production of pellets. Freight as per above but handling cost 1.5 US$/ton. Addition 2% on tonnage price C&F for dust formation for ARA and Tokyo and 1% for Tubarão. ARA 1.02x(34x0.6518 + 5)+1.5 = 29.20 US$ Tokyo 1.02x(34x0.6518 + 6)+1.5 = 30.22 US$ Tubarão 1.01x(34x0.6518) = 27.43 US$

Scrap (ton)	ARA 100 US$ Tokyo 16.67 US$ Tubarão 84.34 US$
Limestone (ton)	Assumed content of $CaCO_3$: 98 % ARA 30x98/97.5 = 30.154 NLG(11.461 US$) Tokyo 12x98/99.3 = 11.843 US$ Tubarão 12.75x98/(54.4/56/100) = 12.87 US$
Dolomite (ton)	Calculated as limestone + 1.5 US$ ARA 11.461 + 1.5 = 12.96 US$ Tokyo 11.843 + 1.5 = 13.34 US$ Tubarão 12.87 + 1.5 = 14.37 US$
Burnt lime (ton)	Assumed content of CaO: 92 % ARA 170 NLG (64.77 US$) Tokyo 86x92/92.14 = 85.87 US$ Tubarão 47.10x92/93.76 = 46.22 US$
Burnt dolomite	Assumed equal with burnt lime price + 3 US$/ton ARA 64.77 + 3 = 67.77 US$ Tokyo 85.87 + 3 = 88.87 US$ Tubarão 46.22 + 3 = 49.22 US$
Steam coal (ton)	1.5 US$ charged for handling. Steam coal is imported to ARA and Tubarão. Spot price American Gulf-coast April 2, 1986 40 US$/ton (oil, coal & coke 1986:4/SPK) + calculated freight 6 US$/ton. ARA 40 + 6 + 1.5 = 47.5 US$ Tokyo 46 + 1.5 = 47.5 US$ Tubarão 40 + 6 + 1.5 = 47.5 US$
Coal for injection	Assumed being steam coal + 8 US$ for grinding. ARA 47.5 + 8 = 55.5 US$ Tokyo 47.5 + 8 = 55.5 US$ Tubarão 47.5 + 8 = 55.5 US$
Coking coal (ton)	Additional cost of 1.5 US$ for handling. The price of coking coal in Tubarão is calculated as price of steam coal + 12 US$. ARA 59.5 US$ Tokyo 61.9 US$ Tubarão 47.5 + 12 = 59.5 US$
Oil (kgs)	Calorific value 10 000 kcal/kg to be assumed for all oils. ARA 0.139 US$ Tokyo 0.199 US$ Tubarão 0.117 US$

Coke (ton)	For process routes without internal coking plant the price is based upon the total manufacturing cost of coke in an external 700 kt coking plant.	
	ARA	110.02 US$
	Tokyo	102.57 US$
	Tubarão	108.97 US$
Electricity (kwh)	ARA	0.04 US$
	Tokyo	0.079 US$
	Tubarão	0.041 US$
Credit of electricity (kwh)	To be based as 75 % of normal electricity price.	
	ARA	0.04 x 0.75 = 0.03 US$
	Tokyo	0.079 x 0.75 = 0.059 US$
	Tubarão	0.041 x 0.75 = 0.03 US$
Electrode paste (kgs)	ARA	3.8 SEK (0.517 US$) (assumed)
	Tokyo	0,571 US$
	Tubarão	3.8 SEK (0.517 US$) (assumed)
Coke oven gas (Gcal)	ARA	13.044 US$
	Tokyo	20.0 US$
	Tubarão	7.72 US$
Blast furnace gas (Gcal)	ARA	11.739 US$
	Tokyo	20.0 US$
	Tubarão	7.143 US$
BOF-gas recovered (Gcal)	ARA	13.04 US$
	Tokyo	20.0 US$
	Tubarão	7.143 US$
Manpower (manhours)	ARA	18.8 US$
	Tokyo	18.2 US$
	Tubarão	4.8 US$
Other raw materials	The following standard costs are assumed for other raw materials	
(ton)	Manganese ore	300 SEK (40.79 US$)
(kg)	Limestone	3 SEK (0.408 US$)
(kg)	Silica	0.02 US$
(ton)	BOF-slag	10 SEK (1.360 US$)
(ton)	Limebearing slag	55 SEK (7.478 US$)
(kg)	Ferro-silicon	5.8 SEK (0.789 US$)
(kg)	Ferro-manganese (high in carbon)	2.85 SEK (0.387 US$)
(kg)	AL-granules	7 SEK (0.952 US$)
(kg)	Tar	1.51 SEK (0.205 US$)
(kg)	Coke breeze	0.05 US$
(kg)	Steam	0.16 SEK (0.022 US$)
(m^3)	Water	0.12 SEK (0.016 US$)
(Nm^3)	Nitrogen	0.30 SEK (0.041 US$)
(kNm^3)	Blast (excl el)	5.80 SEK (0.789 US$)
(kNm^3)	Blast (incl el)	49.10 SEK (6.676 US$)
(kg)	Magnesite bricks	6 SEK (0.816 US$)

Table I: Consumption figures per tonne of desulphurised hot metal for smelting reduction processes

	BF coal injection		ELRED	INRED	Plasma-smelt	Plasma-smelt Oxy	COREX	COIN	SC
	Sinter	Pellets							
Sinter[1] kg/t	1,276								
Pellets[2] kg/t	177	1,408					1,474		1,418
Concentrate[3] kg/t			1,449	1,491	1,388	1,388		1,478	
Steam coal[4] kg/t	50	75	723	697	218	329	795	692	288
Coking coal[5] kg/t	610	549							
Coke[6] kg/t	57				75	156			204
Electricity kWh/t	88	67	-308		1,123	662	62	249	165
Electrodes kg/t			7	4.5					
Plasmaburner $/t					1.87	0.589			
Lime kg/t	70		35	15	25	25		61	40
Limestone kg/t	170	80	114	244			115		
Oxygen Nm^3/t	20		150	700		227	525	445	215
Labour manhours/t	0.63	0.45	0.44	0.26	0.25	0.25	0.33	0.35	0.23
Gas (credit) GJ/t	-4.5	-4.0	-	-	-	5.0	-8.8		3.9

---

[1] Carajas sinter fines 67.5% Fe

[2] Samarco pellets 65.2% Fe

[3] Samarco pellets 68% Fe

[4] US Gulf coast: C.v. 27.2 MJ/kg ash = 12%

[5] C.v. 31.4 MJ/kg ash = 2%

[6] C.v. 30.1 MJ/kg ash = 10%

Table II: Process characeristics of direct smelting reduction processes

PREREDUCTION

FLUIDIZED BED	SHAFT FURNACE	FLASH SMELTING
ELRED* SKF-PLASMA KAWASAKI COIN	COREX (COIN) SC	INRED

↓

FINAL REDUCTION AND SMELTING

ELECTRIC FURNACE	SHAFT FURNACE SMELTER	CON-VERTER
ELRED INRED	PLASMA COREX SC KAWASAKI	COIN

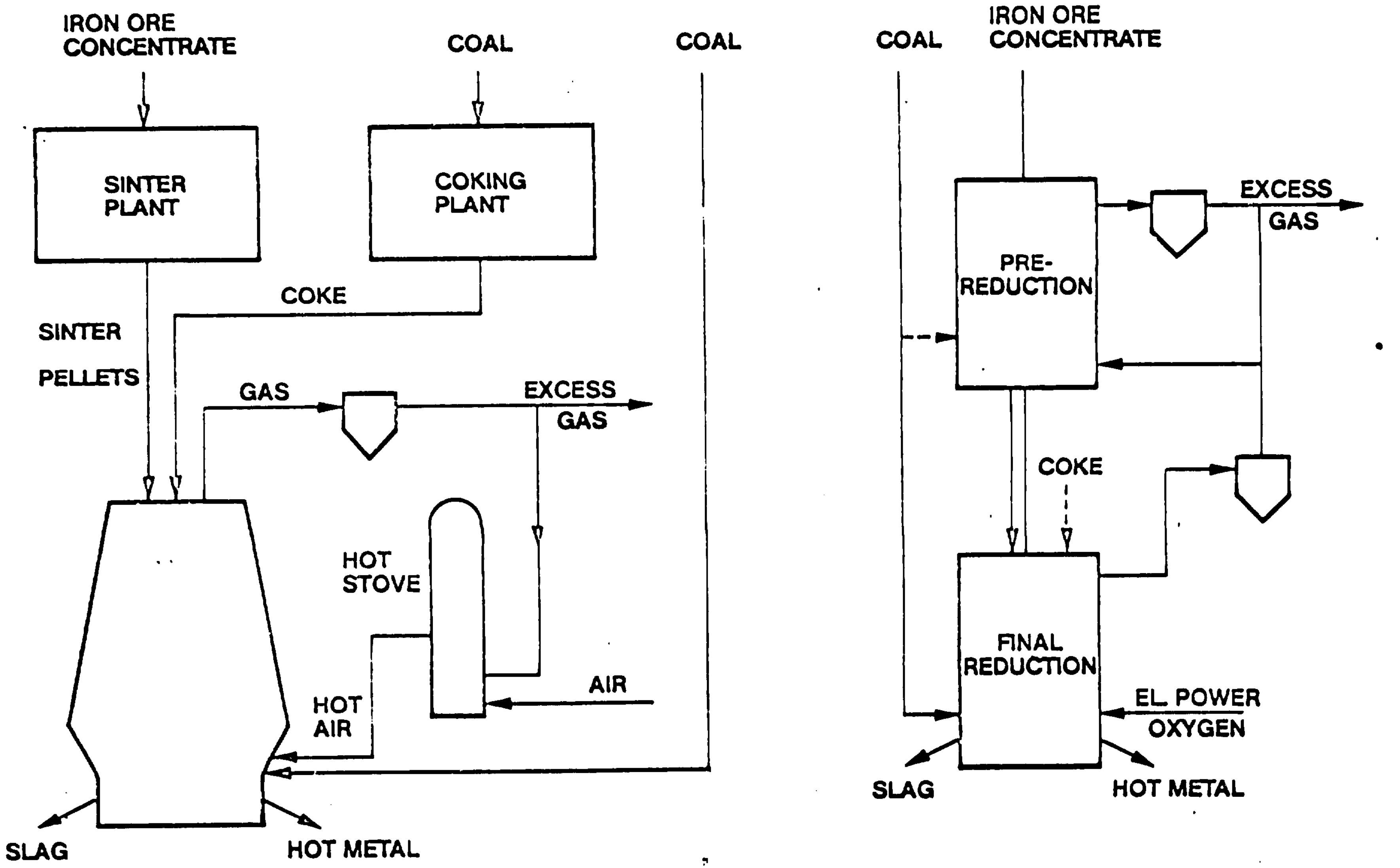
*Circulating fluidised bed

Table III: Raw material aspects

IRON ORE CONCENTRATES	IRON ORE PELLETS OR LUMP ORE
ELRED	COREX
INRED	SC
SKF-PLASMA	(COIN)
KAWASAKI	
COIN	

Table IV: Energy consumption in smelting reduction processes (GJ/t)

Process	Coking coal	Steam coal	Coke	Electricity	Other energy	Gross energy	Energy/ credit	Net energy
BF sinter	14.5	1.3	1.7	0.3	1.9	19.7	-4.5	15.2
BF pellets	13.1	2.0		0.2	2.7	18.0	-4.0	14.0
ELRED		19.7	0.2		0.1	20.0	-3.2	16.8
INRED		19.0	0.2		0.1	19.3		19.3
Plasmasmelt		5.9	2.3	4.1	0.1	12.4		12.4
Plasmasmelt Oxy		9.0	4.7	2.9	0.1	16.7	-5.0	11.7
COREX		21.6		0.2	1.5	23.3	-8.8	14.5
COIN		18.8		0.9	0.3	20.0	-	20.0
SC		7.8	6.2	0.6	1.7	16.3	-3.9	12.4

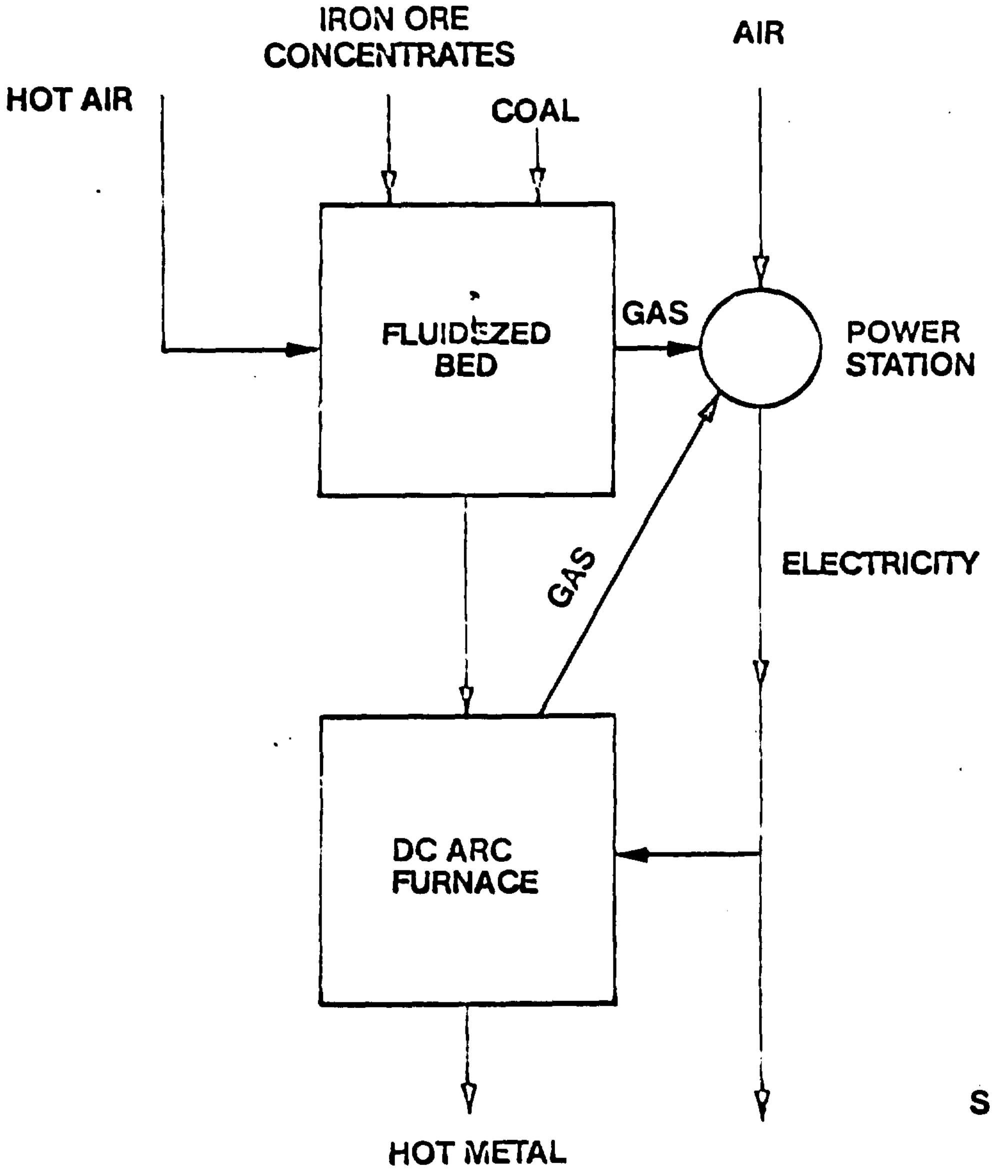


BLAST FURNACE SYSTEM

SMELTING REDUCTION SYSTEM

FIG 1

ELRED


IRON ORE CONCENTRATES
AIR
HOT AIR
COAL
FLUIDIZED BED
GAS
POWER STATION
GAS
ELECTRICITY
DC ARC FURNACE
HOT METAL

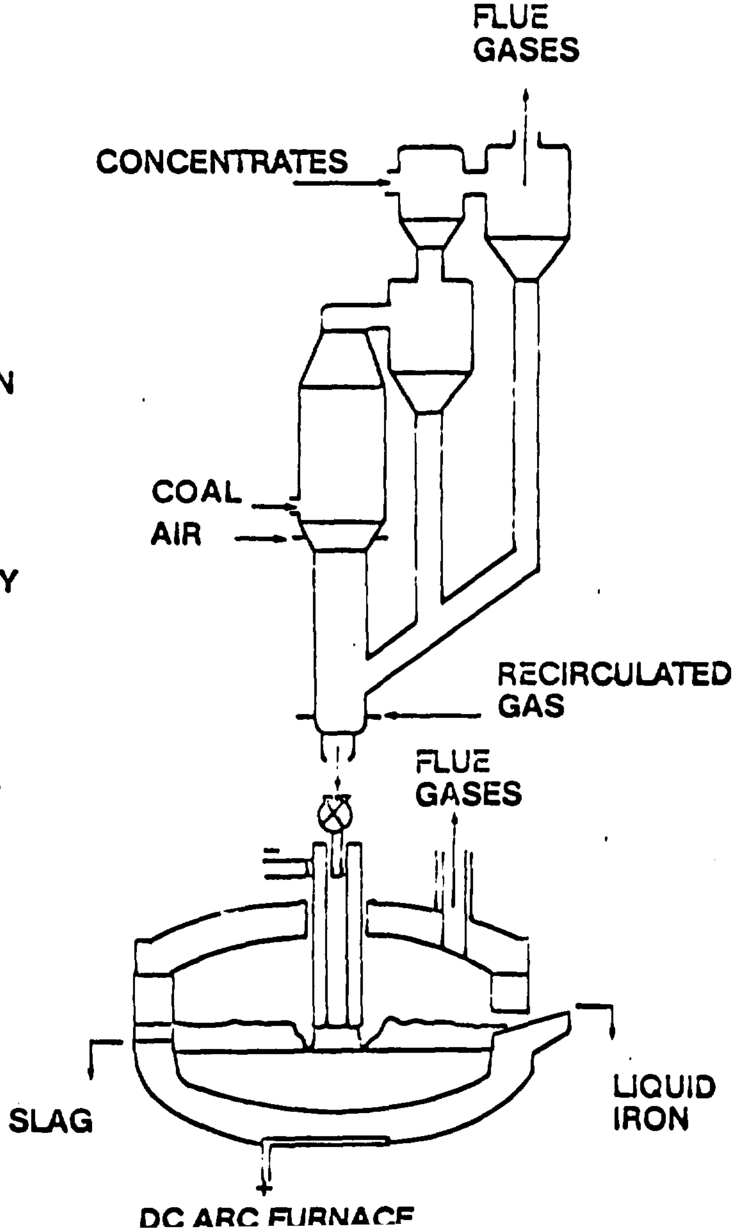

FLUE GASES
CONCENTRATES
COAL
AIR
RECIRCULATED GAS
FLUE GASES
SLAG
LIQUID IRON
DC ARC FURNACE

FIG 2

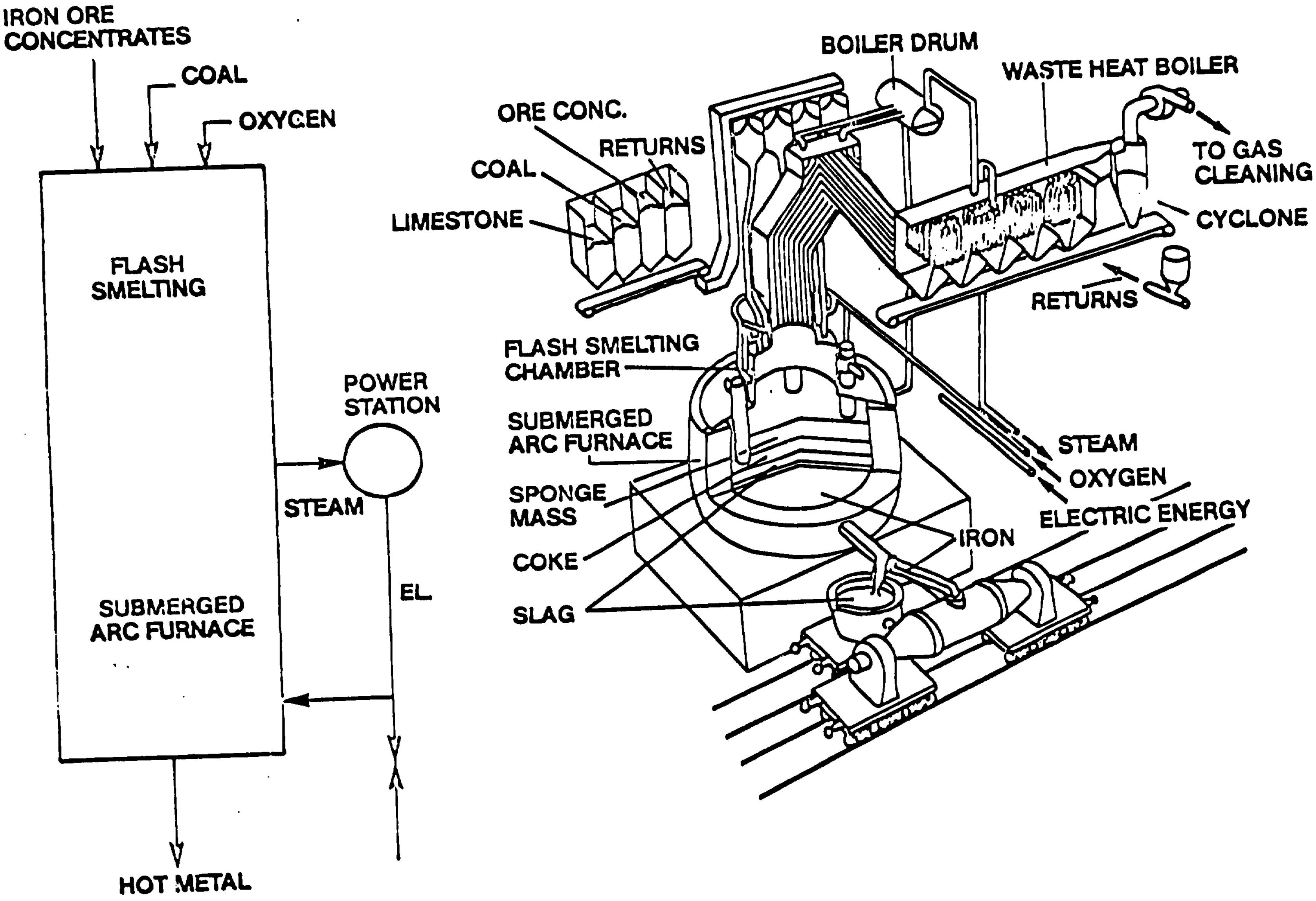
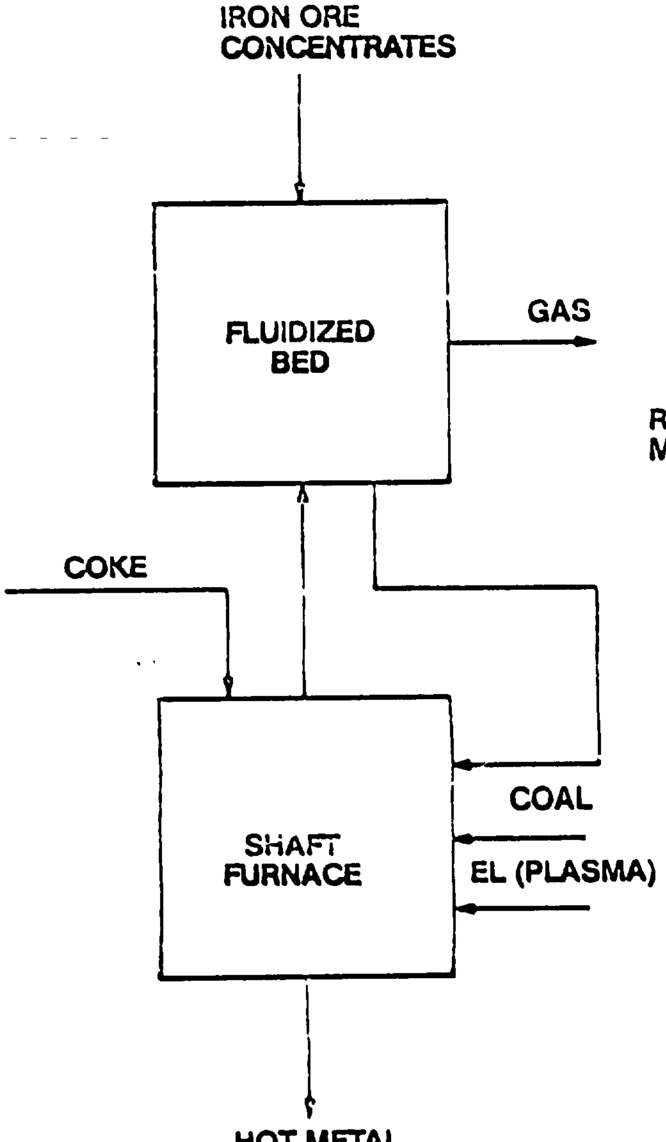

IRON ORE CONCENTRATES
COAL
OXYGEN
FLASH SMELTING
SUBMERGED ARC FURNACE
POWER STATION
STEAM
EL.
HOT METAL
BOILER DRUM
WASTE HEAT BOILER
ORE CONC.
RETURNS
COAL
LIMESTONE
TO GAS CLEANING
CYCLONE
RETURNS
FLASH SMELTING CHAMBER
SUBMERGED ARC FURNACE
SPONGE MASS
COKE
SLAG
IRON
STEAM
OXYGEN
ELECTRIC ENERGY

FIG 3

PLASMASMELT



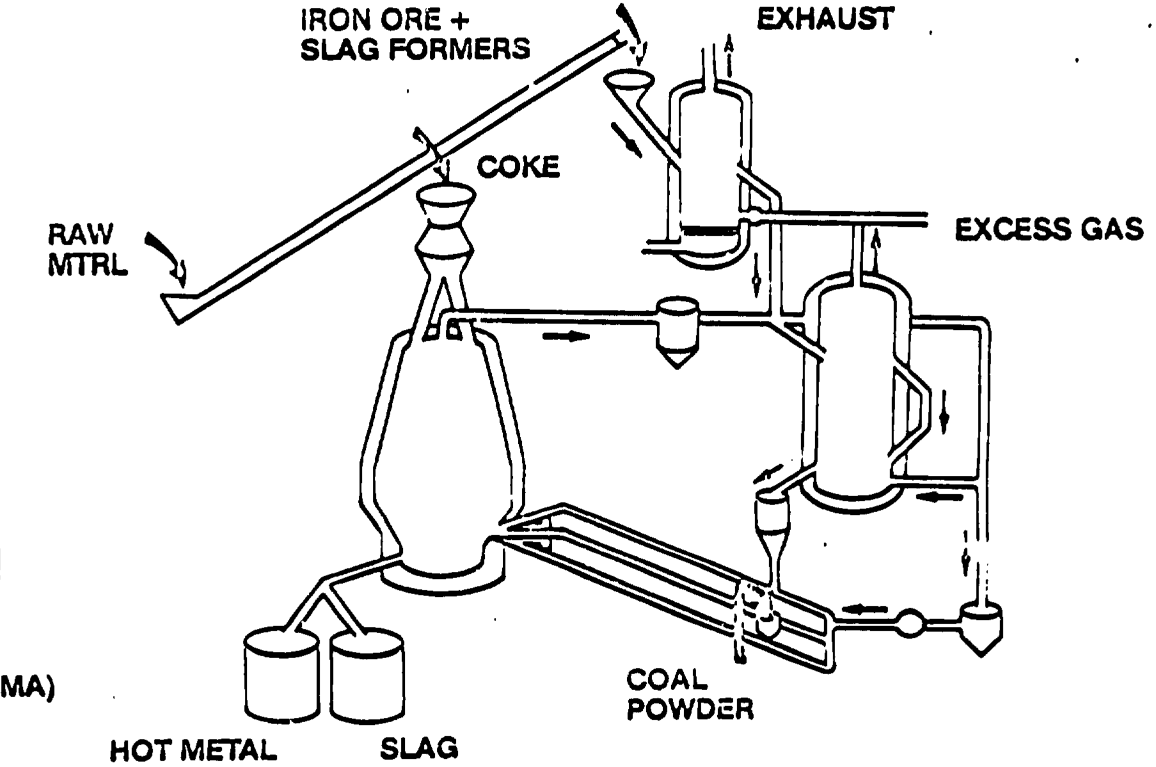


FIG 4

COREX

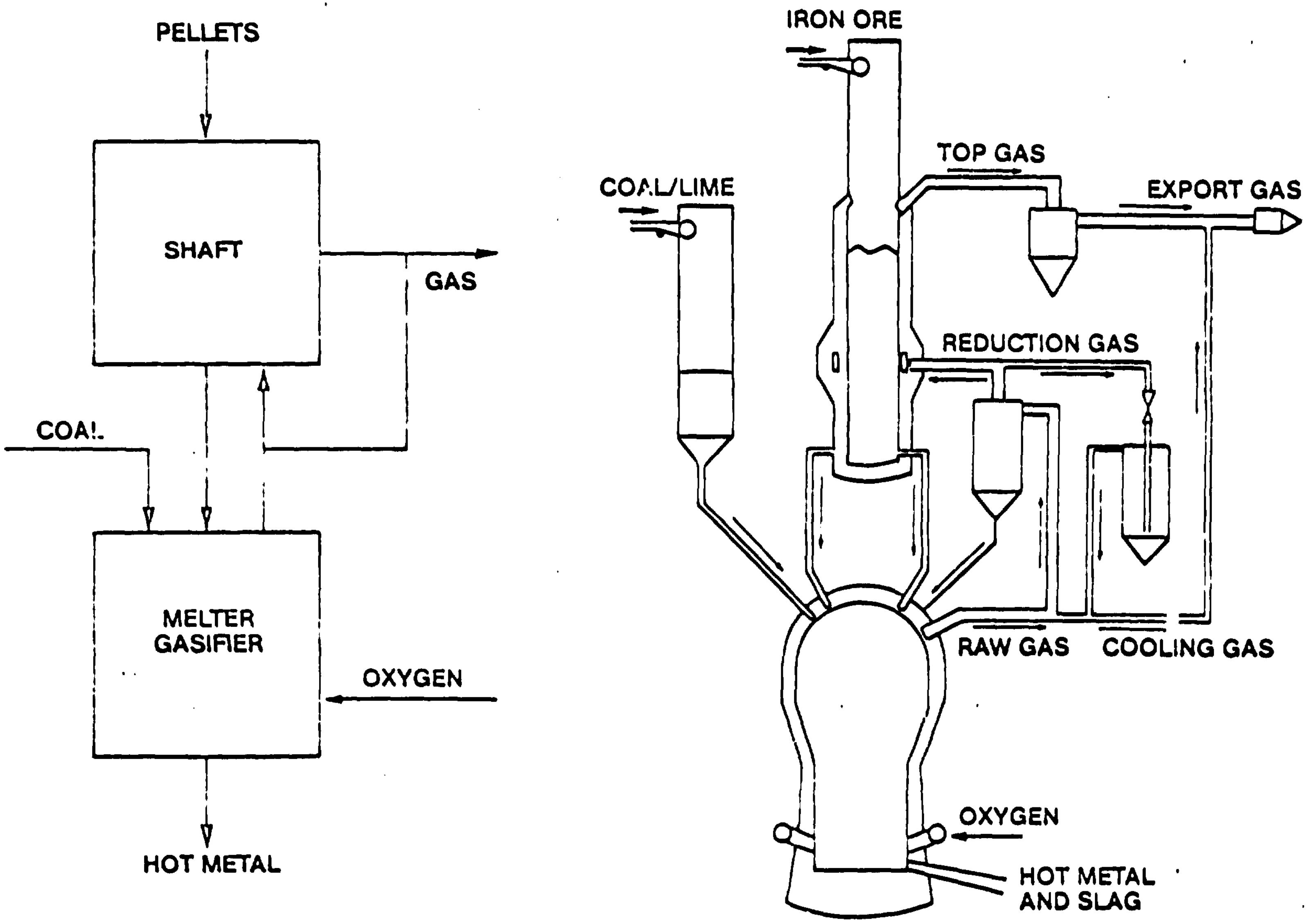
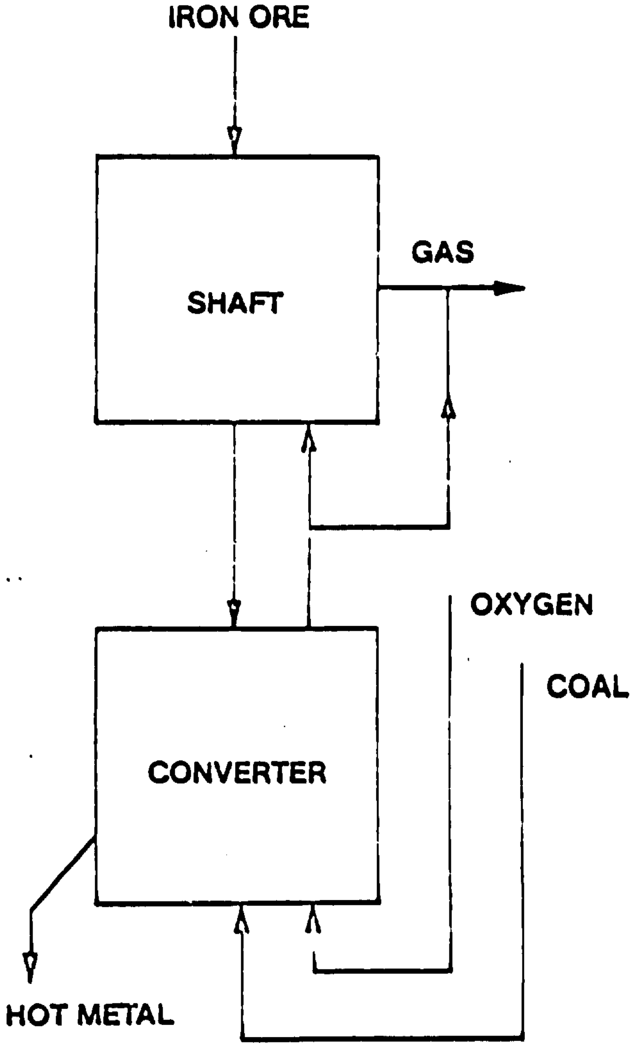
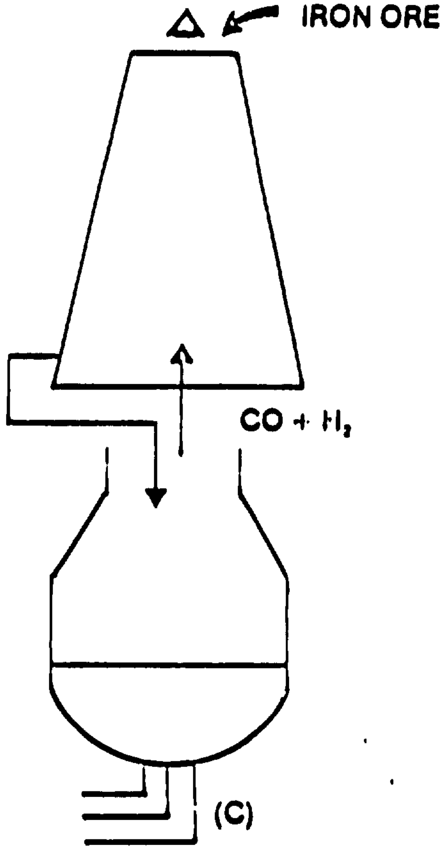

PELLETS
SHAFT
GAS
COAL
MELTER GASIFIER
OXYGEN
HOT METAL
IRON ORE
TOP GAS
COAL/LIME
EXPORT GAS
REDUCTION GAS
RAW GAS
COOLING GAS
OXYGEN
HOT METAL AND SLAG

FIG 5

FIG 6

COIN


IRON ORE
SHAFT
GAS
OXYGEN
COAL
CONVERTER
HOT METAL


IRON ORE
CO + H₂
(C)

SC (SUMITOMO)

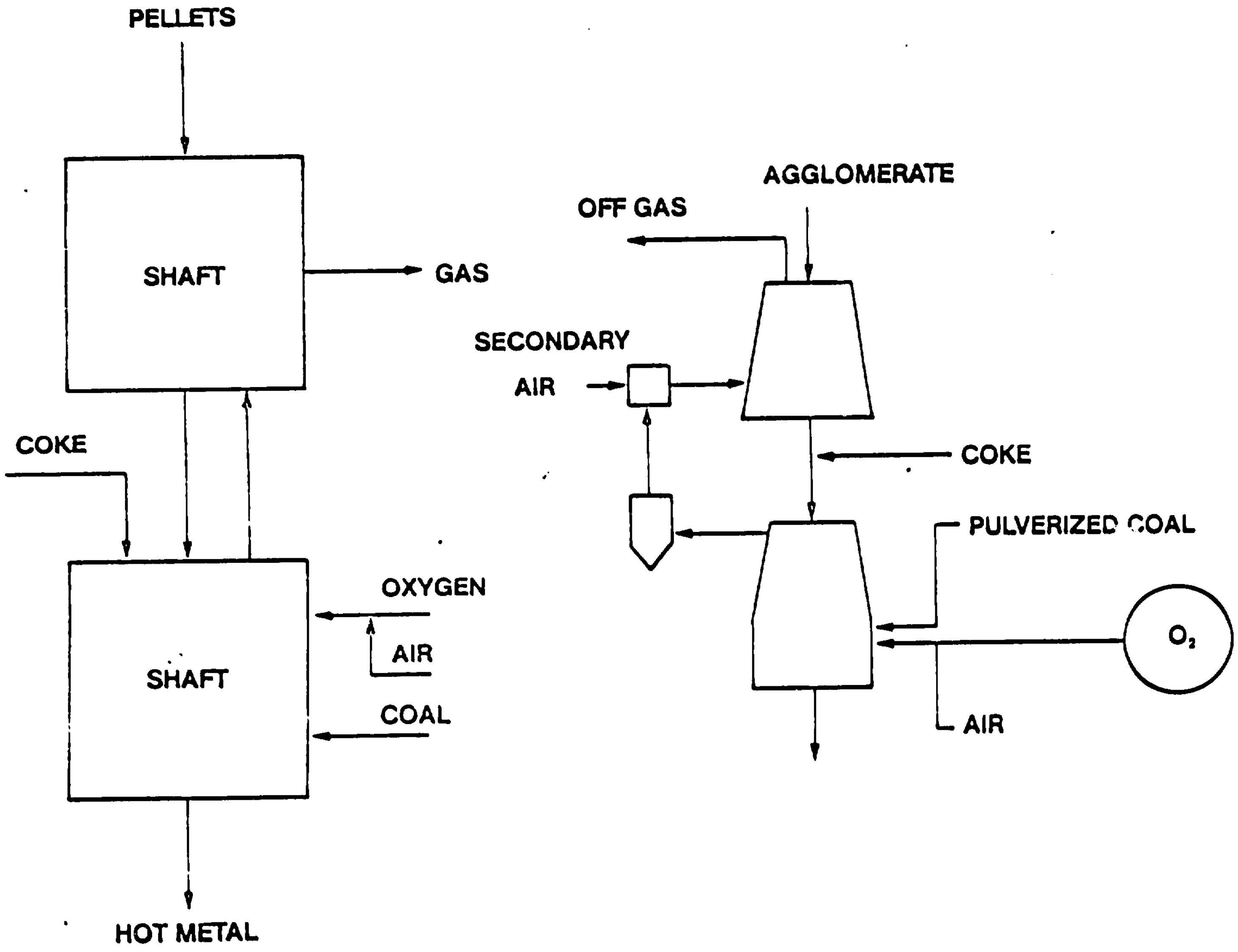


FIG 7

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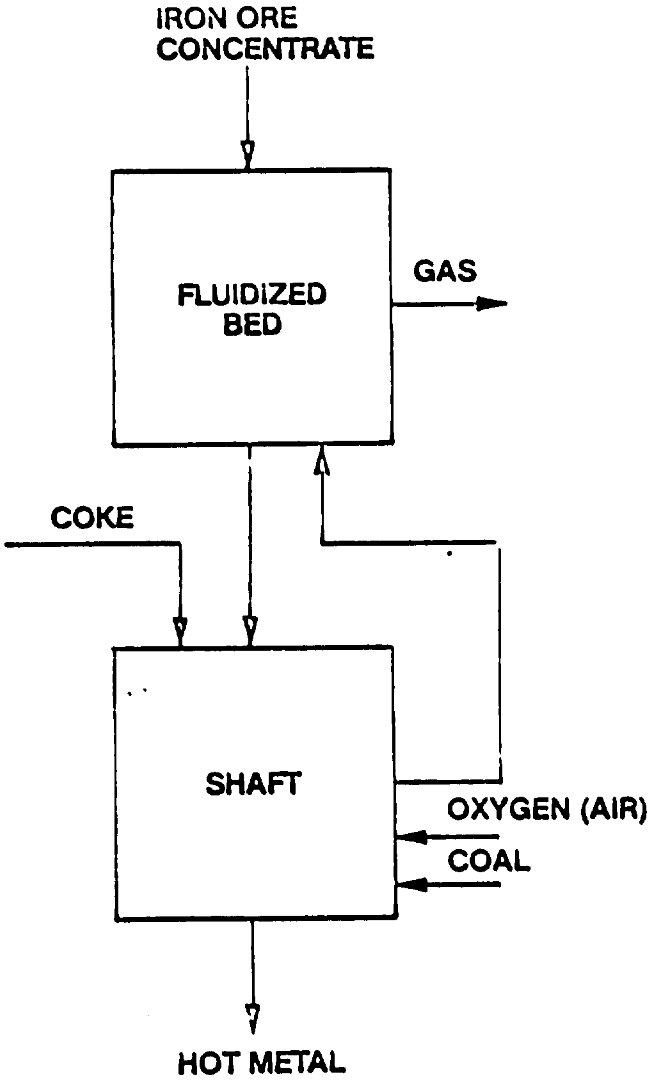


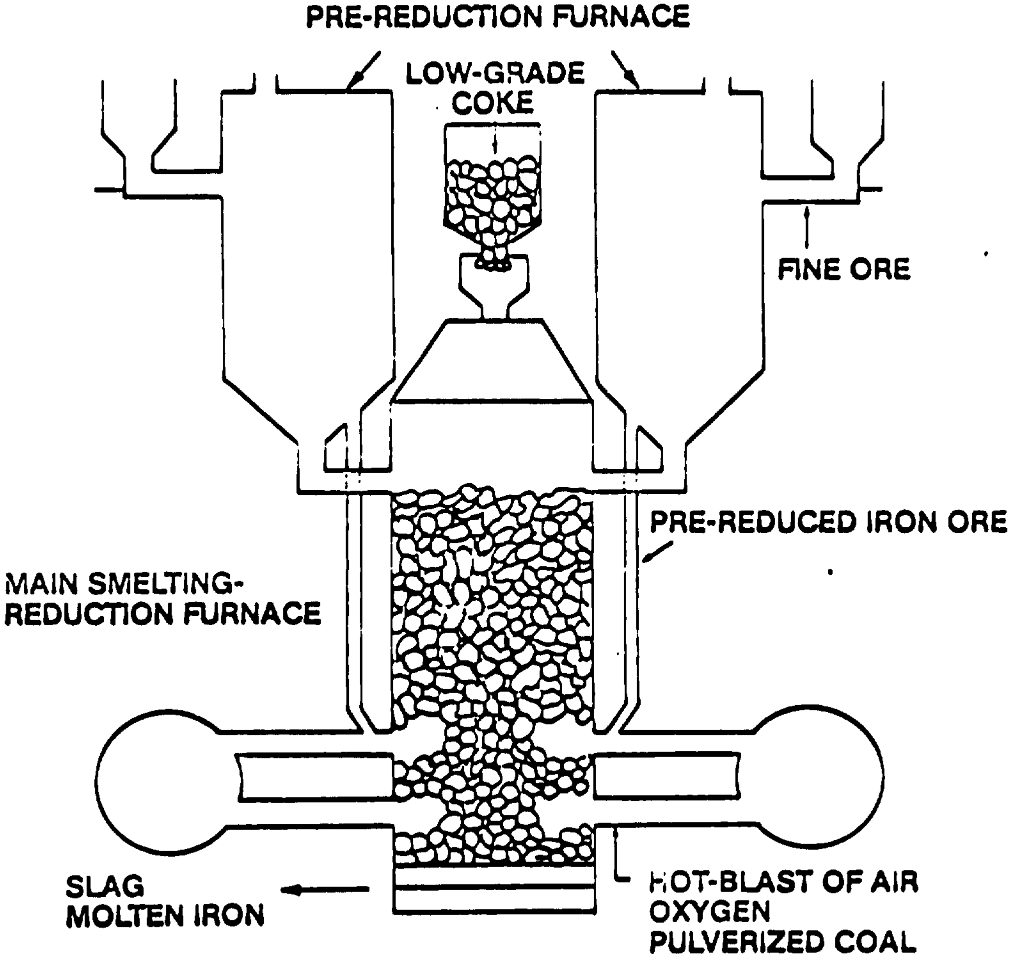
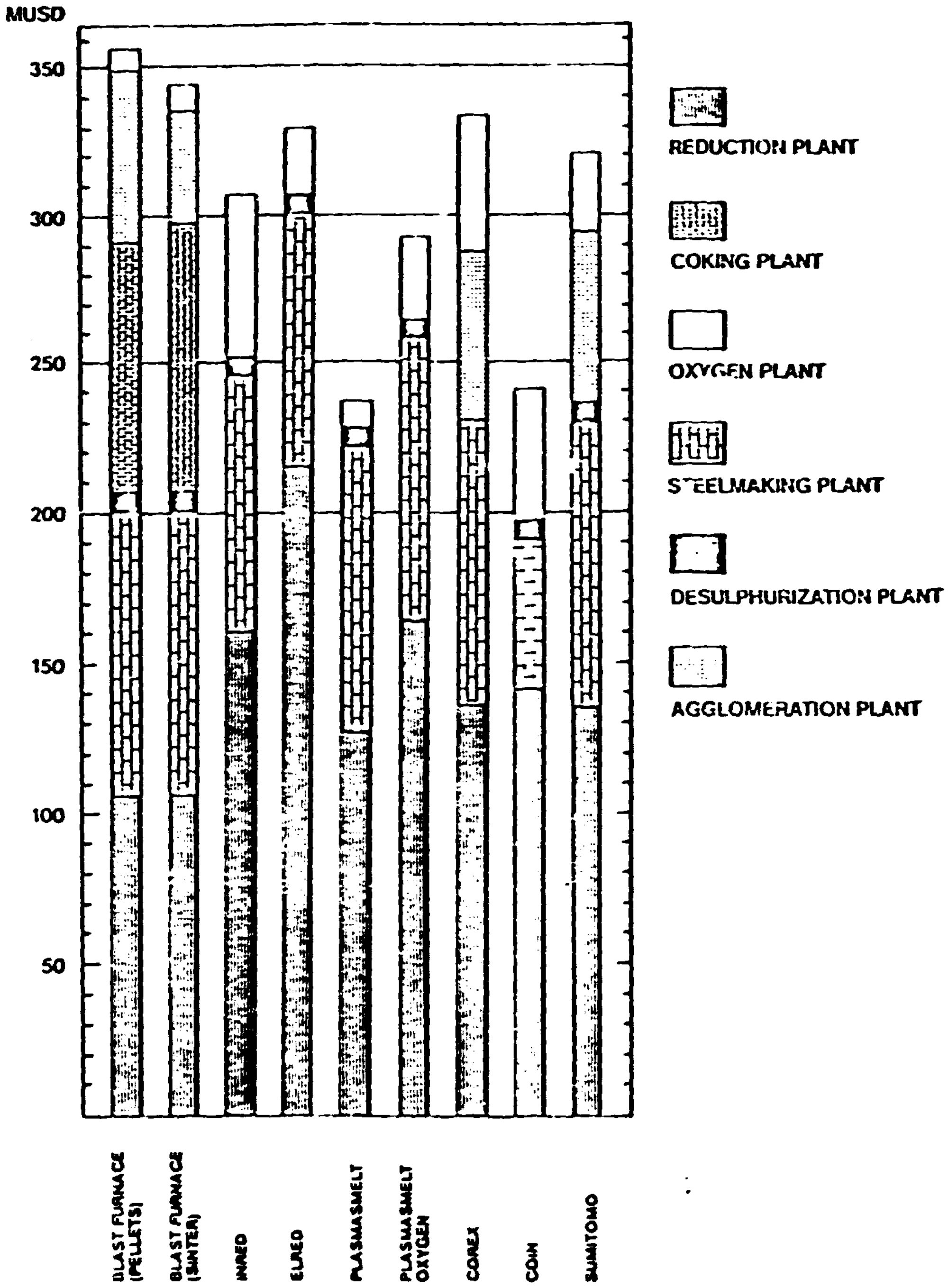


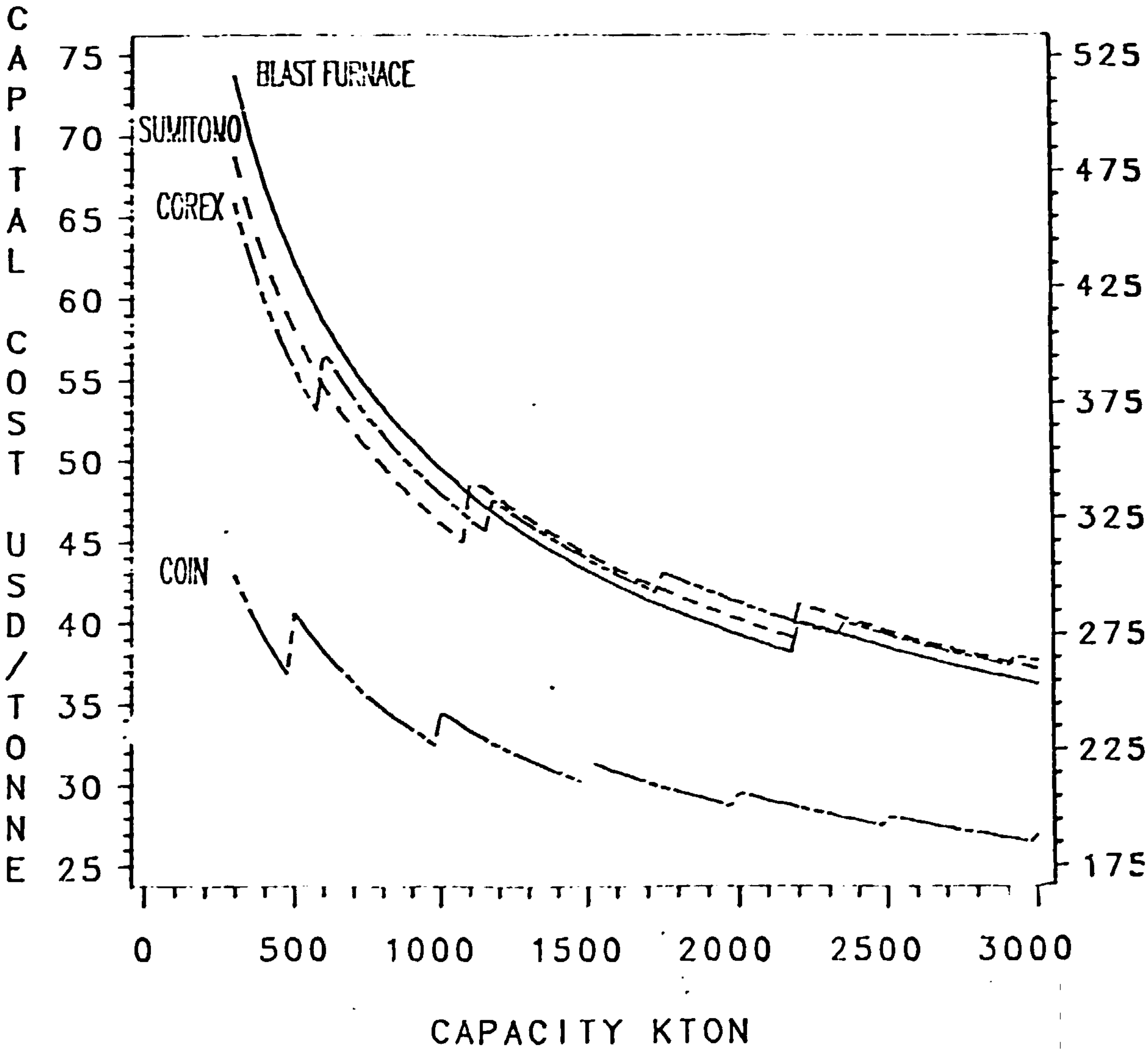
FIG 8

FIG 9

INVESTMENT COST IN ARA FOR PRODUCTION OF 1 MILLION TONNE LIQUID STEEL PER YEAR



CAPITAL COST CRUDE STEEL – CAPACITY



CAPITAL COST CRUDE STEEL – CAPACITY

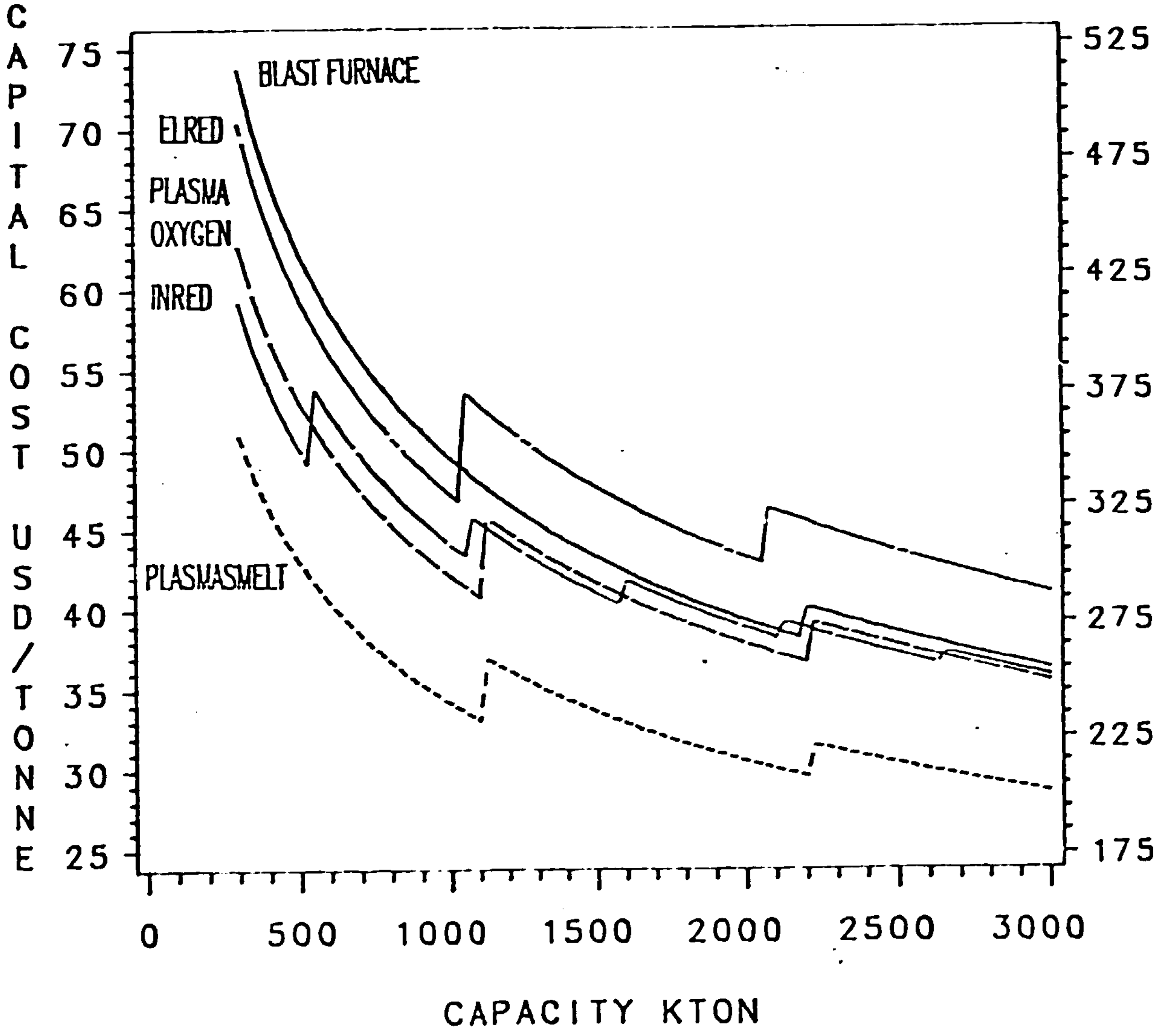
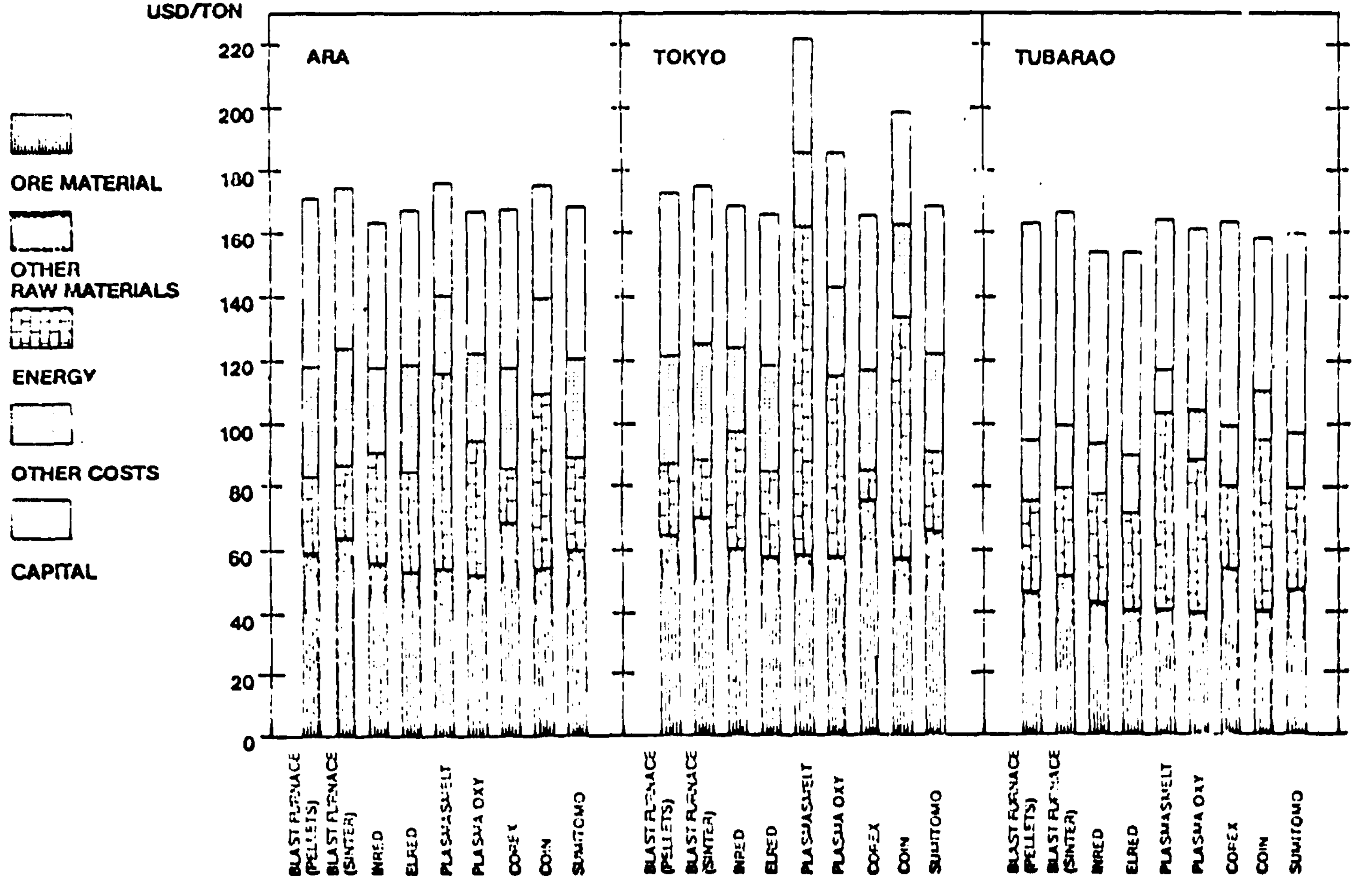
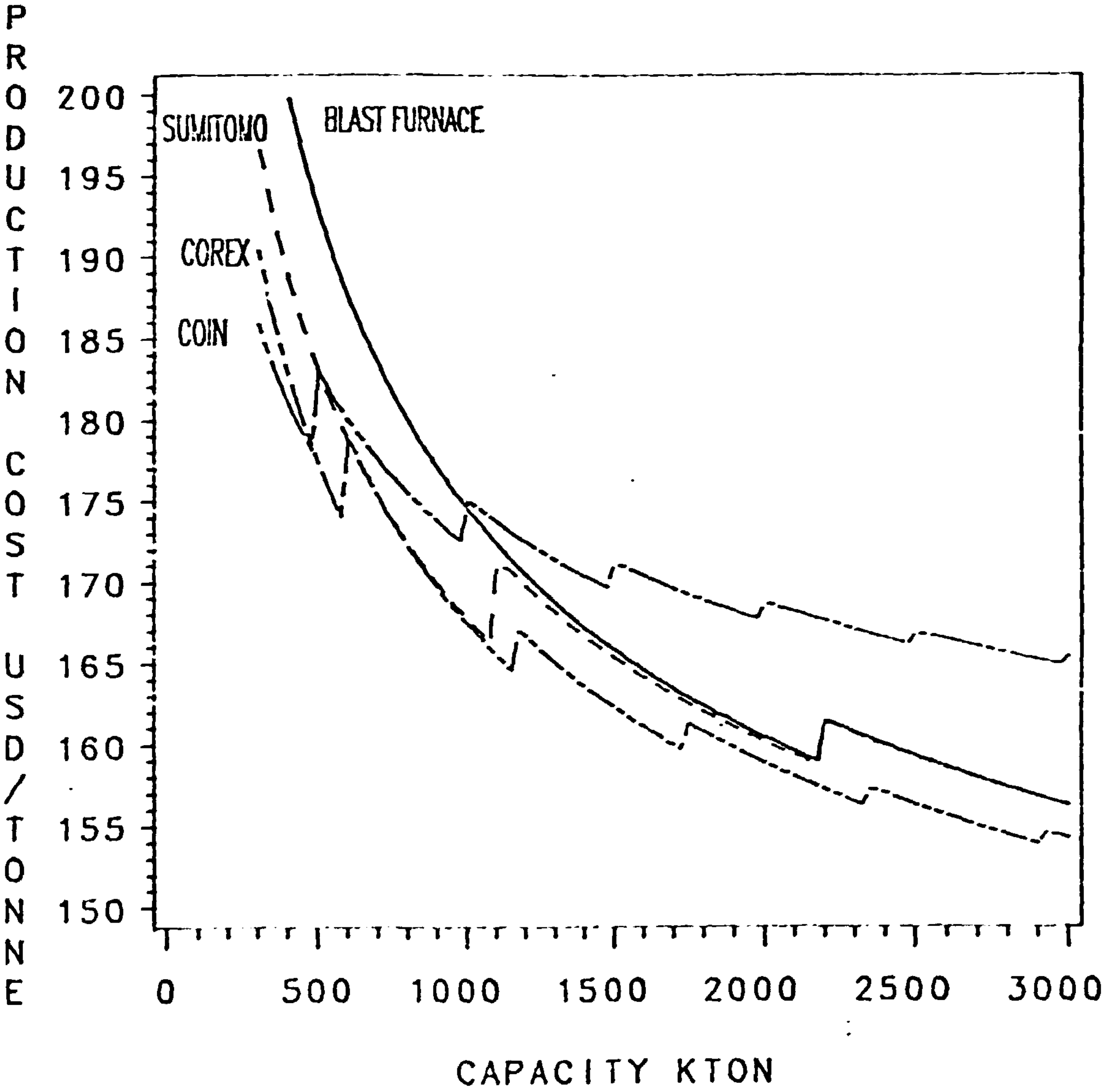


FIG 12

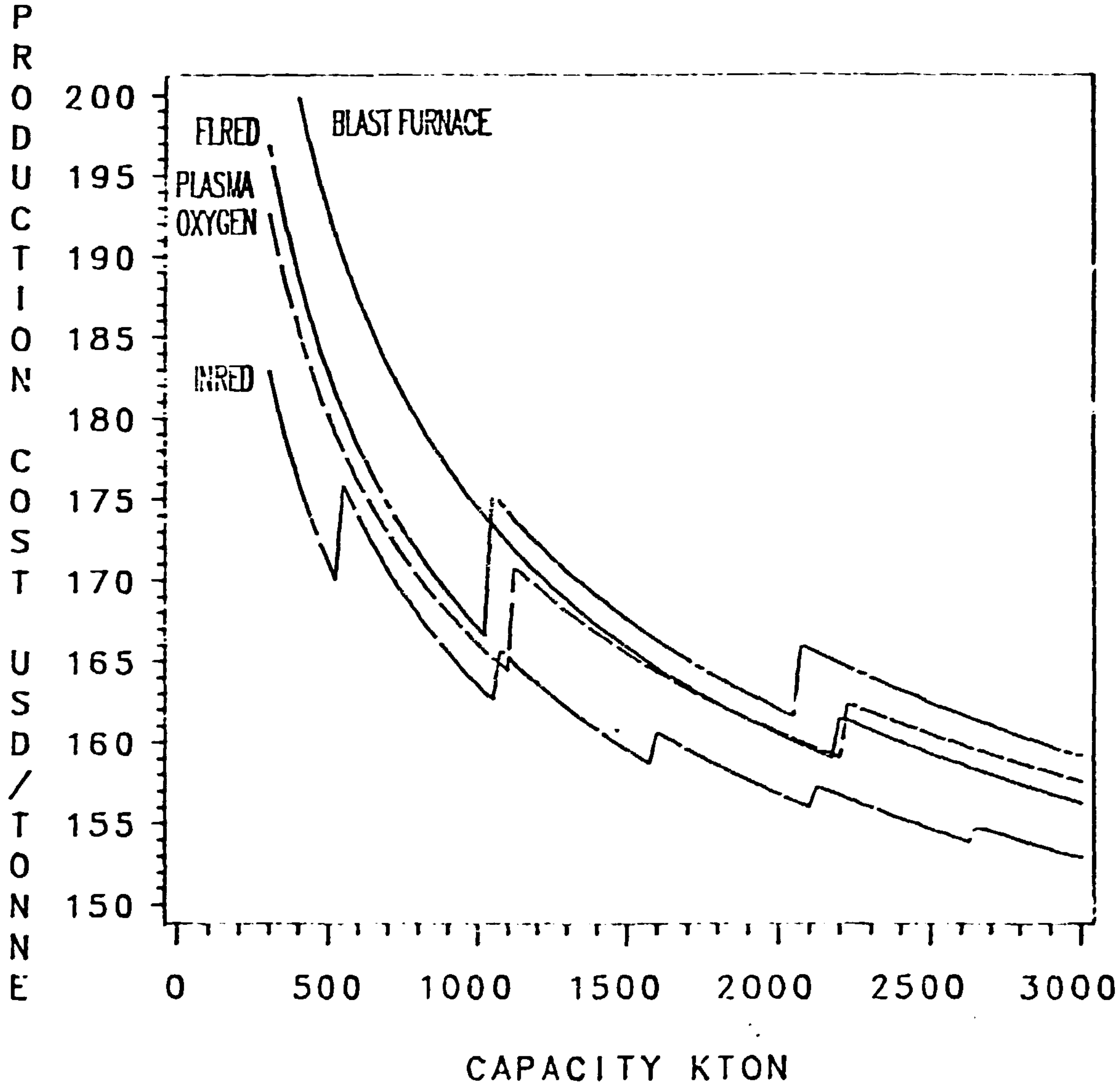
TOTAL MANUFACTURING COST AT AN ANNUAL PRODUCTION OF 1 MILLION TONNE LIQUID STEEL



PRODUCTION COST CRUDE STEEL – CAPACITY



PRODUCTION COST CRUDE STEEL -- CAPACITY



BEST PROCESS IN DIFFERENT ENERGY SITUATIONS

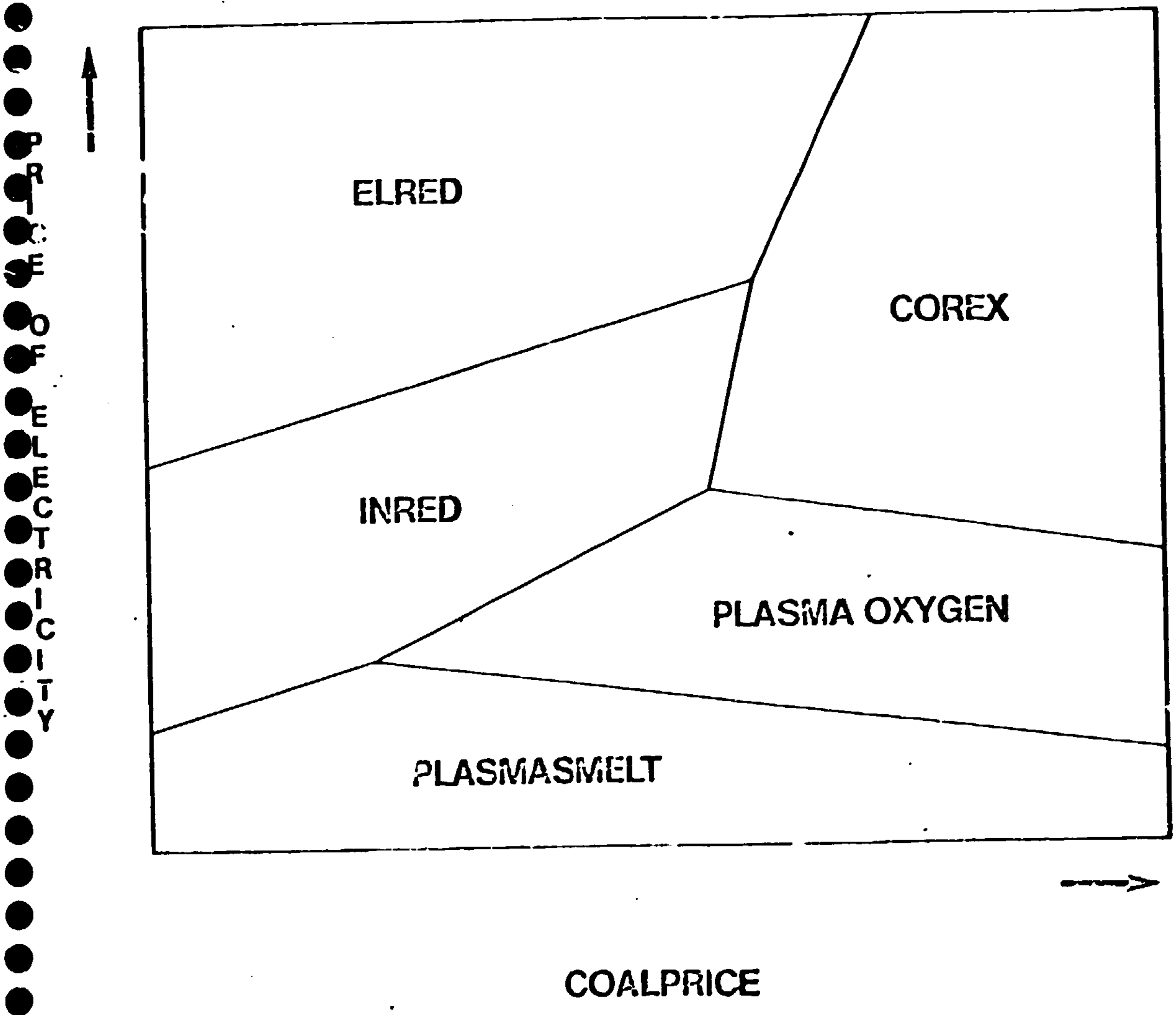
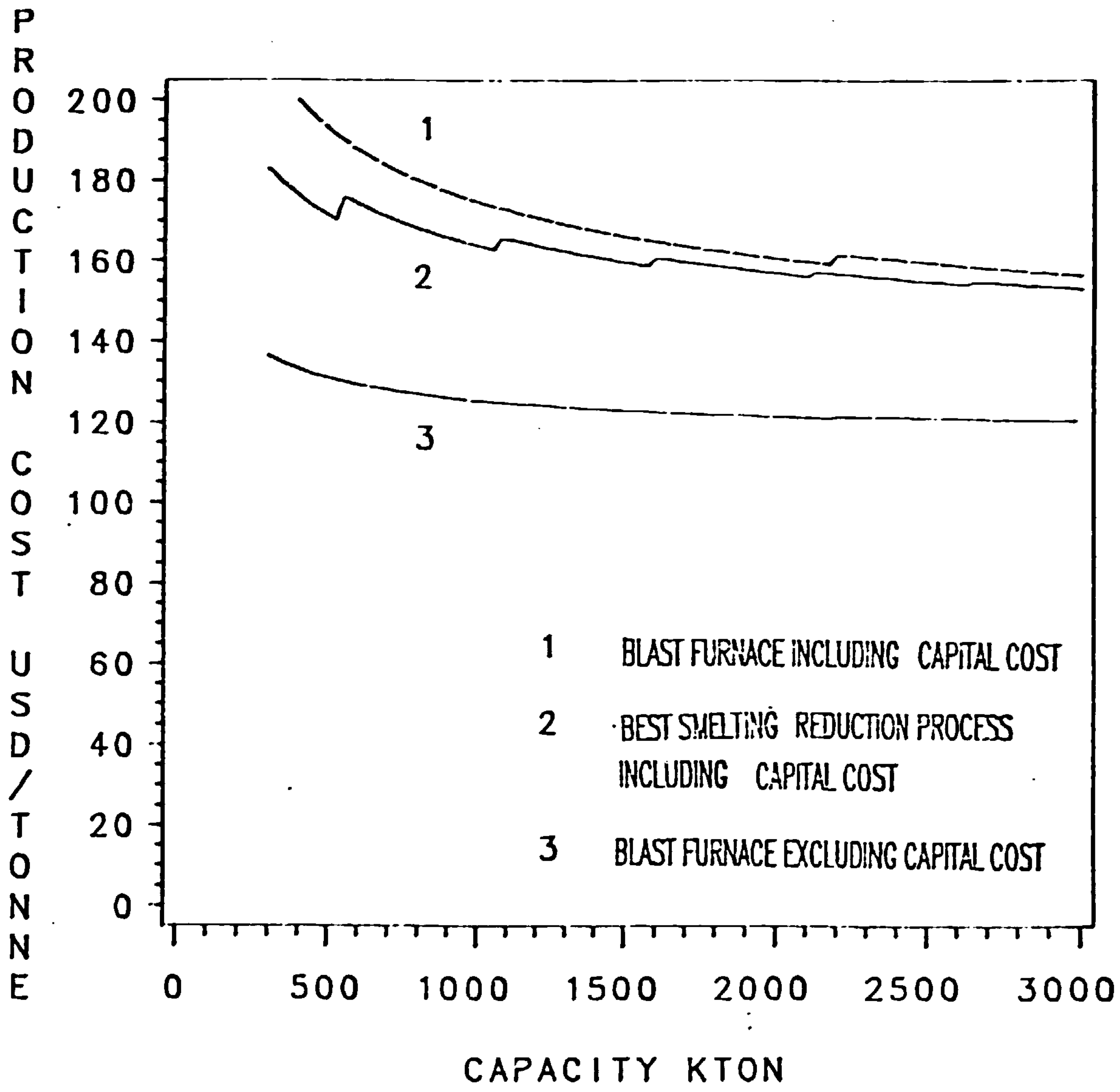


FIG 1

PRODUCTION COST CRUDE STEEL – CAPACITY



ANNEX 4

THE COAL BASED SMELTING REDUCTION PROCESS

KE

COREX®

THE COAL BASED
SMELTING REDUCTION
PROCESS

J.FLICKENSCHILD Dr. G. PAPST

MAY 87

COREX - The coal based smelting reduction process

Jürgen Flickenschild : KORF ENGINEERING GMBH
Dr. Gero Papst : KORF ENGINEERING GMBH

Introduction

The steel industry, worldwide, urgently needs a true alternative for the blast furnace and coke oven technology. Therefore it has been repeatedly tried during the past ten to twenty years to produce a similar product but independent from coke.

More than 10 years ago, a new ironmaking process began to compete with the well-developed blast furnace technology. The natural gas-based direct reduction technology expanded beyond laboratory boundaries and, after some years, gained a remarkable market potential. Today, it is an open secret that such processes are no longer under consideration in the industrialized countries, and in areas where high amounts of natural gas are still being flared, the demand for sponge iron has remained small.

The sponge iron production in rotary kilns on the basis of coal was intended to complement and/or replace natural gas and coke. This technology has not found real acceptance and plays a secondary role as far as quantity is concerned.

All these processes are no true alternative for the blast furnace, because sponge iron always comes off badly compared with hot metal as far as its value is concerned. This is not only connected with the lack of perceptible heat and/or melting heat, but also with the separation from the gangue. At best, the gangue of ore is about 4 %, i.e. in sponge iron it is 6 %. Since the gangue is almost exclusively purely acid, extremely large quantities of quicklime are always required in the steel plant for adjusting a basicity allowing metallurgical work as well as a very high degree of melting energy.

Besides these developments, everybody knows about the coming scrap shortage, especially of high-quality scrap, caused by the ever-increasing share of continuous casting. The only possibility to produce higher steel qualities can be seen in a higher consumption of hot metal.

The hot metal production is combined with the blast furnace technology and, again, with the availability of coke. It is known that only 12 % of the world coal reserves are coking coals. Even for example in the USA having bigger quantities of cokeable coals, the distances between the mines and the consumers extend with the result that a price difference between steam coal and metallurgical coal is established. For this reason, it is extremely important that the blast furnace is modified to a coal-based alternative.

Today the most advanced coal-based hot metal production process is the COREX process jointly developed by Messrs. Korf Engineering GmbH, F.R. of Germany and VOEST Alpine AG, Austria.

PROCESS DESCRIPTION

Hot metal with export gas production

The COREX process is an iron-making technology for the production of hot metal where coke can be replaced by a wide range of coals. The replacement of coke is the primary goal which helps to reduce the cost of hot metal and the associated environmental burden.

The COREX process (figure 1) separates the iron ore reduction and melting steps into two reactors.

- Generation of reducing gas and liberation of energy from coal for melting occurs in the melter gasifier.

- Reduction of iron ore occurs in a shaft furnace.

Because of this separation, a wide variety of untreated coals can be used in the COREX-process.

The COREX-process is designed to operate under elevated pressure, up to 5 bar. Charging of coal and iron ore is done through a lock hopper system. The coal is stored in a pressurized feed bin and charged into the melter gasifier by a speed controlled feed screw. The coal falls by gravity into the gasifier where it comes into contact with a reducing gas atmosphere at a temperature of approx. 1,000 to 1,200 °C. Instantaneous drying and degasification of the coal particles occur in this upper portion of the melter-gasifier.

Generation of reducing gas is done in a fluidized bed, by partial oxidation of coal. First of all the carbon is oxidized to CO_2. Then, the CO_2 reacts with free carbon to form CO. The gas temperature in the fluidized bed is in the range of 1,600 to 1,700°C. The temperature conditions in the freeboard zone above the fluidized bed guarantee production of a quality reducing gas which contains some 65 - 70 percent carbon monoxide, 20 - 25 percent hydrogen, and 2-4 percent carbon dioxide. The remaining constituents are methane, nitrogen and steam.

After leaving the melter-gasifier, the hot gasifier gas is mixed with cooling gas to attain a temperature of approx. 850 to 900°C. The gas is then cleaned in hot cyclones and fed to the shaft furnace as reducing gas. A small amount of the cleaned gas is converted to cooling gas in a gas cooler.

The fines captured in the hot cyclone are recirculated into the gasifier via dust burners.

The reducing gas is fed into the reduction furnace through a bustle and ascends through the iron burden according to the counterflow principle. The iron ore, charged into the shaft furnace through a lock hopper system, descends by gravity. Transferring of the direct reduced iron (DRI) from the reduction furnace to the melter-gasifier is carried out by a controllable transport system which discharges into connected downcomers. Metallization of the DRI averages 95 percent, and its carbon content is in the range of 3 to 6 percent, depending on the raw material used and operating conditions.

The reduction reaction in the shaft furnace, using gas with approx. 70 percent CO and 25 percent H_2 is exothermic, leading to temperatures in the burden which are above the reducing gas temperature. Because of CO decomposition, carbon forms on the iron and acts as a lubricant, therefore no sticking occurs. The formation of Fe_3C takes place as well. The top gas is cleaned and cooled in a scrubber, and is then available for export purposes.

The hot DRI with a temperature of 800 - 900°C is charged continuously to the melter-gasifier, by means of the transport system mentioned above. The velocity of fall of the sponge iron particles is reduced in the fluidized bed, so that complete reduction, heating and melting occurs. Hot metal and slag drop to the bottom of the melter-gasifier. Analogous to blast furnaces hot metal and slag are discharged by conventional tapping procedures. The hot metal tapping temperatures can be controlled over the range of 1,400 to 1,600°C. Gasification and sponge iron throughput are controlled so that the energy balance in the fluidized bed remains in equilibrium.

Tapping is carried out every 2,5 to 3 hours on an average. The hot metal quantities tapped in the demonstration plant were up to 20 tons per tapping. For a good desulfurization, a slag basicity as follows is aimed at:

$$\frac{CaO + MgO}{SiO_2 + Al_2O_3} > 1$$

The CO_2 content of the reducing gas coming out of the gasifier is the overall controlling parameter.

The CO_2 content primarily influences the carbon content of the sponge iron and the metallization degree. The proper sponge iron carbon content leads to high carbon levels in the hot metal and low FeO content in the slag. This is necessary for a good sulfur distribution between slag and metal.

The CO_2 content which should be in the range of 2 - 3 percent can be adjusted by a variety of different process conditions. For example it can be reduced through:

- lower humidity of the coals;
- finer coal fractions;
- reduced amount of ultra fines in the coal;
- reduced height of the fluidized bed;
- reduced system pressure;
- use of calcined slag additives (calcination in the shaft);

The temperature and the silica content of the hot metal can be adjusted by different process conditions. An increase can be achieved by:

- coarser coal fraction;
- increased height of the fluidized bed;
- higher system pressure;
- lower hot metal production.

The melter-gasifier may generate some surplus gas depending on the coal selected. This surplus gas becomes part of the cooling gas stream, and can be either used separately or mixed with the top gas from the shaft furnace. When using a high volatile bituminous coal, the resulting gas mixture (export gas) approximates 1,800 Nm^3 per tonne of hot metal with a net calorific value of approx. 8,000 kJ/Nm^3.

The export gas can be used:

- for oxygen generation

- drying of coal

- as heating gas in pelletizing facilities, foundries, steel mills or connected industries

- for the generation of electrical energy.

- as synthesis gas in chemical industry.
  (production of methanol, ammonia, urea and other chemical products)

According to the composition and quality of the coal, the specific oxygen consumption is approx. 500 - 600 Nm^3/tonne of hot metal. The energy for oxygen production can be covered by about one third of the export gas of the COREX plant. The coal consumption depends on the coal quality and is about 0.5 - 0.7 tons C_{fix}/tonne of hot metal.

Hot metal production without export gas

In case the export gas cannot economically be utilized, the top gas will be re-converted into reducing gas by CO_2-Removal (Fig. 2). One part of the reducing gas from the CO_2-Removal serves for cooling the generator gas. The greater part being reheated in the melter gasifier.

The advantage of this operation mode is the fact that the coal consumption will be reduced to less than 500 kg/t of hot metal and the oxygen consumption to less than 300 Nm^3/t of hot metal.

Depending on the location of the plant, the CO_2 from the CO_2-Removal process can be markted.

Basic diagrams of both COREX process routes for hot metal production with and without export gas are shown in Fig. 3 and 4. The flow balance is based on the U.S. raw materials (Minntac pellets and West Virginia coal).

For the example with export gas production, coal consumption comes to 800 kg/t of hot metal; for the example without export gas production to 470 kg/t of hot metal, only.

CHARACTERISTICS OF COALS FOR THE COREX-PROCESS

The COREX-process can be operated with nearly all coals, with none or a minimum coal preparation.

Figure 5 shows a selection of coals in the form of a diagram; the coals are characterized by their ash and volatile contents. Left of the hatching are those coals which can be used almost unrestricted. The coals to the right of the hatching (e.g., lignite) have to be mixed with coals of higher quality or processed in some way. All coals within the hatching are theoretically be usable, however, must be confirmed by tests.

For the COREX-process the most important property of the coal is its volatile content, since this determines the gasification temperature. Coals with low volatile content generate a high temperature when gasified with oxygen, releasing energy for sponge iron melting. Coals with a high volatile content such as lignite result in a low temperature since the volatile hydrocarbons must be cracked before gasification can occur. Such coals have to be mixed with anthracite, low volatile bituminous coal, charcoal, or coke breeze.

The ash content of the coal is less critical. The mainly acidic ashes of the coals can be compensated for by additives in order to form basic slags.

Unprepared coal should have a particle size between 0 - 50 mm. The fines content (smaller than 1 mm) should not be above 10 percent, the coarse particles (bigger than 35 mm) should not exceed 20 percent. Other properties such as ash melting behaviour, swelling index, and Hardgrove index are of little or no concern. Coal with a water content of 3 - 8 percent need not to be dried; in case the water content is higher than 8 percent the coal has to be predried with a state of the art coal drying facility.

Due to its high C-content, petrol coke excellently suits the requirements of the COREX-process. A higher metal content and low reactivity have no negative influence. In regards to the COREX process route with export gas production, the higher sulphur content of some of the petrol coke qualities can be reduced by blending coals with low sulphur contents.

For the COREX process route without export gas production, the sulphur content decreases sufficiently due to the low petrol coke consumption (approx. 430 kg/t of hot metal).

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CHARACTERISTICS OF IRON ORES FOR THE COREX-PROCESS

As the direct reduction section of the COREX-process is comparable to other DR shafts or to the upper part of a blast furnace, great experience with a wide range of feeding materials is available.

During the various demonstration periods the COREX-plant at Kehl has been operated on pellets of direct reduction and blast furnace quality, different kinds of lump ore and with sinter.

Some requirements to be considered for selecting ores for the COREX-process, are:

- on the physical side, a uniform grain size, easy reducibility and adequate strength under reducing conditions should be given since these parameters determine reduction efficiency;
- requirements as to the chemical properties of the iron ores are considerably lower than in the case of DRI production because DRI causes much higher cost in the following step in steel shop with the increased amount of acid gangue content, that means slag volume.

CHARACTERISTICS OF ADDITIVES FOR THE COREX-PROCESS

Limestone, dolomite and silica sand are used as additives. Limestone and dolomite serve for adjusting the basicity based on the ore analysis and the ash analysis of the coals used. With high Al_2O_3-contents in the coal ash it is partly necessary to add silica sand in order to decrease the Al_2O_3-content in the slag: The additives are charged either with the coal or via the reduction shaft, for the reason that the calcination is carried out in the reduction shaft.

CHARACTERISTICS OF REFRACTORY MATERIALS FOR THE KR-PROCESS

During the demonstration periods carried out in the last few years, a multitude of refractory materials have been tested, and it has turned out that no special prerequites are needed in the reduction shaft. The usual fire-clay qualities are sufficient. In the melting gasifier, there are three areas subjected to different stresses:

- the area of the calming cone:

  in this area, fire-clay qualities are used;

- the area of the fluidized bed:

  in this area are high gas temperatures as well as highly reducing wear due to the quantity gasified. The temperatures range between about 1,500 and 1,800°C. After several tests had been carried out, even for this purpose stable brick materials were found, which are produced by several well known companies;

- the area of the tuyere level:

  here the lining is attacked mainly by liquid slag. For the wall as well as for the bottom materials can be used which have already proved to be successful in the blast furnace.

EXPECTED EMISSION AND EFFLUENT REDUCTION

The COREX-process operation and the blast furnace operation are similar in respect to the raw materials charged and the products produced. They both employ a lock hopper materials feed system, enclosed processing, and enclosed off-gas cleaning. Consequently it is reasonable to assume that emissions and effluents generated by the COREX-process are similar to emissions and effluents from the blast furnace. But the conventional iron making route is made up of several separate processes (coke oven plant, coke oven gas treatment, blast furnace) all of which have associated their own air emissions and water effluent. The COREX-process, on the other hand, is a single process with no significant direct air emissions, i.e. the by-product gas is utilized as a medium BTU export gas for nearby industrial facilities.

The effluents from iron making by the COREX-process and from the coke oven/blast furnace operation are derived from cleaning and cooling of the co-product gases. Cyanide is the principle com- ponent produced by reaction within the blast furnace, plus fluorides, sulfides, ammonia, organics and trace metals are pass-through products from the raw materials feed. In the COREX-process cyanide, organics and ammonia are to be of much less significance because of the high temperatures maintained in the melter gasifier.

The coke plant waste water principal pollutants are ammonia, thiocyanate, toxic organics and sulfide. The COREX-process eliminates the need for coke and this eleminates or minimizes the pollutants associated with effluents from iron making by the coke plant/blast furnace route.

Todays waste water treatment technology, although it is costly, is quite effective and it will be possible to meet the latest standards with the minimized pollution problems of effluent from the COREX-process with economic state of the art water treatment.

The process related emission in principal is carbon monoxide from the blast furnace as well as from the COREX-process and may be released by slips and by tapping operations, but emissions by slips are unlikely from COREX-process operations. The more severe process related emissions are derived from the operations at the coke ovens and from the by product plant area. The many sources of fugitive emissions of a host of potentially toxic pollutants qualifies the coke plant as the most serious environmental problem with conventional ironmaking which again can be eliminated or minimized within the COREX-process. First studies have indicated that there is a 30 to 40 percent particulate emissions reduction for the COREX-process against the coke plant/blast furnace route. Although this is attractive, the principle attraction is the elemination of toxic organics and cyanide plus the minimization of fugitive emissions that are impractical to collect. The COREX-process is an environmentally very acceptable replacement for ironmaking by the conventional technology.

OPERATIONAL EXPERIENCE

Between 1981 and 1986, a total of 9 demonstration periods were carried out, during which a wide range of raw materials and their combinations were tested. With coal, the entire range from lignite to anthracite was tested. Moreover, tests with a lignite high-temperature coke were carried out.

The performance of the two latest production phases in the demonstration plant were executed in October/November 1984 and May/June 1986.

Representing the formidable number of trials and tests two examples out of all shall give you an overview of the results obtained with the COREX-process.

Demonstration with U.S. raw materials in 1984:
After the problems caused by the longlasting downtime between the last production phase in 1983 and this production phase 1984 (little rust flakes occuring in the water systems in the first few days) had been solved, it was possible to set very stable and - as far as metallurgy is concerned - very good values.

During the 1984 demonstration period West Virginia coal and Minntac pellets were used.

West Virginia coal and the Minntac pellets were processed for ten days in the COREX plant in Kehl in West Germany. The average hot metal output exceeded 6 t/h. The availability of the plant was loo % during the entire U.S. raw material test period. With this test, the constancy of the plant, but not the energy optimization, was intended to be emphasized.

The figures of hot metal (figure 6) and slag (figure 7) composition are attached. A characteristic of the COREX process is the highly reducing effect in the gasifier, which can be inferred from the FeO-contents of slag of 0.6 to 0.7 % on an average. These values form an excellent basis for good sulfur distribution between slag and hot metal, which were partly above 100.

When charging about 1,000 kg of coal (with 0.6 % sulfur) per ton of hot metal, mean sulphur contents of 0.02 % in the hot metal must convince even sceptics that the COREX process is a true alternative for the blast furnace.

Demonstration with Braislian raw materials in 1986:
The objective of the first trial of Brasilian raw materials was to prove the possible use of Santa Catarina coal (CMSC) together with CVRD blast furnace pellets and CVRD lump ore (Conceicao) in the COREX-process. This test was conducted between May 11th, and May 20th, 1986. Data taken during the test were examined and used to prepare material balances for the process. Based on these analyses and on observations made during the test, the following significant results can be reported:

1. Process operability was quite good during the 10-day-test period as evidenced by no process-related outages being required.
2. The process is controllable and responded to control adjustment implemented by the operators.
3. The COREX-process can produce hot metal on the basis of Brasilian ores and coals.

Unstable process conditions during the first part of the trial were generated by the high content of fines and the high moisture content of the coals. It was first tried to process the coals as delivered with medium success but still operable.

Then the Brasilian coal was dried and screened to get good metallurgical results. This means higher carbon-content, better desulphurisation conditions and lower FeO content in the slag.

After drying and screening the Brasilian coal the hot metal produced by the COREX-plant could be compared to iron from a blast furnace.

The following hot metal quality was produced:

C	%	3,7	-	4
Si	%	1	-	1,5
S	%	about		0,1

Tapping temperature: 1,500 - 1,550 °C.

For the above mentioned data it is necessary to take in account that CMSC-coal contains about 40 percent volatiles (waf), 20 percent ash (wf) and 1,5 percent sulfur.

The conclusion to be drawn from the entire test period (May 11th to May 20th) is the fact that the CMSC-coal is processable in the COREX-process without any restrictions.

The CVRD-Pellets and lump-ore did not create any problems. The shorttime use of 20 % lump-ore from Conceicao indicated the suitability of this material for the COREX-process.

Not only the independence of the coking coal is the main advantage of the COREX technology, the COREX process offers also an ecological benefit.

The COREX plant is very compact in comparison to the normal blast furnace procedure (figure 8) with the result of a much lower investment cost per ton installed capacity of hot metal.

INVESTMENT COST, HOT METAL COST

Hot metal with export gas production

The attached figure 9 shows the hot metal costs for a 300,000 tpy modul with various ore prices and gas credits. The investment cost for this graph were assumed to be US-$ 200.00/tpy., 15 years depreciation time and 10 % interest.

With an ore price of approx. US-$ 30.00/t, a coal price of about US-$ 50.00/t and a gas credit of US-$ 3.00/GJ a hot metal price of US-$ 115.00/t is achievable.

Hot metal without export gas production

Fig. 10 shows the hot metal costs for a 300,000 tpy module without export gas production based on various iron ore and coal prices.

The investment cost for this variant were assumed to be 220 US-$/tpy with 15 years depreciation time and 10 % interest.

With an ore price of approx. US-$ 30/t and a coal price of about 50 US-$/t, a hot metal price of 125 US-$/t is achievable.

The higher investment cost due to the CO_2-Removal equipment are nearly compensated by lower operating cost because of low coal and oxygen consumption. The investment cost for the oxygen plant are reduced because of lower oxygen consumption.

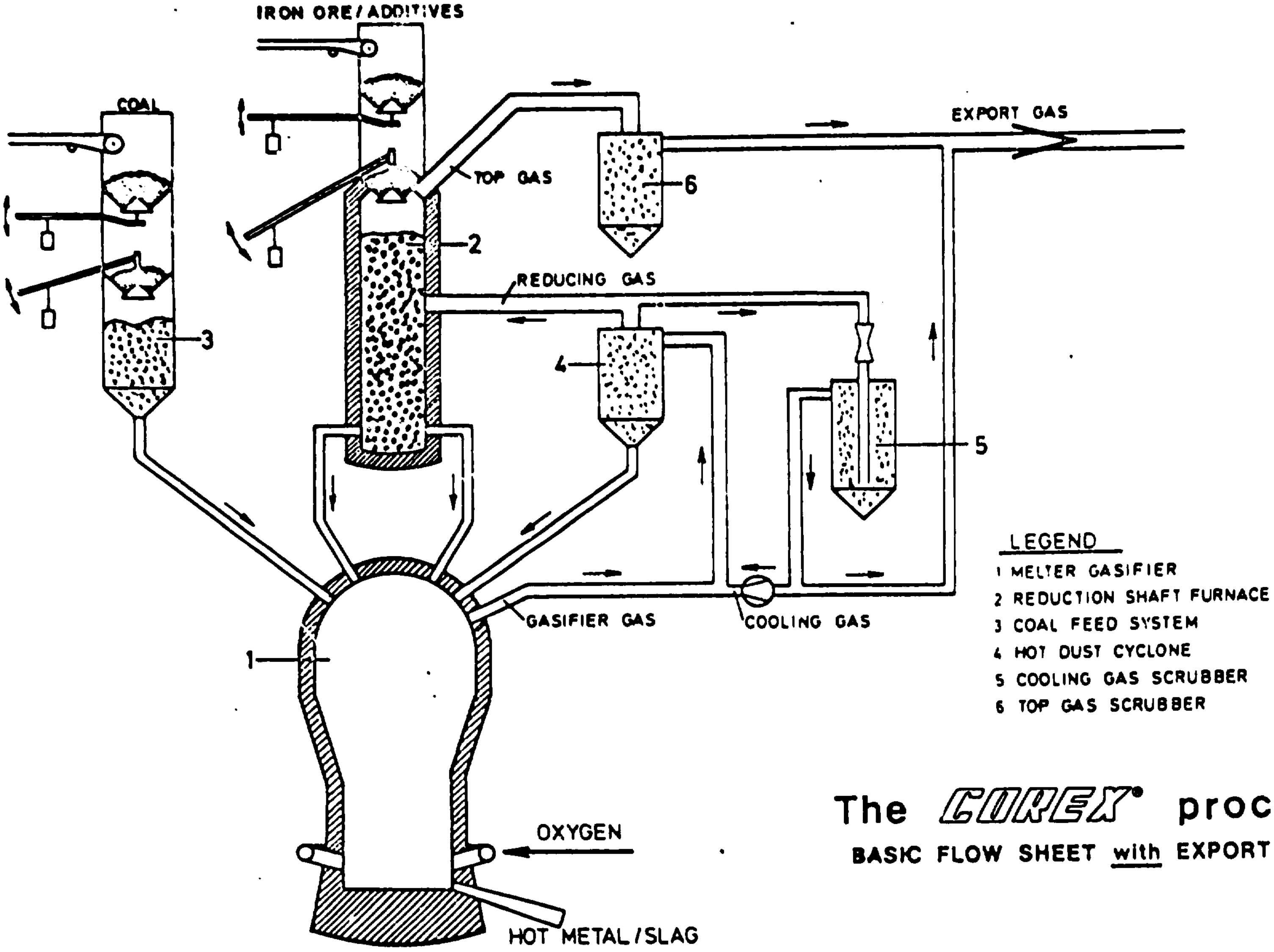
SUMMARY

With the COREX-process, a metallurgically high-grade hot metal is produced in an environmentally beneficial way without using coke oven plants, on the basis of untreated coals for which crushing or storage in an inert atmosphere can be generally waived.

The advantages of the COREX process can be summarized as follows:

- independent of coking coals
- independent of coke ovens
- clean coal technology
- generation of clean fuel gas if desired
- low investment cost
- high flexibility
- enables the economical production of hot metal.

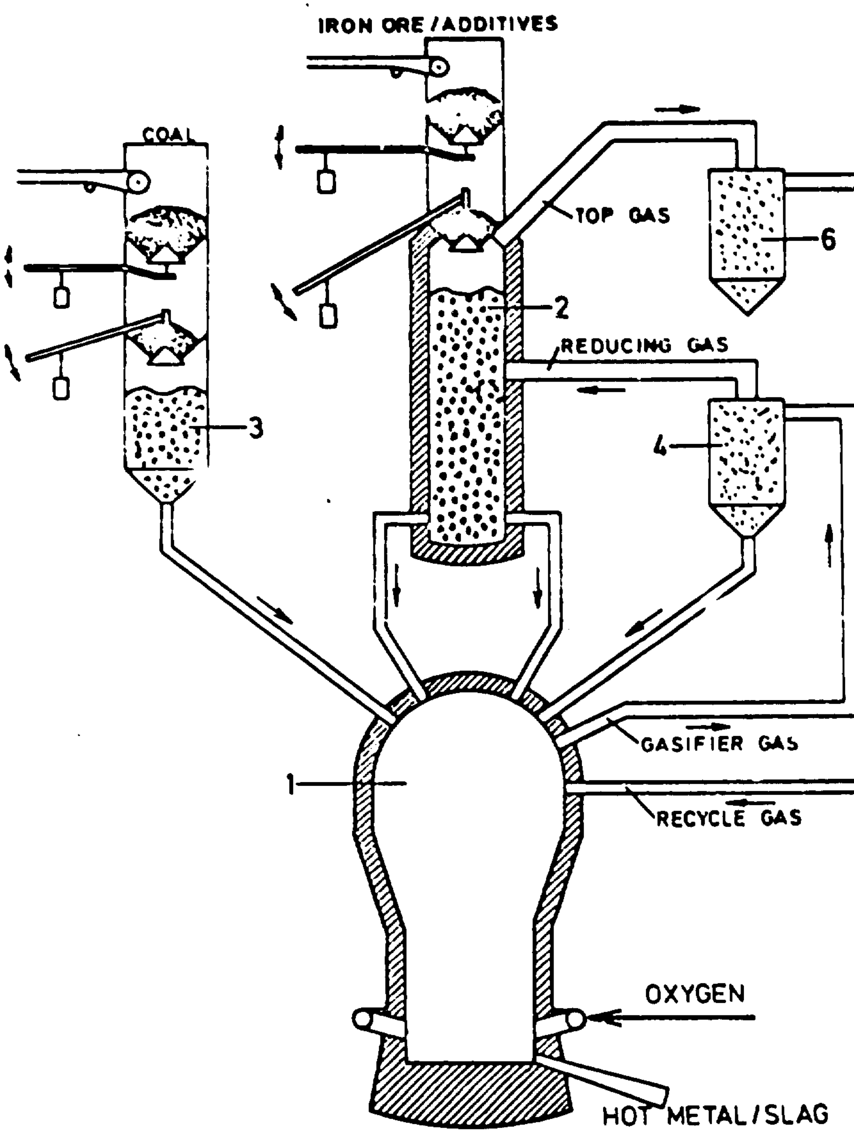
At present, plants with a hot metal production of 100,000 to 300,000 tpy can be offered as an alternative to the blast furnace production process.



The COREX® process

BASIC FLOW SHEET with EXPORT GAS

FIG. 1



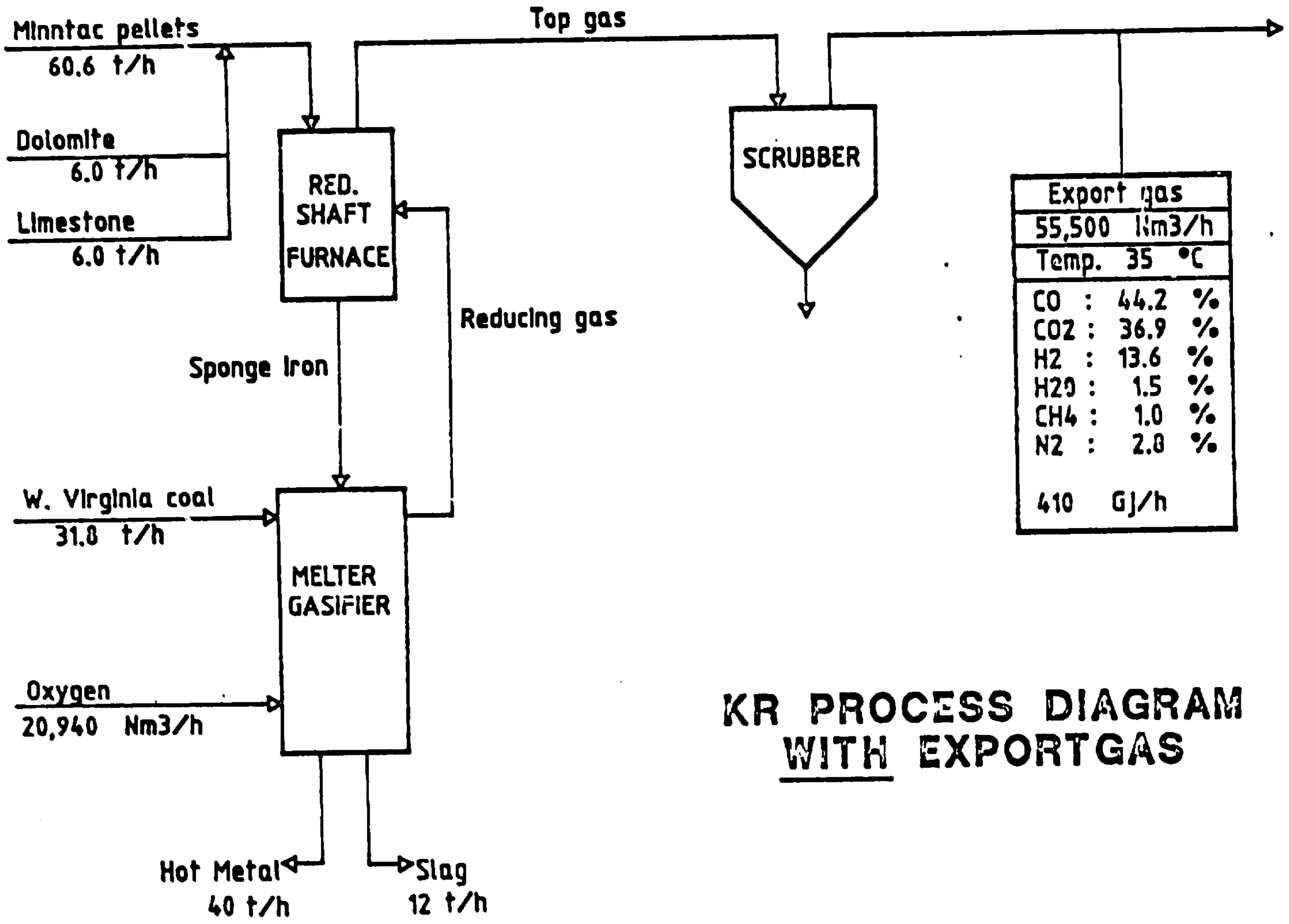
LEGEND:

1 MELTER GASIFIER
2 REDUCTION SHAFT FURNACE
3 COAL FEED SYSTEM
4 HOT DUST CYCLONE
5 CO_2 - REMOVAL
6 TOP GAS SCRUBBER

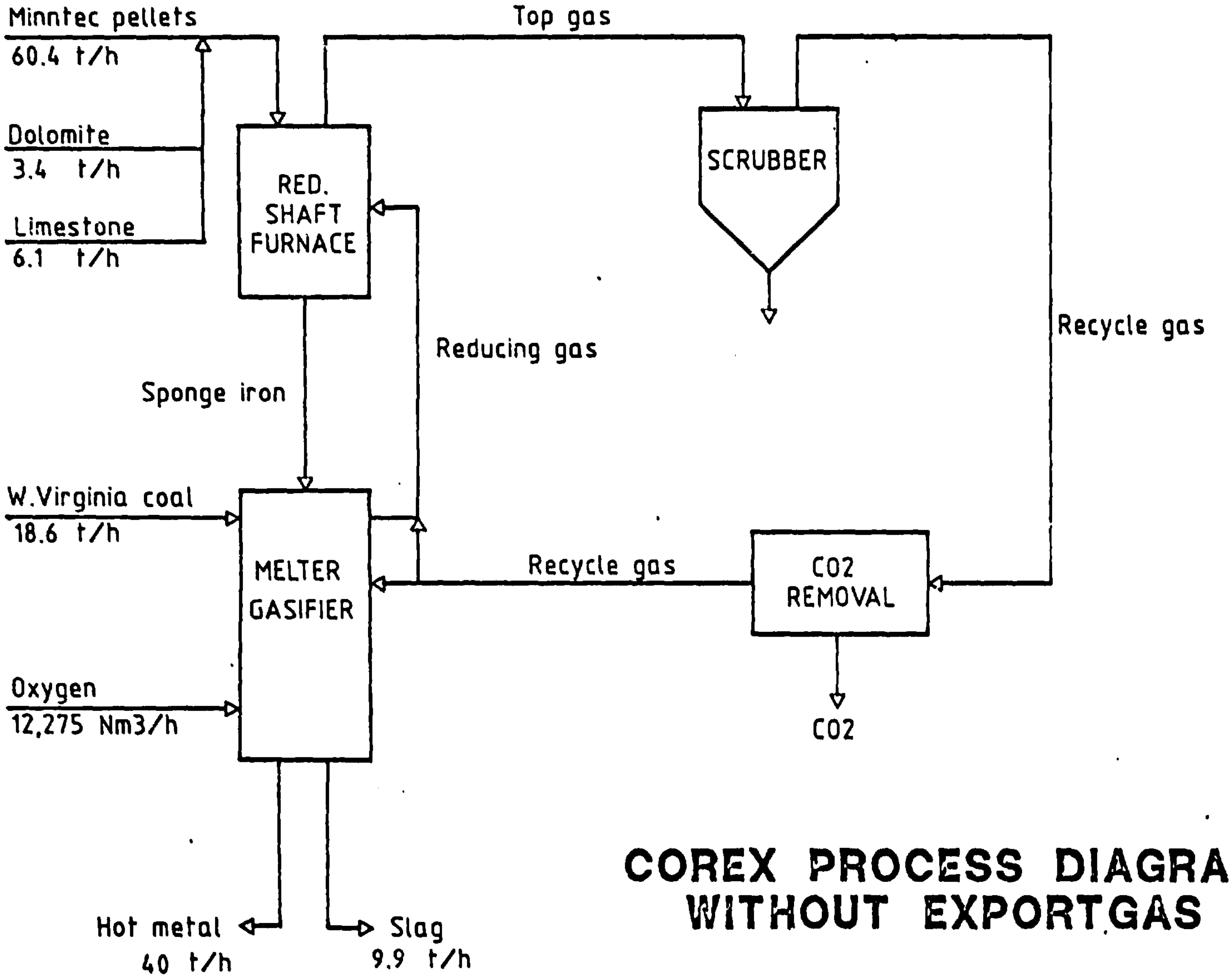
The COREX® process

BASIC FLOW SHEET without EXPORT GAS

FIG. 2



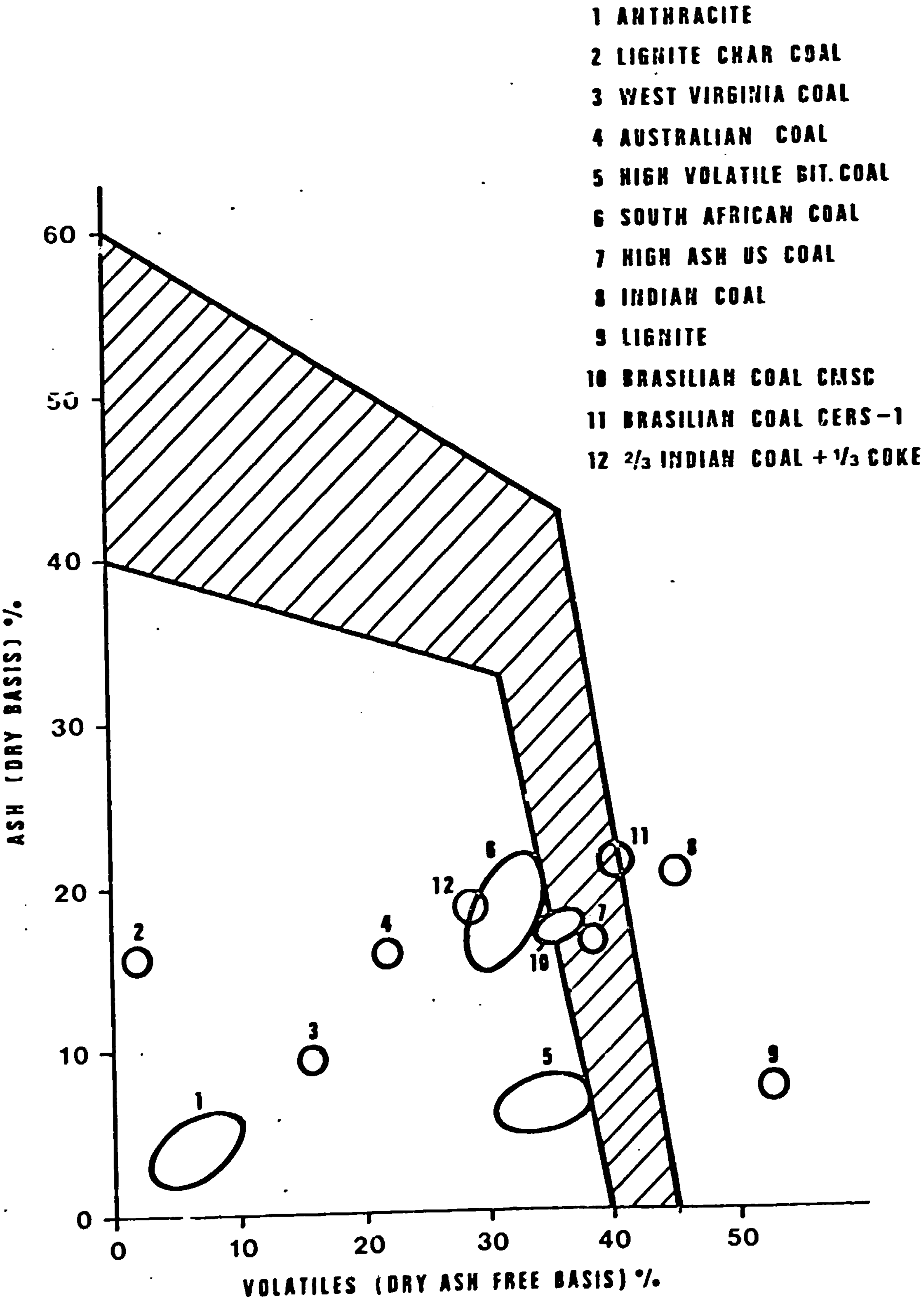
KR PROCESS DIAGRAM
WITH EXPORTGAS



**COREX PROCESS DIAGRAM
WITHOUT EXPORTGAS**

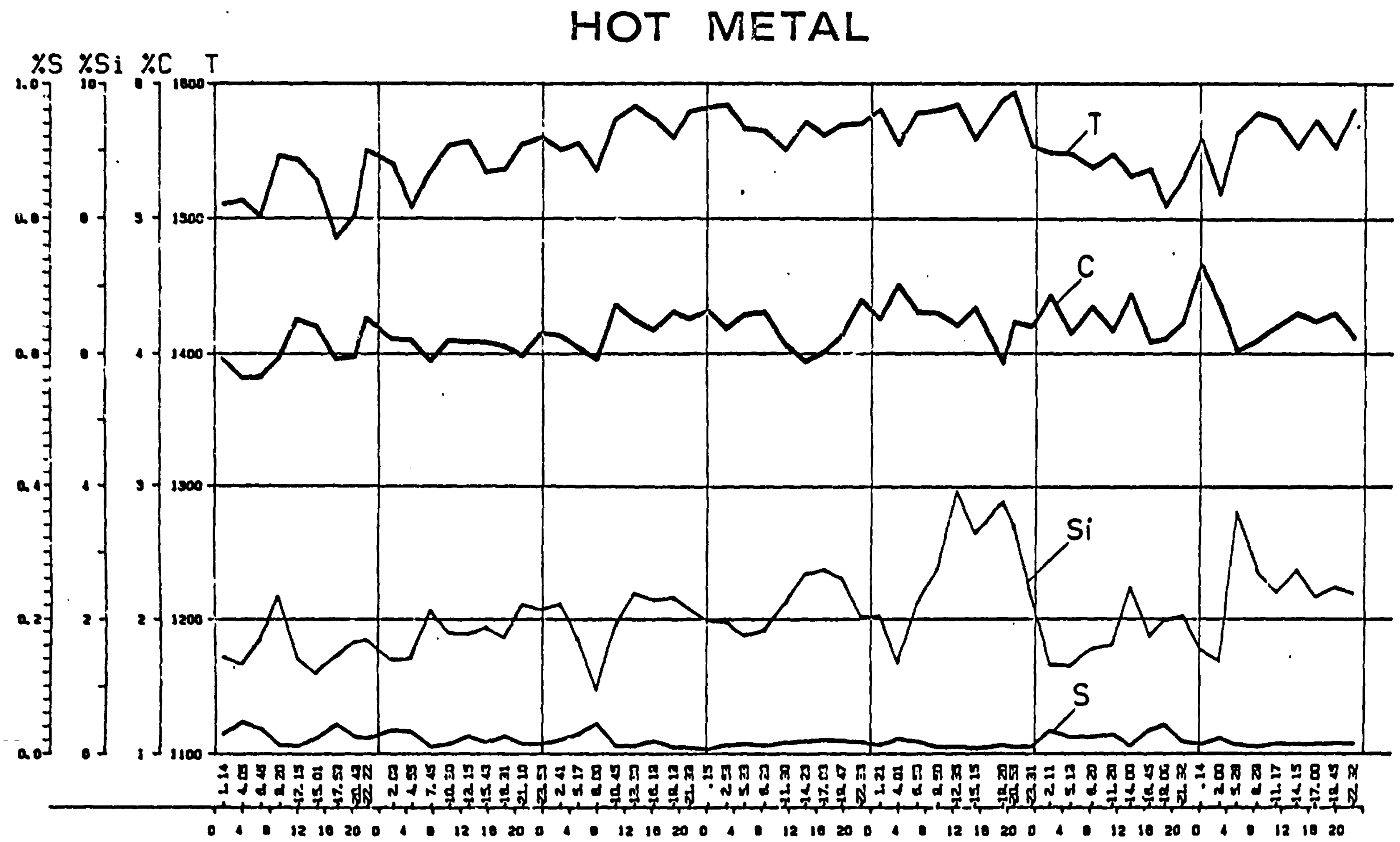
KORF ENGINEERING GMBH

Fig 4.



Classification of coals
for COREX – the KR process

HOT METAL



COREX
THE KR PROCESS

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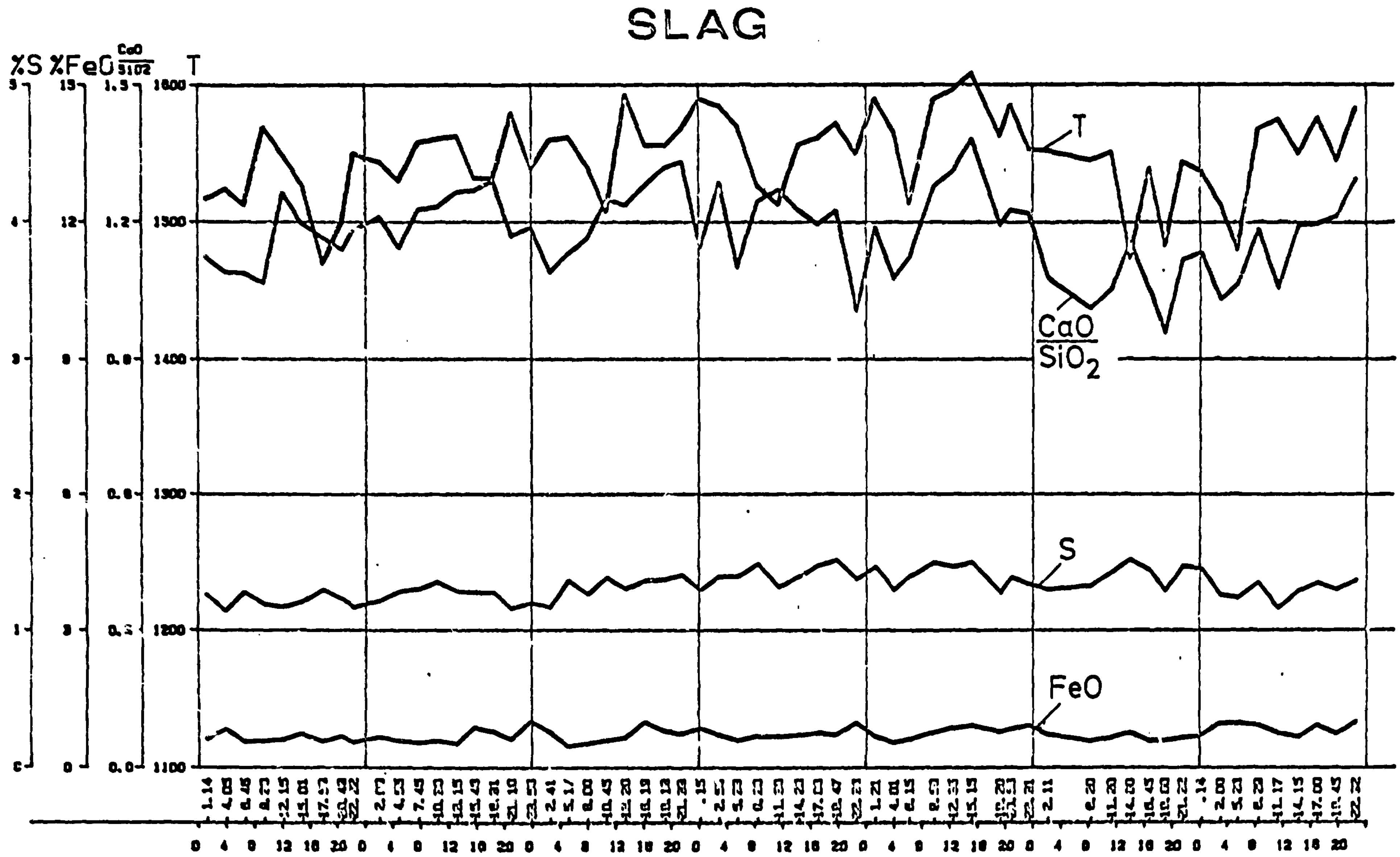
FIG.6



COREX
THE KR PROCESS

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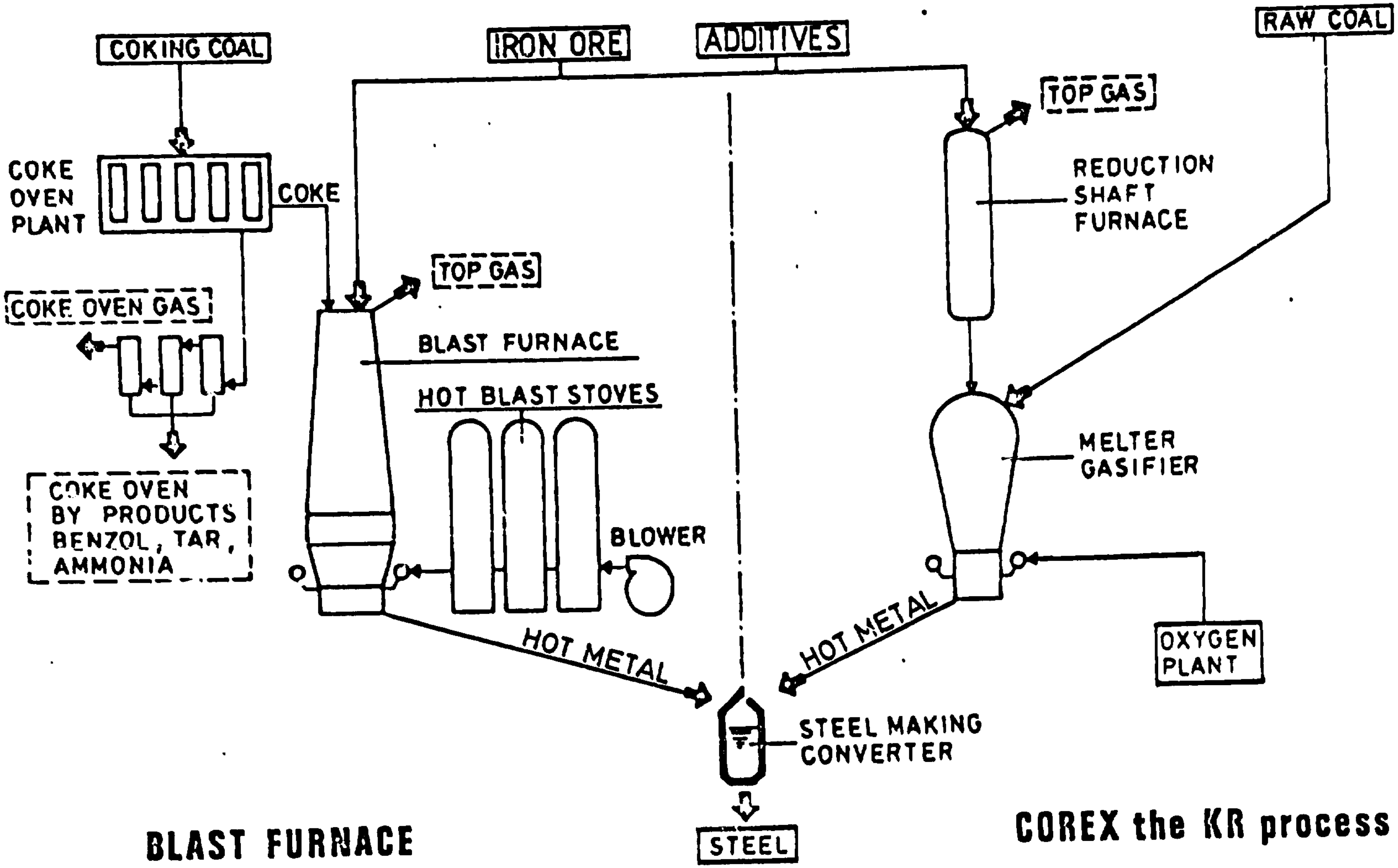
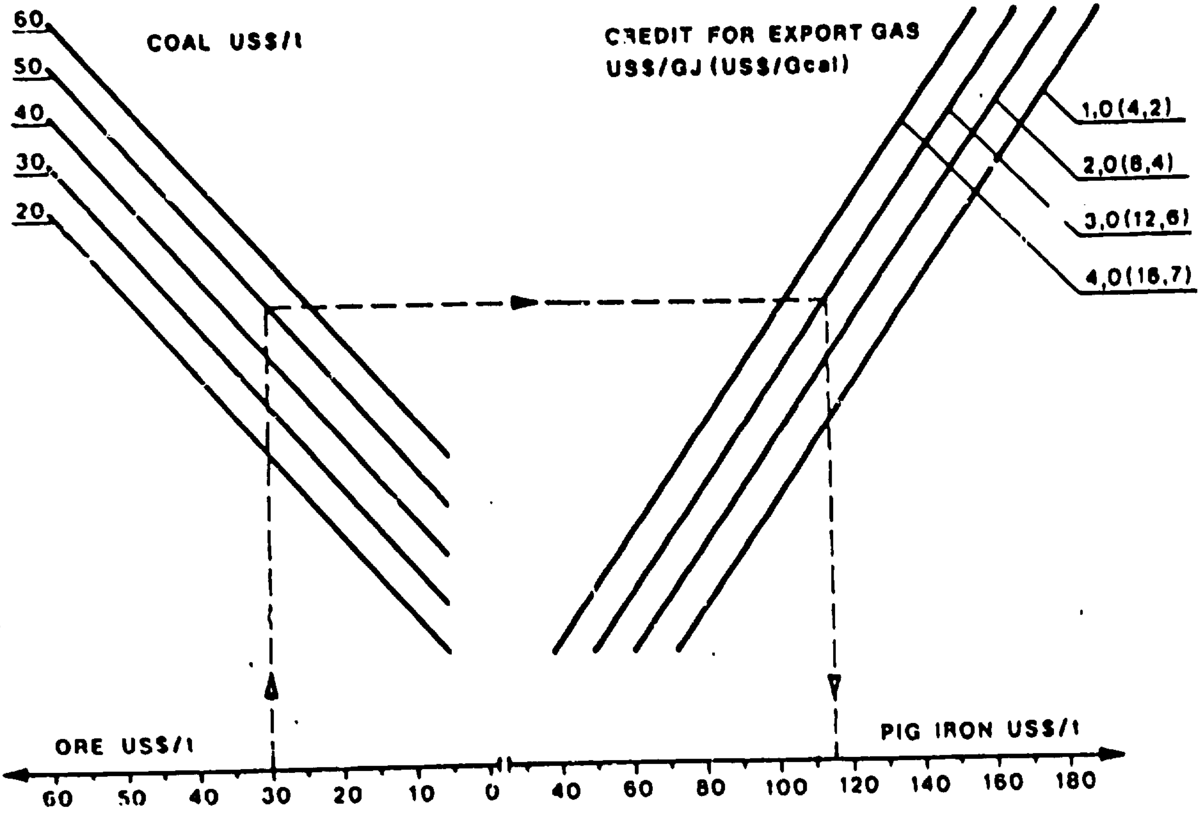
FIG 7



COMPARISON of COREX–STEELMAKING ROUTE vs. BLAST FURNACE ROUTE

FIG. 8



THE DIAGRAM INCLUDES:

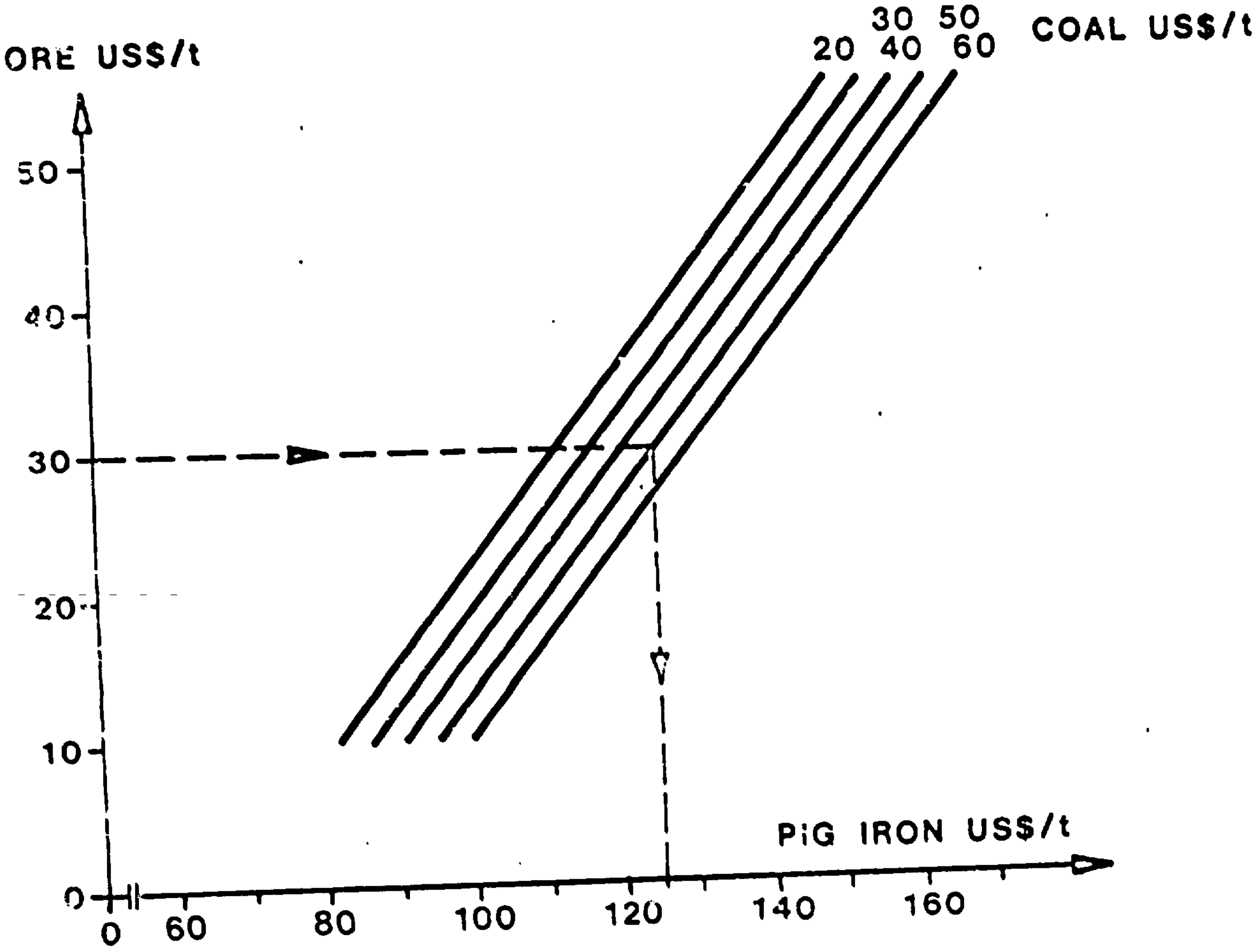
(BASED on 200 US$/t installed capacity)

Capital cost : (10 % ; 15 y)
Oxygen cost : 0,04 US$/Nm³
Electrical cost : 0,04 US$/KWh
Man power cost : 50 men; 20 000 US$/y
Maintenance : 4 % of equipment cost

1$ = 2DM

COREX PIG IRON COST AS A FUNCTION OF ORE AND COAL COST
WITH EXPORT GAS
(PLANT CAPACITY: 300,000 TPY)

FIG. 9



THE DIAGRAM INCLUDES:

(BASED on 220 US$/t installed capacity)

Capital cost : (10 % ; 15 y)
Oxygen cost : 0,04 US$/Nm³
Electrical cost : 0,04 US$/KWh
Man power cost : 50 men; 20 000 US$/y
Maintenance : 4 % of equipment cost

1US$ = 2 DM

COREX PIG IRON COST AS A FUNCTION OF ORE AND COAL COST WITHOUT EXPORT GAS
(PLANT CAPACITY: 300,000 TPY)

FIG.10

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ANNEX 5

THE EOF PROCESS: PERFORMANCE AND OUTLOOK

THE EOF PROCESS: PERFORMANCE AND OUTLOOK (1)

Ralph Weber (2)
Henrique Carlos Pfeifer (3)

SUMMARY

The EOF ("Energy Optimizing Furnace") process was developed by the Korf Group at its brazilian Companhia Siderúrgica PAINS plant, with the idea of ultimate rationalization of the open hearth furnace. Although preserving the great flexibility of the OH as to the proportion of hot metal and solids in the charge, the EOF has dramatically increased productivity and reduced cost, thanks mainly to its thermal efficiency.

Starting operation at the end of 1982, in these three and half years of industrial operation the EOF at PAINS became responsible for 50 % of the company's production, which today approaches the 30.000 ton per month level. Right from the start the equipment presented a high availability and the learning curve progressed very quickly. Productivity, consumptions and costs reached highly satisfactory indices. Right now a number of improvements is being introduced, aiming at a further increase in process flexibility regarding the metallic charge and at even higher efficiency.

The size range of the EOF is between 15 and 100 t, equivalent to 100.000/650.000 tpy, which is in line with the size of micro and mini-mills. Major interest for the new technology comes from three areas: small integrated plants, based on charcoal blast furnaces or other non-conventional reduction units; plants that want to substitute open hearth furnaces which are still in operation; scrap-based plants which want to substitute obsolete arc furnaces or which are going to be installed now. Such a widespread interest range is promoting great attraction for the EOF.

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(1) Technical paper presented to the International Conference of Iron and Steel Technology in Developing Countries - November 1986. São Paulo/Brazil.

(2) Metallurgical Engineer. Superintendent of Co. Siderurgica PAINS.

(3) Mechanical and Metallurgical Engineer. Director of KTS Korf Tecnologia Siderurgica Ltda.

1. DEVELOPMENT OF THE PROCESS

The EOF ("Energy Optimizing Furnace") process was developed by the Korf Group at its brazilian Companhia Siderurgica PAINS plant, in Divinópolis, state of Minas Gerais. This plant produces about 350.000 tpy of long products, from charcoal blast furnaces, open hearth furnaces and one EOF unit, continuous casting, rolling mills.

Development of the process passed through three well defined stages, the first of which (1981/82) corresponded to the installation of a pilot plant, without scrap preheater, with a capacity of 22 t, where all the basic process and equipment parameters were developed. The second stage (1983/85) related to the installation and commercial operation of a 28 t EOF unit, with a scrap preheater specifically designed to suit the metallic charge available at PAINS. Average charge of this EOF has been 60 % hot metal, 30 % pig iron and 10 % return steel scrap.

Once the operation practice under these conditions was consolidated, at the end of 1985 the third stage was started, which is still going on, comprising the installation of equipment and systems to attain the following aims:

- increase the capacity of the EOF to 55/60 t
- allow the scrap preheater to take any kind of scrap, from light shredder or sheared scrap up to dense pieces like skulls
- demonstrate the feasibility of operating with high proportions (40 up to 100 %) of steel scrap in the charge
- introduce the slag-free tapping, i.e., retaining the slag in the furnace, with the resulting quality improvement in steel.

2. DESCRIPTION OF THE PROCESS

The EOF process is essentially an oxygen steelmaking process using combined side blowing. Oxygen is injected horizontally through specially designed tuyeres into the molten bath, and oxygen is blown into the furnace atmosphere by water-cooled injectors, as shown in Fig. 1.

Oxygen injected underneath the liquid level oxidizes carbon forming CO which accomplishes the task of bath agitation. The resulting intense splashing multiplies the steel surface exposed to the oxygen injected into the atmosphere, accelerating carbon oxidation. The CO thus formed burns to CO_2 in the furnace's atmosphere and the generated heat is partly absorbed by the bath, whereas the remainder preheats the scrap, the average temperature of which may even exceed 800 °C at the moment of dropping, with local peaks of up to 1.100 °C.

Two are the modes of charging the EOF, according to the available metallic charge. At the conventional operation at PAINS, where hot metal answers for 60 % of the charge and steel is completely tapped at the end of the heat, the preheated scrap is dropped on the hearth and afterwards the hot metal is poured into the furnace. C content of hot metal is enough to care for the heat balance of the heat. Oxygen blow, both submerged and into atmosphere, starts together with the hot metal pouring.

In the operation with higher proportions of steel scrap the previous heat is not entirely tapped, but rather a liquid rest ("heel") is left in the furnace. In this mode operation starts with the injection of coal fines into the liquid heel, through special tuyeres, until a C content of about 3% is attained. At this point the preheated scrap is dropped in one or more batches and the blow of oxygen is started, submerged and into atmosphere. Fluxes are added as necessary by means of an automatic weighing and conveying system, which leads to the charging hole in the roof.

Oxygen injection immediately launches the refining reactions, at first oxidizing silicon, phosphorus and manganese, and later on carbon. The generated heat accounts for the melting of the charged scrap and the gradual temperature increase of the bath, whereas the CO generated by submerged injection promotes intense agitation, multiplying the molten metallic surface exposed to the action of the oxygen from the furnace atmosphere.

Slag becomes foaming and "grows"; opening of the dolomite dam at the slag door allows it to flow to the slag pit.

Combustion of the CO and some H_2 available in the furnace atmosphere with the injected oxygen, either pure or in the form of preheated air, generates heat, partially absorbed by the bath, by convection and radiation, and for the rest addressed to preheat the scrap.

The rate of oxygen injection determines the whole reaction kinetics, including the intensity of the combustion reaction of the CO to CO_2 and, therefore, the remaining CO content in the offgas. This CO content is related to the CO_2 dissociation mechanism at high temperatures, to the total flow of O_2 and to the latter's distribution in the furnaces' atmosphere.

Since the flows of oxygen, both submerged and into the atmosphere, are controlled promptly and with accuracy, their control allows to operate the EOF in a precise and predictable way, easily allowing a control by processor. Starting with the inflow analysis and temperatures and with one or two intermediate carbon and temperature takings it is possible to determine in advance the development of the carbon/temperature curve until tapping. Carbon injection or ferro-silicon addition, to increase temperature, or additions of scrap or iron ore, to lower it, safely allow to make all necessary corrections.

The hot gases leave the furnace through the central hole in the roof and proceed to the scrap preheater (Fig. 1), with water cooled elements and partial refractory lining, in this case divided into three sections. Maximum entering temperature into lower section is up to 1.300 °C, whereas the mean temperature upon leaving the upper section is 400 °C. Quantity, size, nature and distribution of scrap have a bearing on heat transfer efficiency. Mechanical reasons limit the maximum lenght (abt. 1,2 m) and weight (400 kg) for the individual pieces. As an average, the scrap preheating temperature has been around 800 °C.

Summing up, the EOF owes its thermal efficiency to the optimized use of energy derived from the following three sources:

i . Chemical energy released in the bath and on its greatly extended surface by the reactions between the oxygen, injected in the bath and into the atmosphere, and the oxidizable elements, including added carbon.

ii . Chemical energy derived from the gaseous oxidation reactions in the furnace atmosphere, envolving CO and H_2 set free from the bath.

iii. Sensible heat transferred by the hot gases from the furnace to the cold scrap charged into the preheater.

For further details see (1) and (2).

3. THE EOF EQUIPMENT

The main features of the EOF equipment are as follows:

- Circular and compact shape of the furnace, in order to keep heat losses to a minimum.
- Fixed, non-tilting design, allowing for the maximum use of water cooled panels in the furnace shell above the molten bath, with consequent reduction in refractory consumption.
- Water cooled roof.
- Oxy-fuel burners in the shell above the bath for use as an auxiliary energy source for heating upon start-up and during down-times.
- Submerged K.O.R.F. tuyeres installed in the furnace shell below the molten bath for injecting oxygen. The three concentric pipe design allows for optimum cooling of the protruding end of the tuyeres, allowing to attain wear indices lower than 3 mm per heat, also as a result of a careful selection of refractory block.
- Oxygen and preheated air injectors installed in the furnace walls, allowing adjustment of the angle of incidence.
- Special tuyeres for the injection of coal fines and lime into the liquid heel, before dropping the preheated scrap.
- Computer controlled oxygen flow, both submerged and into the atmosphere.
- Specially designed scrap bucket, to allow quick charging of the furnace, with no dust emissions and low noise level.
- The removable bottom allows a quick relining of the furnace between successive campaigns, just by exchanging the bottom, which takes no more than 12

hours between the last previous heat and the first one of the new campaign.

- The blowers installed downstream the gas cleaning plant and somewhat overdimensioned, allow a precise pressure control of ± 2 mm of water column inside the furnace, by commanding their valve from inside the control room.

4. OPERATIONAL RESULTS OF THE EOF

Figures 2 to 7 present some of the operational results obtained in the EOF at PAINS over the last three and half years. The figures show in an expressive way the result of the learning curve and the effect of some improvements made, among which two deserve to be mentioned:

- Introduction of the water-cooled roof, at the end of 1983.
- Introduction of the removable bottom, supported by the bottom car and allowing the quick exchange of this part of the furnace, in August 1984. As a consequence, idle time between campaigns was immediately reduced to 48 hours, now being in the range of 24 hours.

In this whole period nothing was changed regarding the basic equipment, which has proven to be efficient and reliable.

Especially the scrap preheater (Fig. 8), conceived in 1982 for the use of dense scrap and pig iron, at a time when no experience existed in regard to scrap preheating with high temperature gases, operated with full success and high availability.

Observation of the graphs also shows two important achievements, namely the increase in number of heats per campaign up to 350 level (record: 406, in campaign nr. 50); and the decrease of tap-to-tap to the level of 71 minutes, which still tends do decrease in the near future.

It should be emphasized that all ongoing tests and improvements are being performed on a production unit, since the PAINS EOF is responsible for about 50 % of the company's steel output. In the conflicts of interest between testing and producing, priority has consistently been given to steel production, which explains the slower evolution of some improvements as well as the operational safety shown by the equipment.

The results presented in Figures 2 to 7 show only part of the operational evaluation of the EOF. Some other indices are worth mentioning:

. Refractory consumption: from a total of 27 kg/t at start-up the refractory consumption has already shrunk to 12 kg/t in the last campaigns Only 6,5 kg/t correspond to formed pieces, whereas the balance is fettling materials. Present improvements will further reduce brick consumption to about 4 kg/t in the near future.

. Oil consumption: This index, which started at 23 liters per ton, was reduced to the level of 10 liters per ton. It is expected to reach 6 liters per ton at the operation mode with a liquid heel.

. Productivity: Productivity is coming close to 25 t/h with all the difficulties inherent to the operation of a melt shop which doubled production with the same infra-structure as before, specially in regard to cranes.

All the results above find their quantitative expression in the production cost of the EOF which, in comparison to the open-hearth operating with K.O.R.F. submerged blowing, presents a saving of US$ 15,00 per ton of tapped steel, for the same charge composition. The cost advantage over a conventionally operating open-hearth is in the range of US$ 30,00 per ton.

5. TRIALS WITH PROPORTIONS OF STEEL SCRAP

In March 1986 some trial heats were made with 60 % hot metal and 40 % steel scrap, still with the original scrap preheater. The aim was to reduce the availability of chemical heat and to demonstrate the energetic efficiency of the EOF, thanks to the high CO afterburning rate.
Table I presents the results obtained, in comparison to the average data of campaign nr. 48, of February/March 86.

As can be seen, the results were excellent, since metallic yield experienced a substancial increase, blowing time was reduced and the addition of energy was limited to some kilograms of coke breeze, whereas the remaining parameters practically did not change.

Number of Consecutive Heats		358 (Campaign nr. 48)		5 (trial)	
Charge Composition:		kg	%	kg	%
Hot metal		703,0	63,0	641,7	59,9
Pig iron		317,1	28,4	–	–
Steel scrap		95,6	8,6	428,8	40,1
Total		1.115,7	100,0	1.070,6	100,0
Metallic yield	%	89,5		93,4	
Oil	kg/t	15,2		15,7	
Coke in charge	kg/t	4,9		8,5	
Oxygen	kg/t	72,7		77,8	
CO_2 (cooling)	Nm^3/t	9,1		8,0	
Lime	kg/t	53,6		52,2	
Total tap-to-tap	min	73,1		(*) 73,5	
Blowing time	min	49,7		46,7	
Average weight of heat	t	28,2		29,6	
Average productivity	t/h	23,15		(*) 24,16	

(*) One of the heats experienced a delay due to hanging of the scrap, which included pieces of excess lenght. This delay has been excluded.

TABLE I: EOF – Comparison of Performance for
Different Compositions of the Charge

The new scrap preheater which has just been installed (see below) is expected to deliver heats with 50 % hot metal and 50 % steel scrap without further additions of coke or coal and with no need of carbon injection through tuyeres. Trial runs are being scheduled and scrap is being bought for a campaign of 20 successive heats.

The proportion of scrap may become even higher in the case of EOF furnaces of bigger size, with lower specific heat losses, operating with hot metal of higher temperature and higher silicon content.

6. OUTLOOK I: IMPROVEMENTS OF THE EOF

C. S. PAINS, which still gets half of its total production from open hearth furnaces equipped with K.O.R.F. submerged injection, has the utmost interest in expanding the capacity of the already installed EOF. Both the cost advantages of the EOF as well as the environmental problems of the OH furnaces exert pressure in this direction. Another purpose is to create the conditions to operate the EOF with 50 % hot metal, up to 15 % pig iron and 35 % at least of conventional steel scrap, thus allowing for maximum flexibility in charge consumption. Such is also the interest of any other potencial user of the EOF.

Reaching of these goals will be obtained by installation of the following equipment, described below:

- New scrap preheater
- New 60 t furnace bottom
- Double ladle car
- Coal injection system
- Slag free tapping system.

The New Scrap Preheater

Based on the experience gained over three years operation with the original downflow preheater, a new multi-stage up flow scrap preheater has been designed, placed directly on top of the furnace, with the following features:

- Flexibility regarding kind and size of scrap, operating with light scrap (0,7 t/m^3) up to pig iron and accepting individual pieces of up to 400 kg weight.
- Flexibility as to the total charge (from 12 to 30 t)
- Optimizing of sensible heat transfer from gases to the scrap.

The new scrap preheater for PAINS was built with three stages, with a maximum capacity of 30 t. Each stage is composed of a set of water-cooled horizontal retractable bars ("fingers"), hydraulically withdrawn when dropping the scrap, with a movement comparable to that of opening a scrap bucket. Thus, the scrap is dropped in four successive steps, from the scrap bucket down to the hearth of the EOF.

The exhaust system keeps the scrap preheater at a negative pressure, and the gases enter the lowest stage at about 1200/1300 °C, leaving the upper stage at between 300 to 500 °C. From there they are conducted to the gas cleaning plant, after passing through a recuperative air preheater. The new unit was installed at PAINS' EOF, replacing the original preheater, in a 12 days period and following a carefully prepared schedule, which even included some structural changes of the building. The first heat with the new preheater was tapped on May 7, and already 4 campaigns have since been completed, until the beginning of August.

The operational indices have not shown any significant alteration during the first three campaigns after the exchange, although this was the learning period and the time for sorting out all the mechanical, hydraulic and operational troubles of a new equipment. In the fourth campaign, however, significantly lower blowing and tap-to-tap times were obtained, with a reduction of about 8 % over the previous average and yielding a corresponding increase in productivity. Once the maturity of the equipment has such been attained, new trials are being scheduled, with higher scrap proportions.

60 t Furnace Bottom

Installation of a new furnace bottom is being prepared at PAINS, with holding capacity of 60 t of molten steel and two tap holes - a conventional one at the 30 t level and another one on the hearth. This new bottom is dimensioned so as to fit on the existing bottom car, preserving all external dimensions. It will allow the furnace to work either with an increased capacity or with 100 % solid charge, maintaining a liquid level and tapping only 30 t per heat. For this purpose it will be equipped with special coal injection tuyeres, besides the oxygen tuyeres.

Double Ladle Car

In order to allow the tapping of 60 t into two ladles of 30 t each - which corresponds to maximum crane capacity - a new ladle car will be installed together with the new bottom.

Coal Injection System

A series of tests has been performed in the existing EOF vessel, aiming at the submerged introduction of coal fines, mixed with lime and additives. Different tuyere sizes and designs have been employed and up to 2.000 kg of coal have been injected per heat, in a flow ranging from 20 to 60 kg/min. The experience gathered is allowing to dimension the coal transport system and to improve cooling of the new tuyeres, to be installed together with the new bottom.

Slag Free Tapping System

A new tapping system is being developed and tested, based upon vacuum siphoning and aiming at the following goals:

- Parcial tapping of the furnace, leaving a liquid heel
- Leaving the slag in the furnace upon tapping
- Minimize the exposure of steel to the atmosphere.

Trials are being made in ladles meanwhile a new and adequately sized vacuum system (pump and tanks) is being expected in order to resume the tests in the furnace itself.

7. OUTLOOK II: WHO IS INTERESTED IN THE EOF

Development of the EOF responds to the idea of ultimate rationalization of the open hearth furnace, the flexibility of which in regard to the hot metal/ scrap proportion was fully preserved, but whose productivity was dramatically increased, at a simultaneous and intense cost reduction. Such results are due to the following items:

- Submerged oxygen injection
- Increased utilization of oxygen in the atmosphere
- Extensive use of water cooled panels on walls and roof
- Almost instantaneous charging of scrap
- Scrap preheating with the process gases.

Contrary to the open hearth, however, where the energy deficit is covered with hydrocarbons, the EOF allows the use of more economic coal. Dimensioned in its first version for 30 t (PAINS), complete engineering has already been accomplished for the 30 and 80 t sizes (200.000 resp. 500.000 tpy), for projects in the U. States, India and Europe. For the time being there is no intention of developing units bigger than 100 t, corresponding to 650.000 tpy. The smallest size is around 15 t, equivalent to 100.000 tpy.

It is apparent that the EOF is especially suited for mini and micro-mills, with or without availability of hot metal, and is of particular interest for three market segments:

(i) Small plants based either on charcoal blast furnaces - which at present show a great potential in Brazil - or on other non-conventional reduction units (KR/COREX, Plasmamelt/Combimelt etc) are finding in the EOF the ideal refining process (3), from the point of view of investment, efficiency and production cost.

In the case of high percentages of hot metal the EOF may operate with preheated air, saving an important part of the oxygen and dispensing with the scrap preheater, which in this case gives way to the traditional regenerators. Figure 10 shows an example for the layout of such a plant, with a capacity of 120.000 tpy of rolled products. Installation of such a plant, complete with infrastructure and utilities, demands a total investment of about US$ 425,00 per ton of yearly capacity, 50 % of which correspond to the rolling mill.

(ii) Replacement of the open hearth furnaces in plants which have their own hot metal, operating with a charge composed of hot metal and scrap, constitutes another field for the EOF. This is the case of countries from Eastern Europe, some countries from the European OECD, from the Indian Subcontinent and from Latin America.

In Fig. 11 an example is given for the integration of an EOF into an existing OH melt shop.

(iii) The substitution of old arc furnaces or the installation of new plants based on scrap also present a great potential. In this case, the EOF introduces itself as an alternative for the electric arc furnace, with which it will compete in the analysis of investment and production cost.

In the final analysis this will be a competition between two energy sources: coal and oxygen, as against electric energy and electrodes. Fig. 12 shows the great advantage of the EOF against the arc furnace in regard to production cost, an advantage which grows with the price of electric energy.

As to the investment, the following figures are representative:

EOF: US$ 41,00 per ton of yearly capacity
EAF: US$ 68,00 per ton of yearly capacity,

comprising for both cases the equipment, civils, erection, site management and licence fee.

Thanks to this wide spectrum of interests which the EOF is able to attract, the appeal of the new technology has been very intense, as evidenced by the number of consultations and of visitors to the industrial plant.

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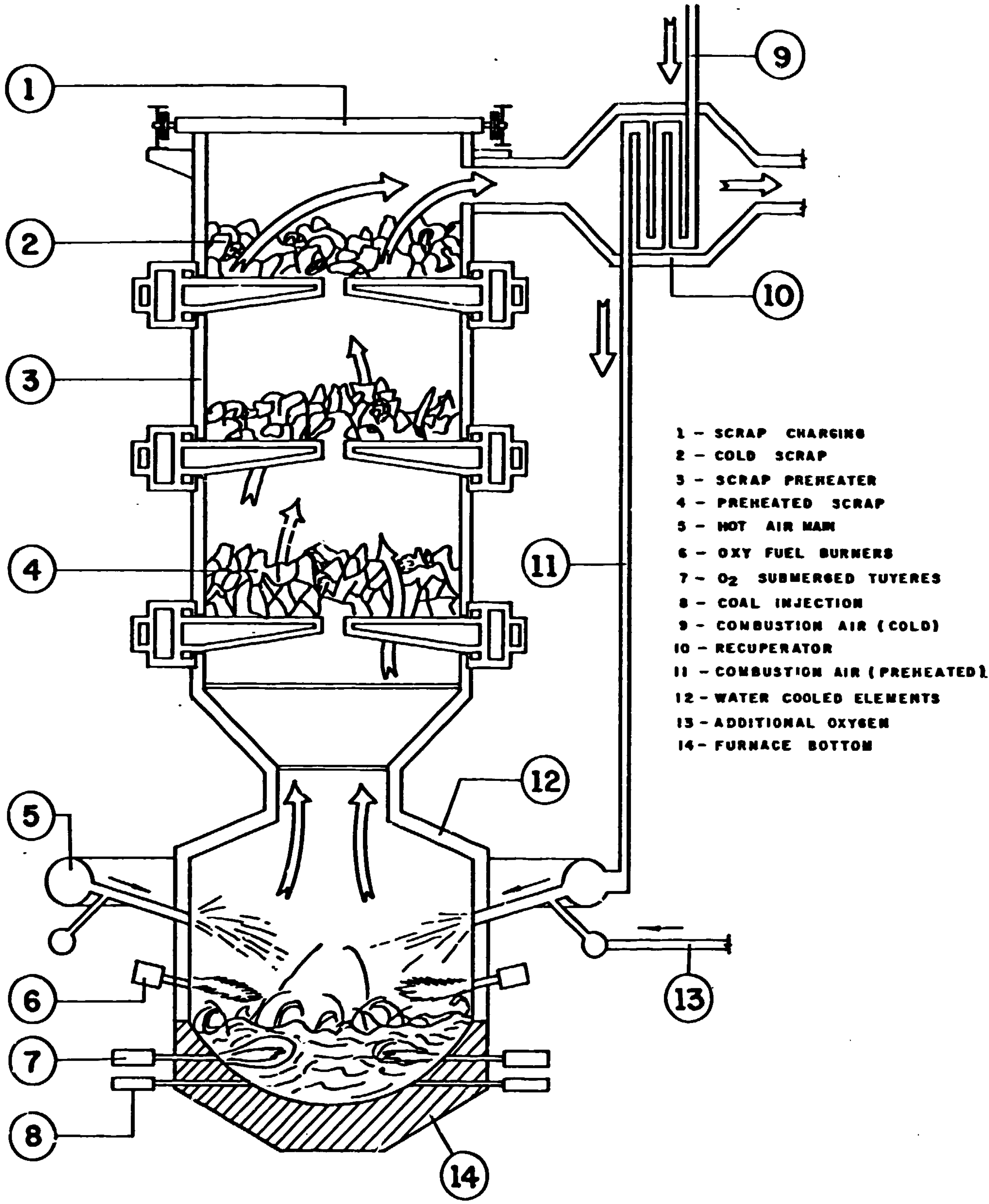
(2) Weber, R. and Rollinger, B.: "Three Years of EOF Operation at The Companhia Siderúrgica PAINS". UN Economic Commission for Europe - Seminar in Izmir/Turkey, May 5 - 9, 1986.

(3) Korf, Dr. W.: "Development of New Technologies for Mini-Plants", the Institute of Metals - Conference "Restructuring Steel Plants for the Ninetees". May, 14 - 16, 1986.



1 - SCRAP CHARGING
2 - COLD SCRAP
3 - SCRAP PREHEATER
4 - PREHEATED SCRAP
5 - HOT AIR MAIN
6 - OXY FUEL BURNERS
7 - O_2 SUBMERGED TUYERES
8 - COAL INJECTION
9 - COMBUSTION AIR (COLD)
10 - RECUPERATOR
11 - COMBUSTION AIR (PREHEATED)
12 - WATER COOLED ELEMENTS
13 - ADDITIONAL OXYGEN
14 - FURNACE BOTTOM

Figure 1 - EOF (Energy Optimizing Furnace)
Scheme

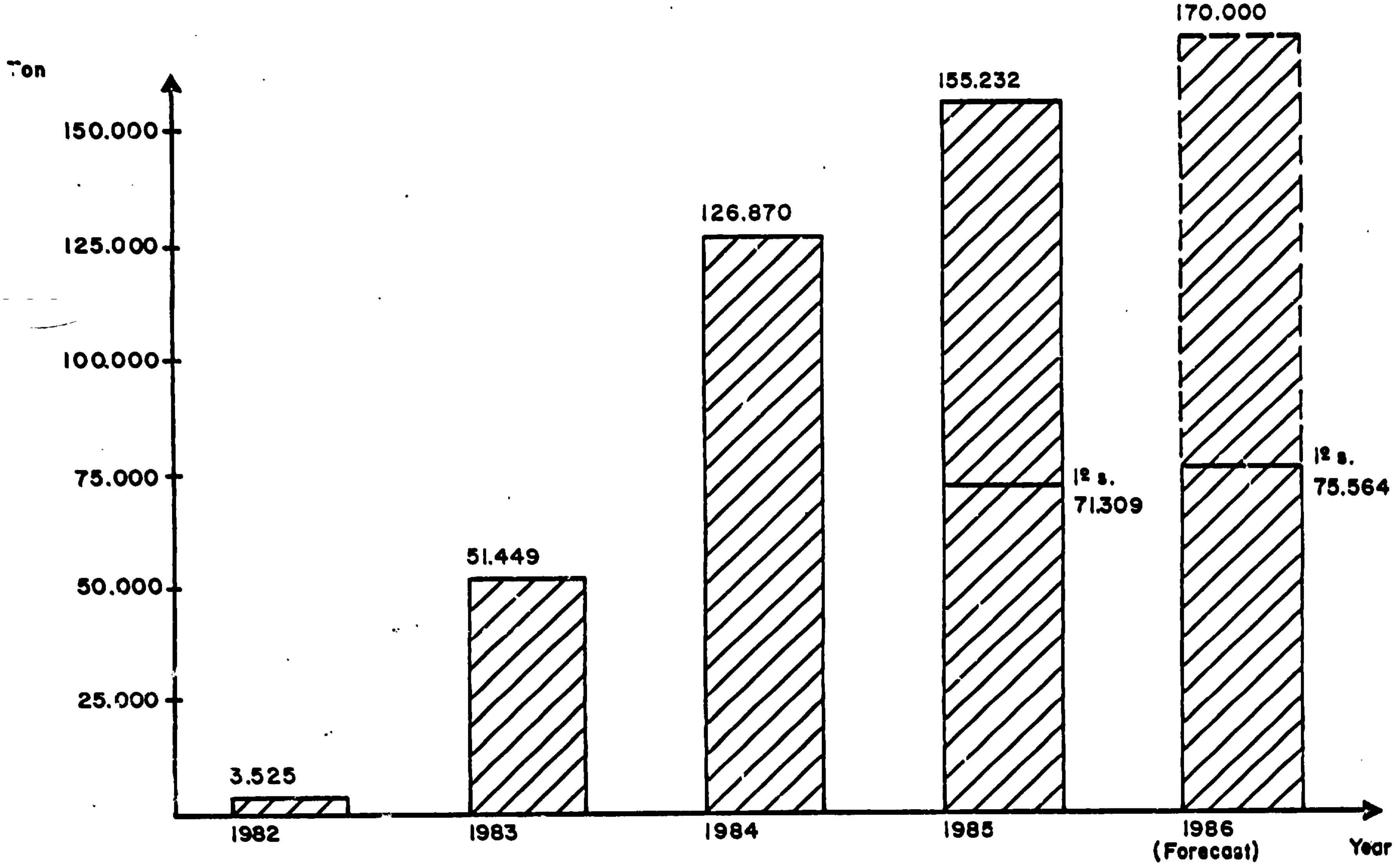


Figure 2: EOF: Annual Steel Production (t)

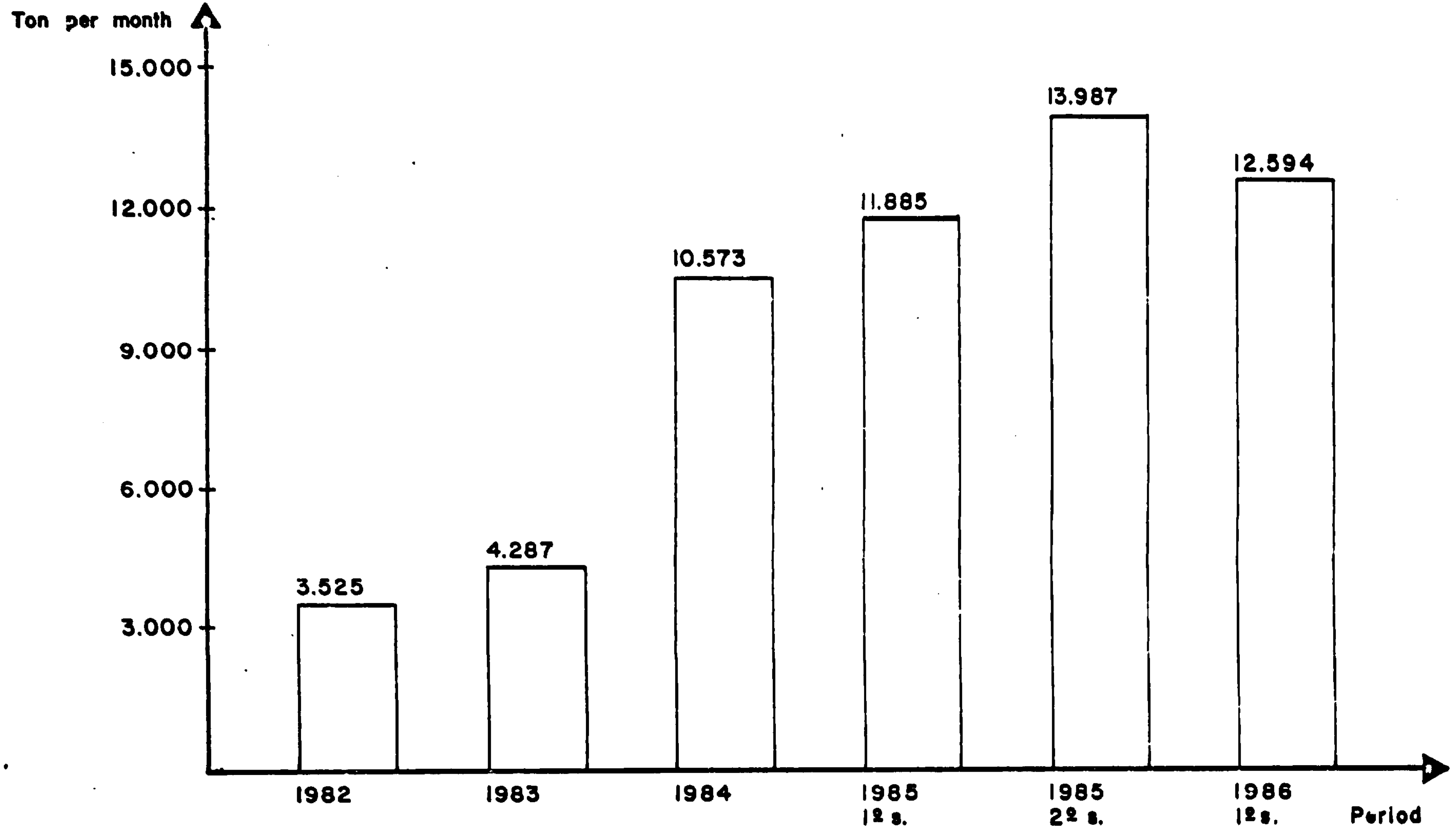


Figure 3 - EOF - Monthly Production - Average (T/month)

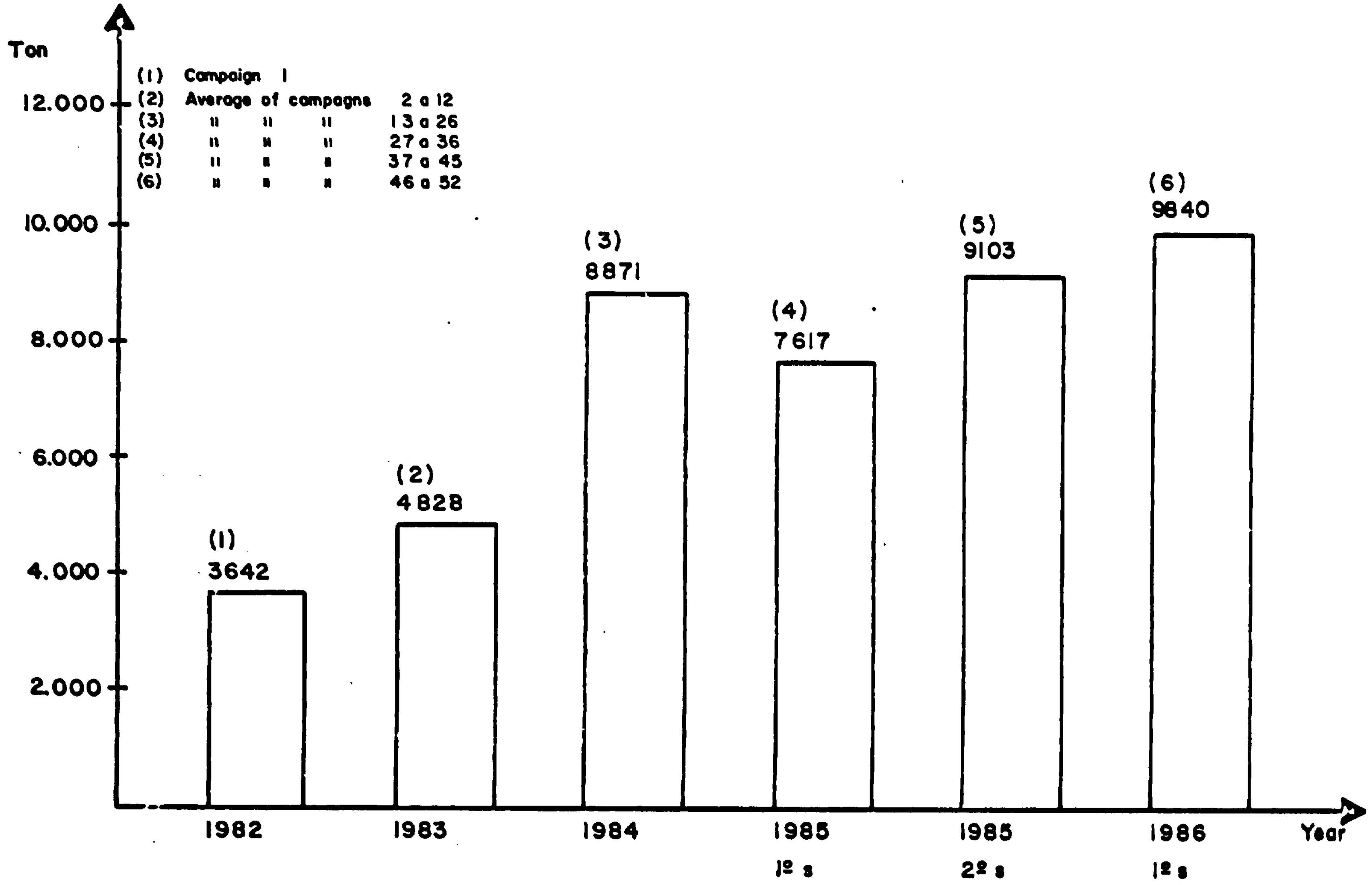


Figure 4 : EOF : Average Production per Campaign (Ton/Campaign)

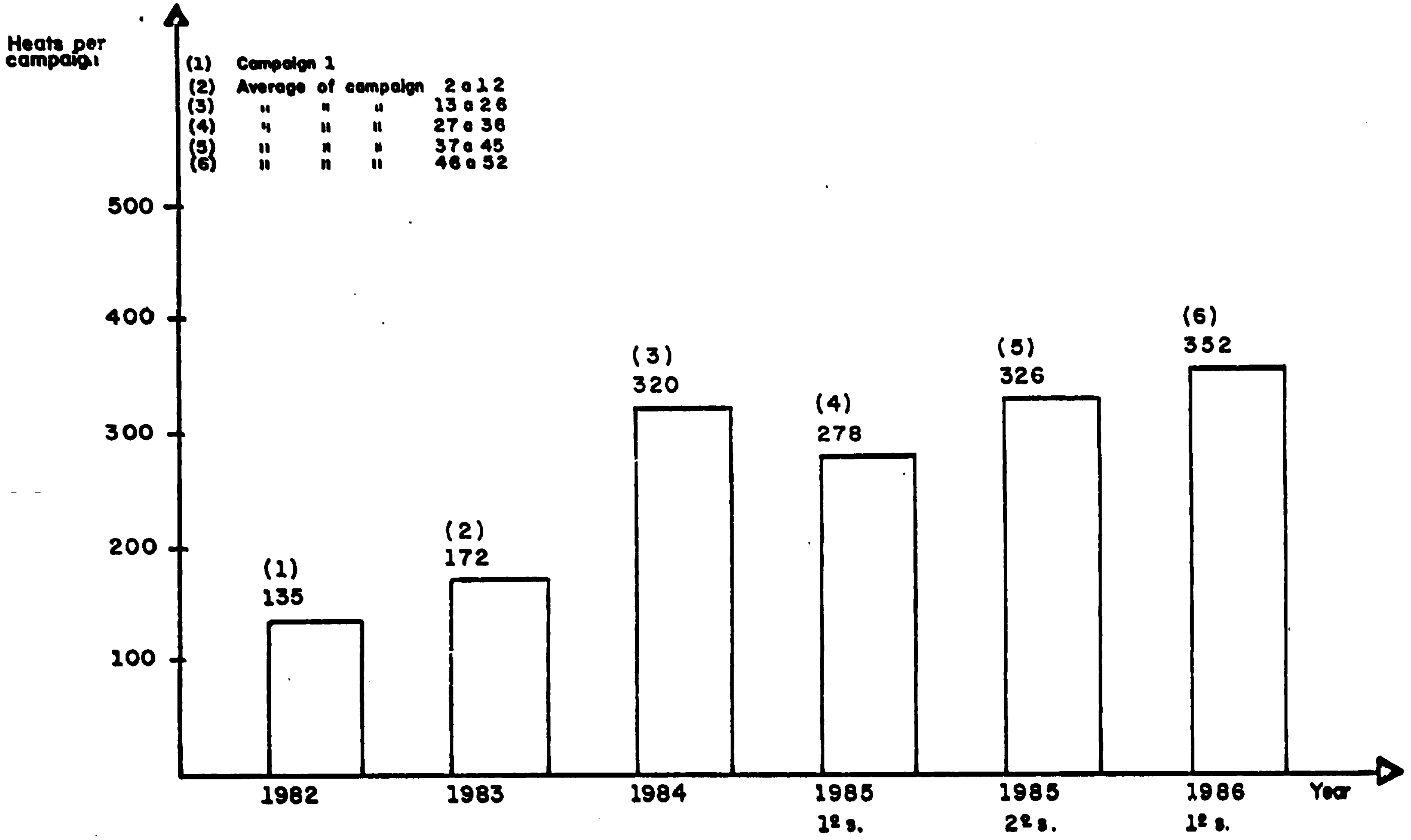


Figure 5: EOF: Average numbe; of heats per campaign

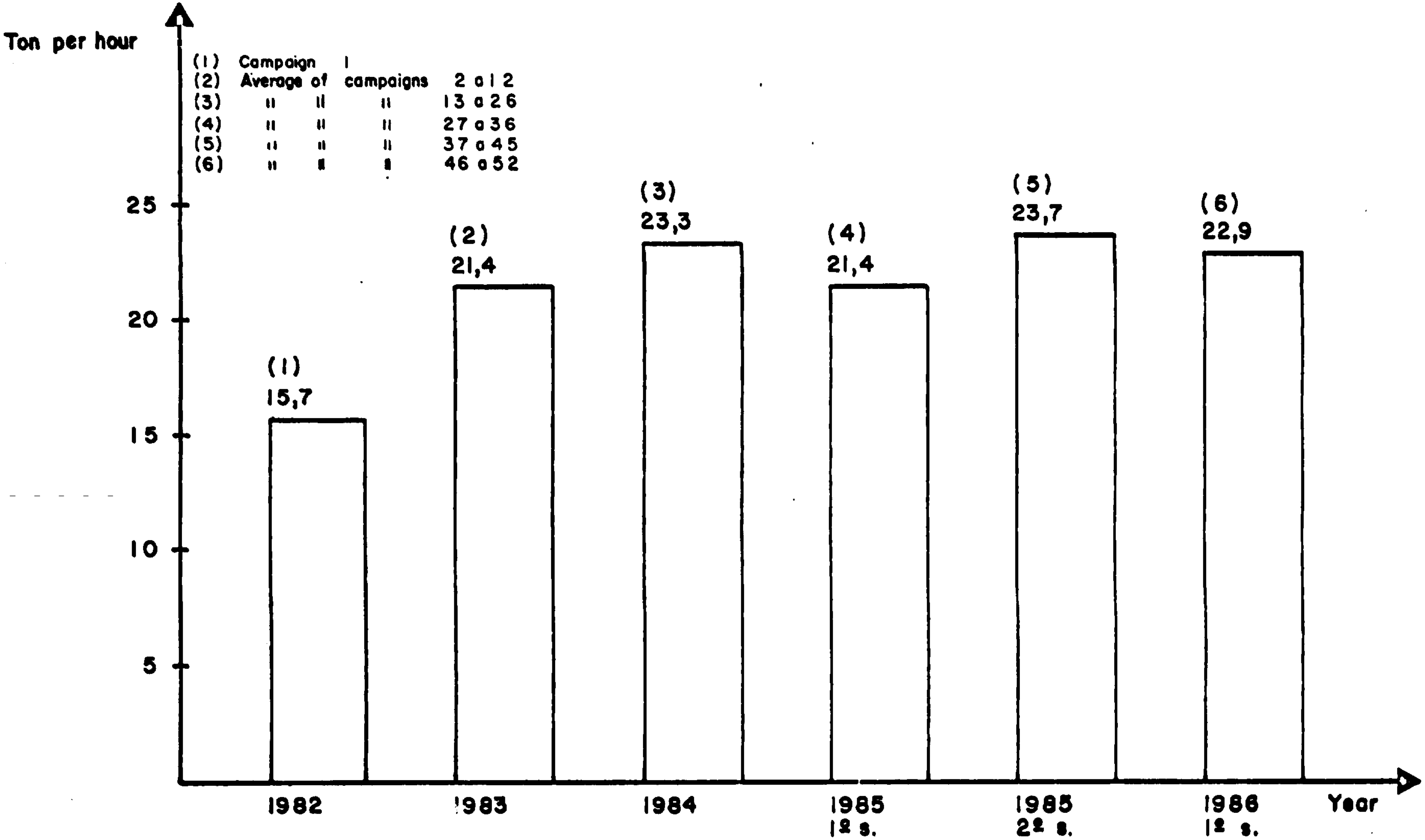


Figure 6 : EOF : Mean Productivity (t/hr)

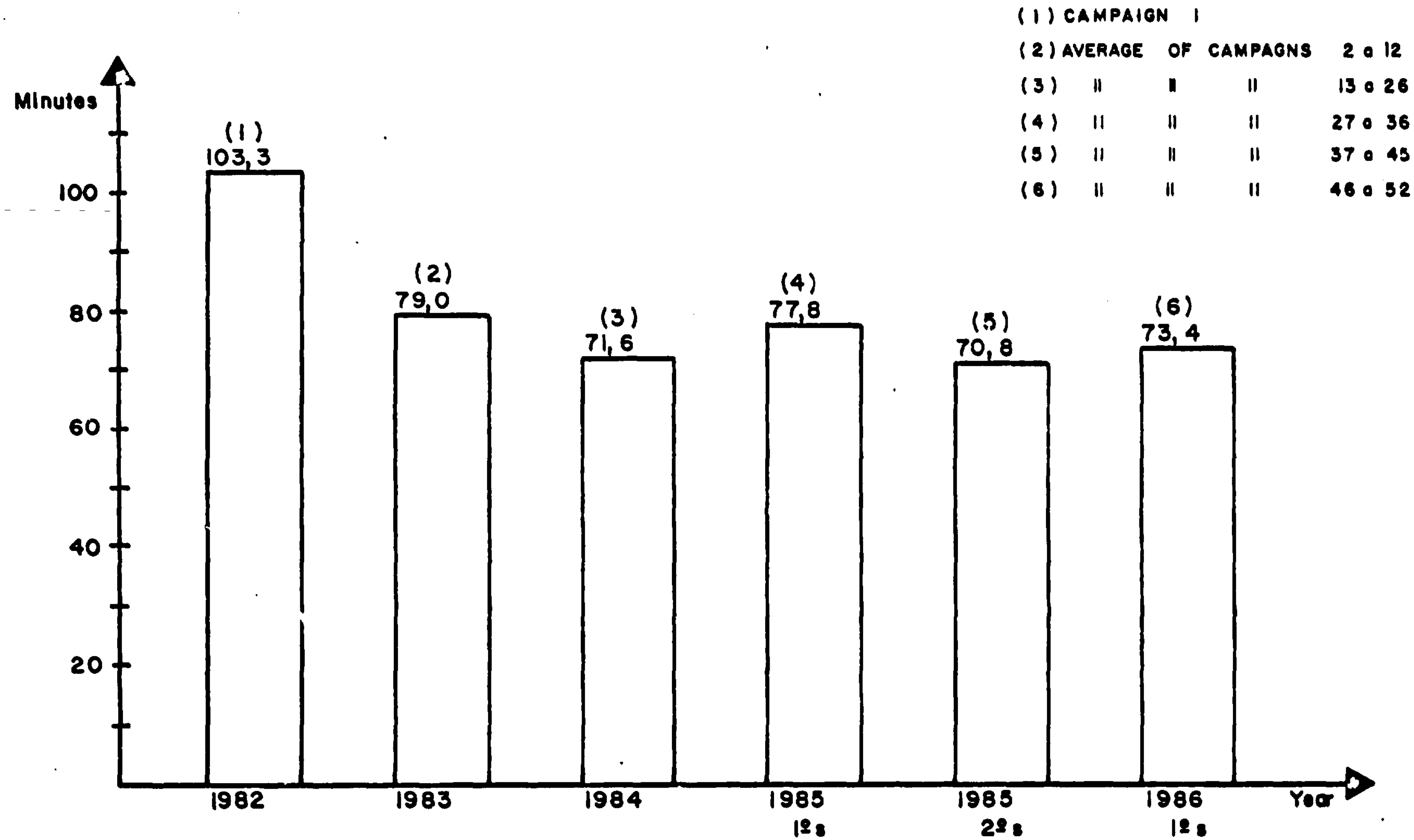


Figure 7: EOF - TAP TO TAP (min)

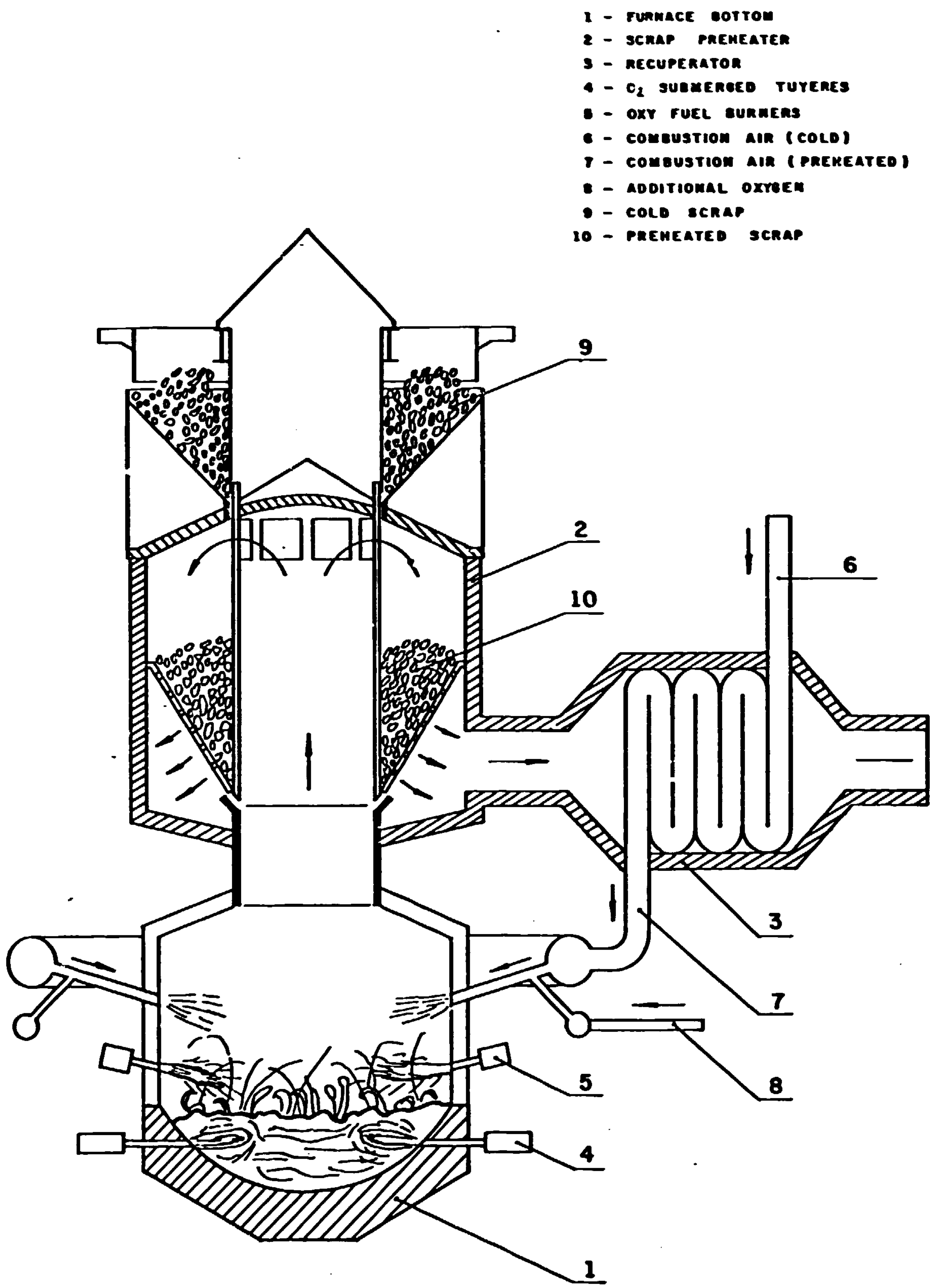


Figure 8- EOF with original Scrap preheater in descending flow

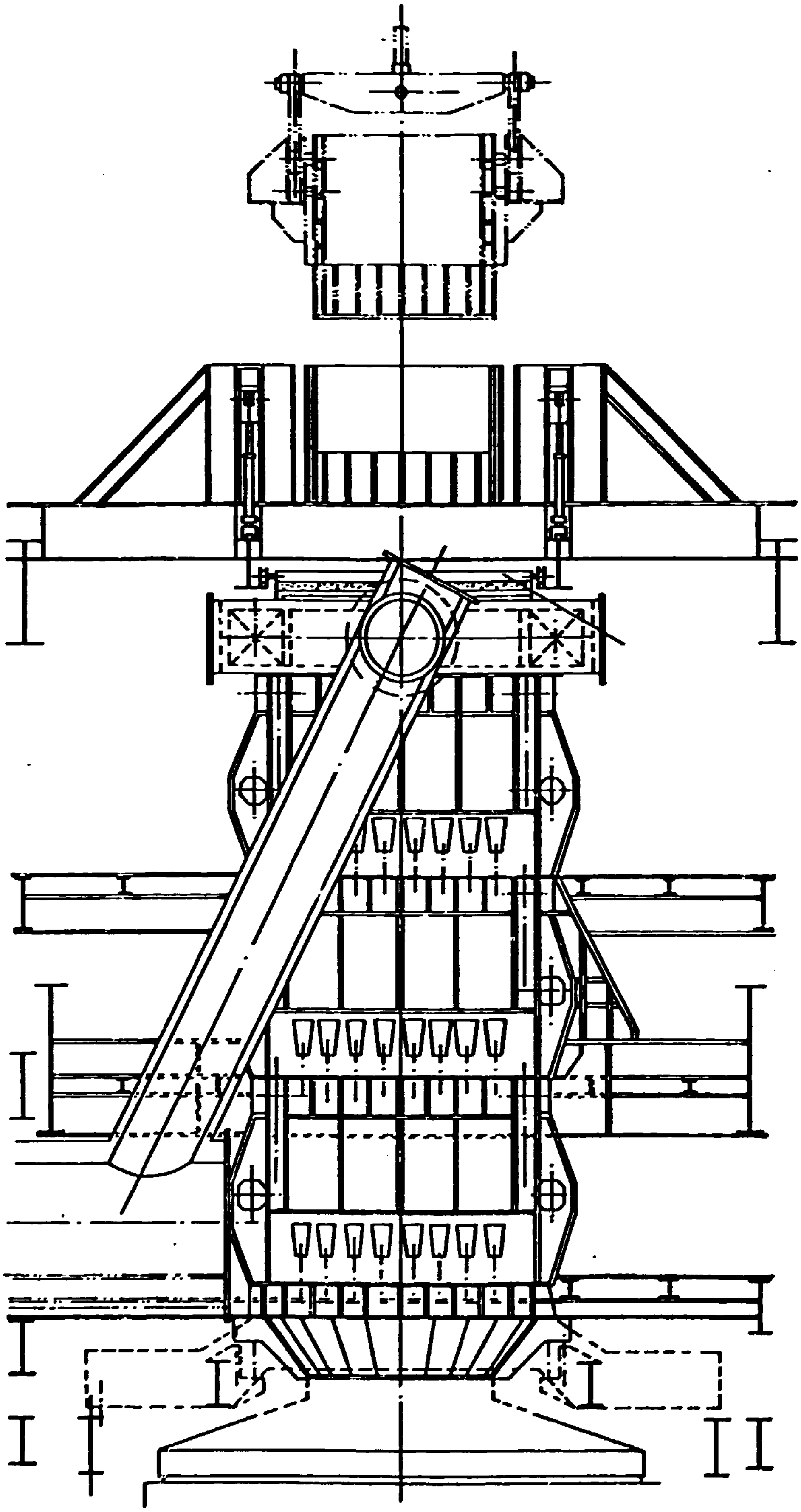
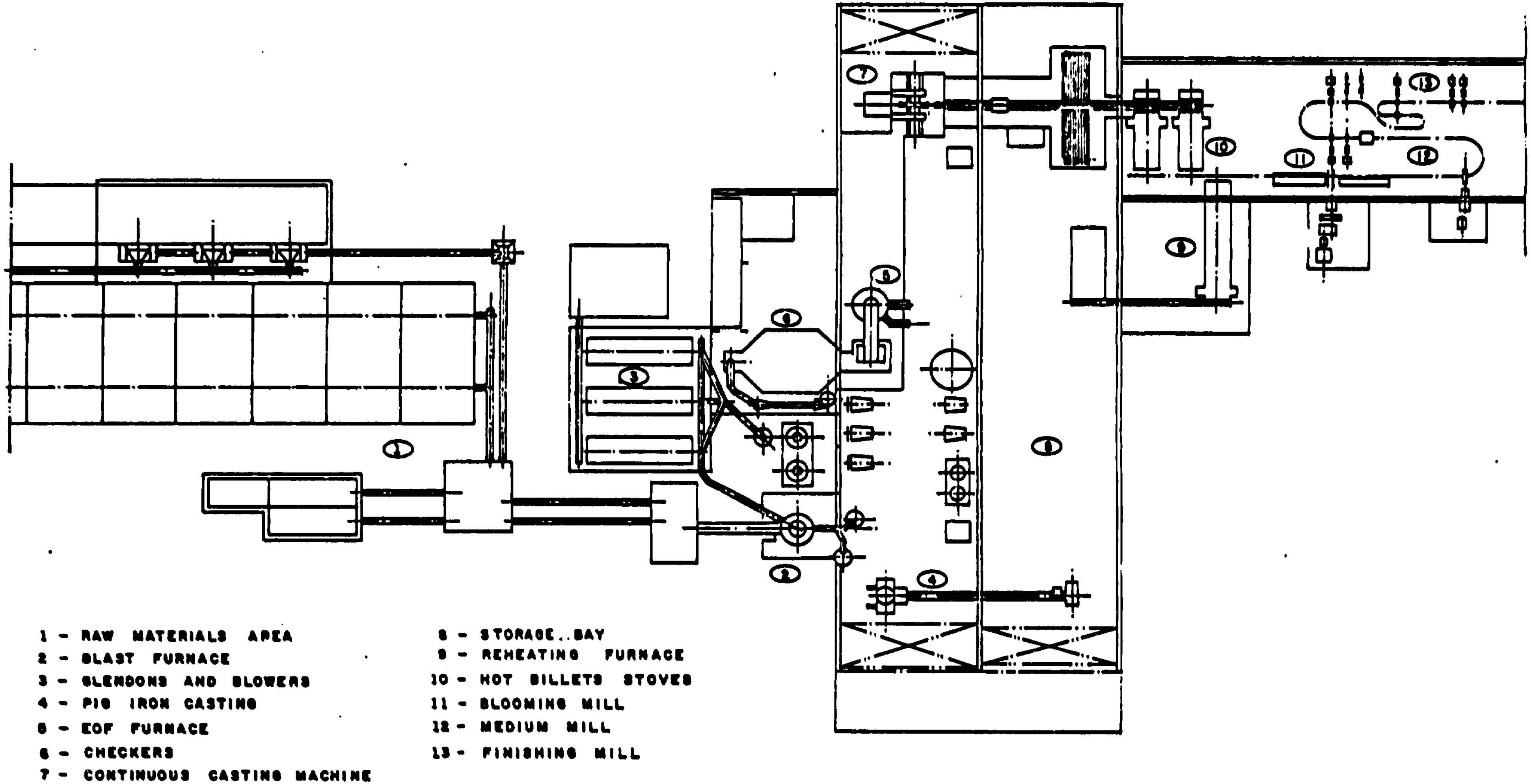


Figure 9: EOF - New Scrap Preheater



1 - RAW MATERIALS AREA
2 - BLAST FURNACE
3 - BLENDONS AND BLOWERS
4 - PIG IRON CASTING
5 - EOF FURNACE
6 - CHECKERS
7 - CONTINUOUS CASTING MACHINE
8 - STORAGE..BAY
9 - REHEATING FURNACE
10 - HOT BILLETS STOVES
11 - BLOOMING MILL
12 - MEDIUM MILL
13 - FINISHING MILL

Figure 10: Micro steel plant based on Charcoal Blast Furnace & EOF Furnace

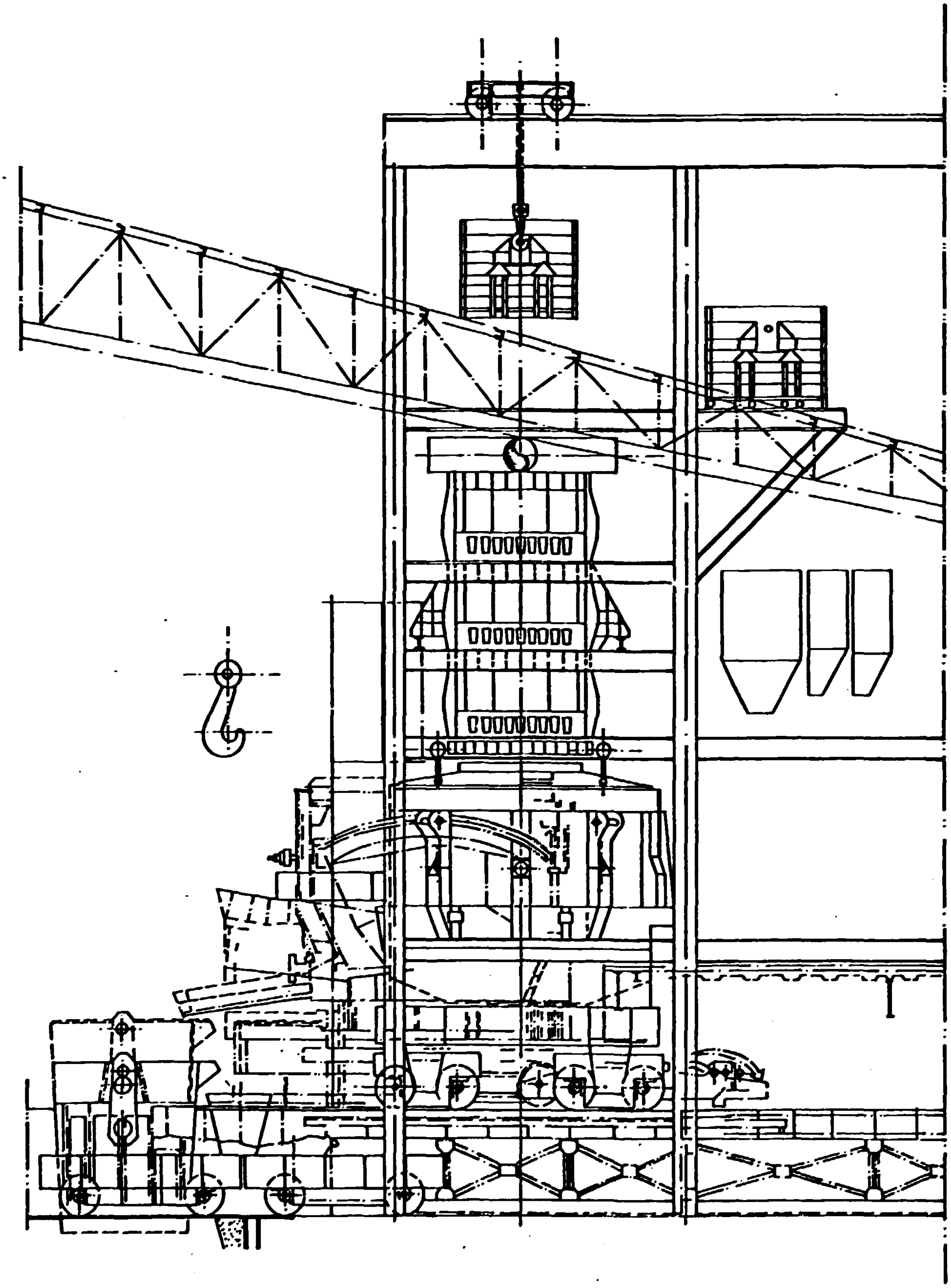
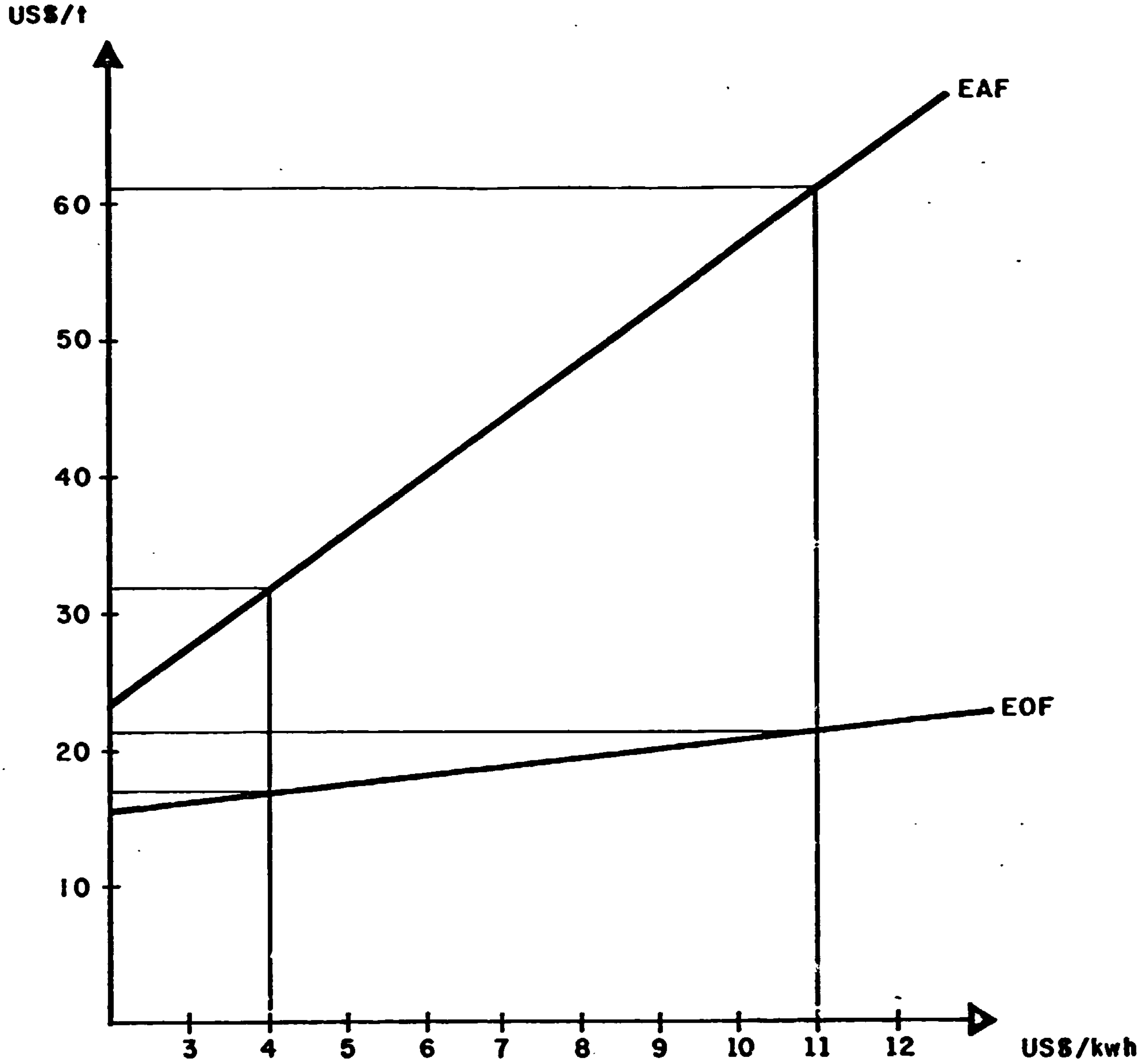


Figure II : Integration of EOF furnace in an existent Open Hearth meltshop



Consumptions per liquid steel ton.

	ELECTRIC ENERGY	OXYGEN	ELECTRODES	CHARCOAL FINES
EOF	25 kwh	86 Nm^3	—	82 kg
EAF	475 kwh	25 Nm^3	3,5 kg	—

Figure 12: Operational cost of EOF and Electric Arc Furnace(EAF)as function of electric energy price

ANNEX 6

PRELIMINARY PROPOSAL FOR A MINI STEEL PLANT

1. Introduction

KTS - Korf Tecnologia Siderúrgica Ltda. has prepared the Preliminary Proposal for a Mini Steel Plant to be installed for [redacted] Colombia.

The Mini Steel Plant will consist of three main units:

- A Hot Blast Cupola Furnace for the hot metal production from steel scrap.
- An EOF - Energy Optimizing Furnace - melt shop for the liquid steel production from hot metal.
- A Continuous Casting Machine for billet casting.

The production program of billets is divided in three stages:

1st	stage	-	50.000 tpy
2nd	stage	-	100.000 tpy
3rd	stage	-	150.000 tpy

Due to the lack of more information about the chemical composition of raw materials, available of water and electric energy, topographyc details and so on, some assumptions had to be made in order to acomplish the preliminary study.
By this way, a "normal" chemical composition for steel scrap, coke, limestone and liquid steel have been assumed, for the calculations of the materilas balance and others.

It was also assumed, that there are no water supply problems and that the infra-estructure for energy supply and water treatment would have to be installed.

Earth moving, special foundations and similar are not included in the budget.

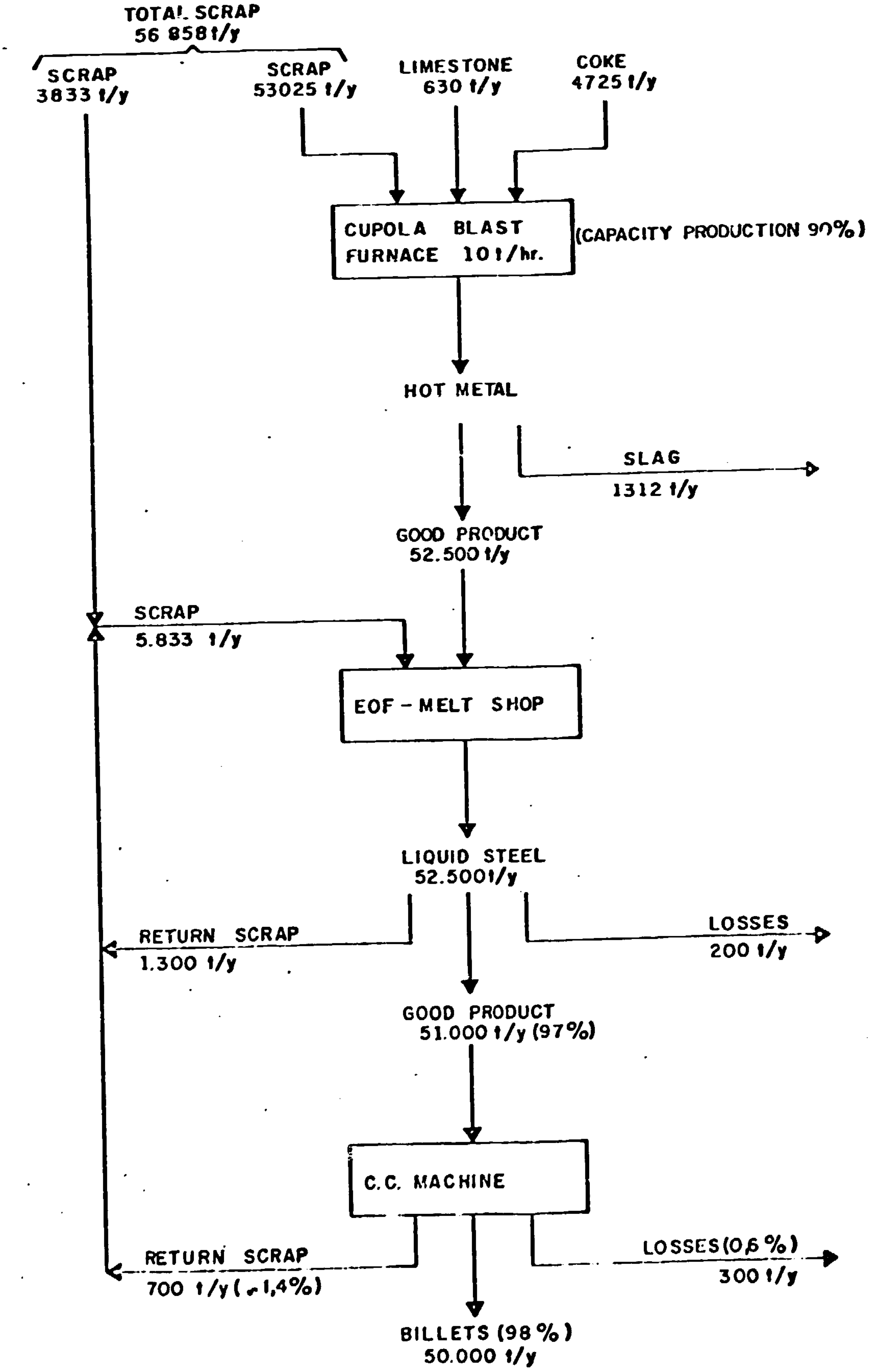
B. PRODUCTION PROGRAM

Materials and Program

Flow diagrams for 1st, 2nd and 3rd stages

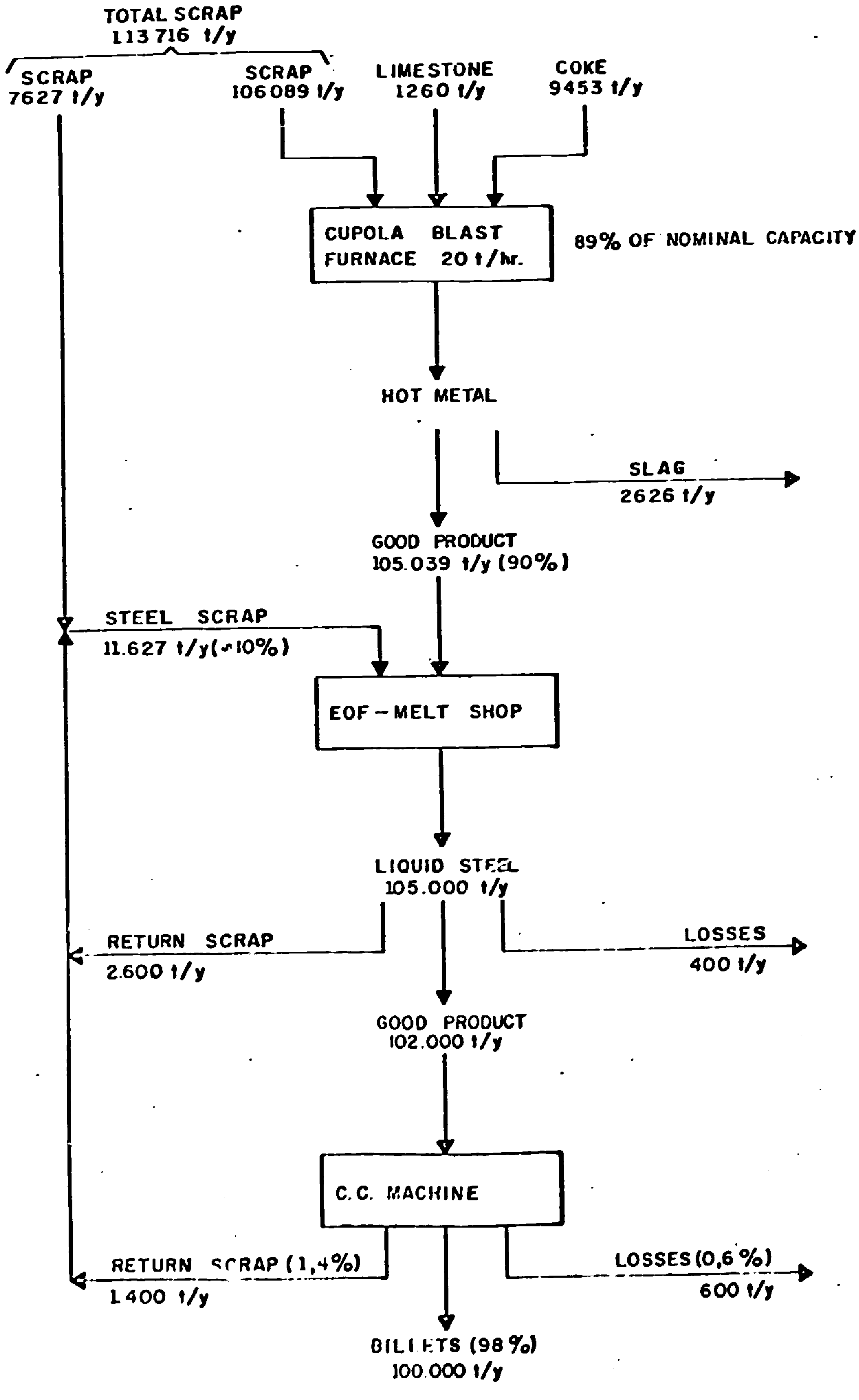
MATERIALS AND PRODUCTS

Flow Diagram - 1st Stage



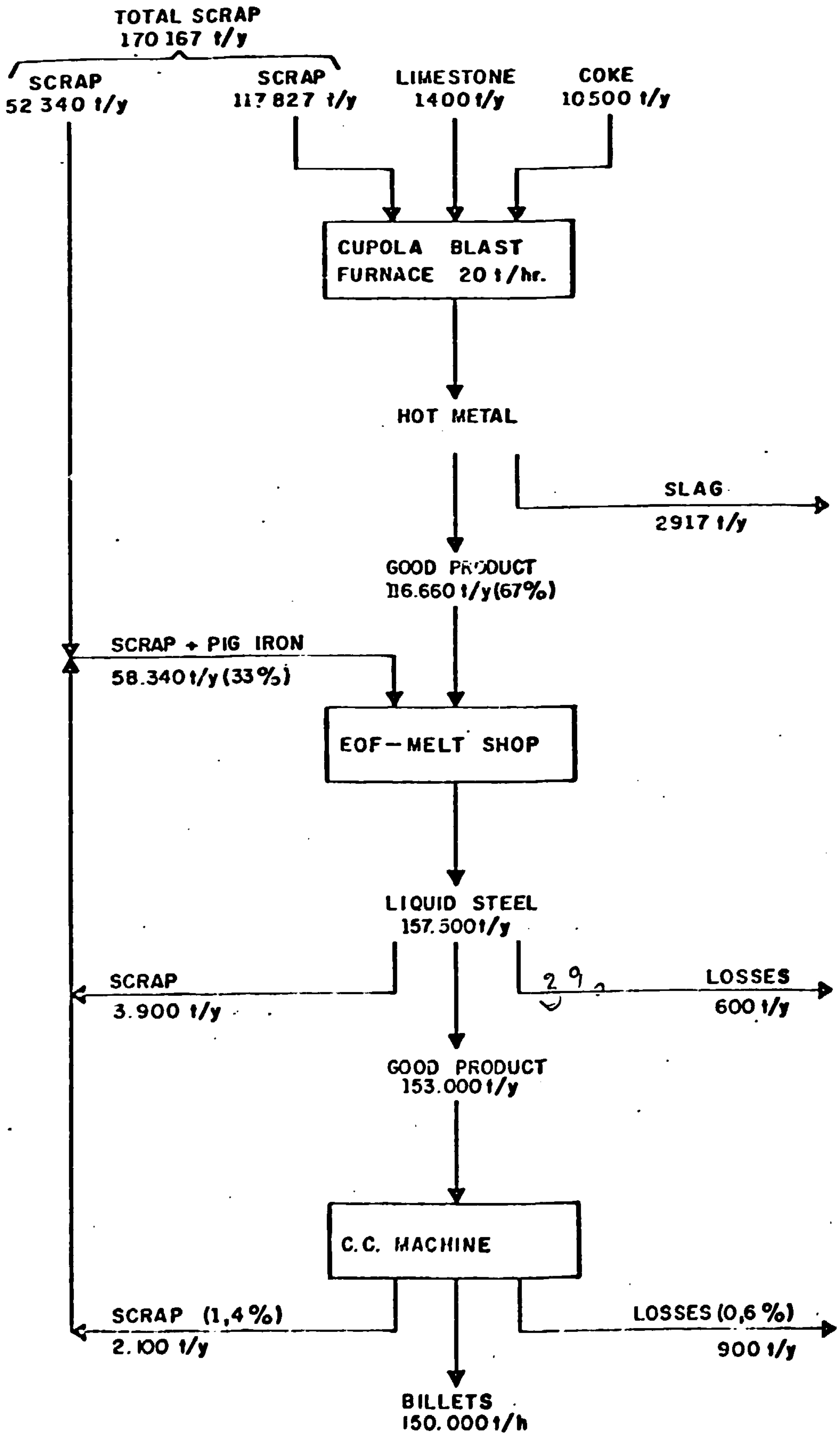
MATERIALS AND PRODUCTS

Flow Diagram - 2nd Stage



MATERIALS AND PRODUCTS

Flow Diagram - 3rd Stage



ANNEX 7

A BRIEF SUMMARY OF THE REDUCING GAS GENERATION

ANNEX 7 - A Brief Summary of the Reducing Gas Generation Schemes (2 - Section 3).

Reformed Natural Gas - Reducing gas, which is rich in carbon monoxide and hydrogen, is produced by reforming natural gas feedstock, which is primarily methane, in catalyst-filled reformer tubes. The carbon monoxide and hydrogen are generated in the methane steam reforming processes according to the reaction:

$$CH_4 + H_2O = CO + 3H_2 \qquad (14)$$

High steam/carbon ratios were once required to prevent carbon formation in the reformer tubes, and catalyst deterioration. The resultant reducing gas then had to be cooled to condense excess water vapor, and then reheated in a second step before the reducing gas could be used to reduce iron oxide. However, modern catalysts now permit operation with steam/carbon ratios approaching the stoichiometric ratio, thus producing a mixed gas of carbon monoxide and hydrogen of 95 per cent purity (wet basis). As produced, the gas contains hydrogen and carbon monoxide in a ratio of about 3.3 to 1.0. Thus, energy saving is achieved by lower steam usage and elimination of reheating of the reducing gas. This near-stoichiometric operation is sometimes referred to as "one-step reforming".

In the natural gas-based reducing processes that recyle part of the reducer-reactor off-gas through the reformer, (for example the Midrex process) carbon monoxide and hydrogen are generated according to the following reactions

$$CH_4 + CO_2 = 2CO + 2H_2 \qquad (15)$$
$$CH_4 + H_2O = CO + 3H_2 \qquad (16)$$

Carbon dioxide and water vapor are also present in the reformed off-gas as products of these reduction reactions. The reforming of natural gas with reducer-reactor off-gas produces a gas containing hydrogen and carbon monoxide in a ratio of about 1.5-1.6 to 1.0.

This ratio can be varied by controlling the amount of water vapor in the feedstock.

The conversion efficiency of reformers is very high as measured by the approach to equilibrium of the gaseous products. In that regard, the methane break-through is roughly 0.5 to 1.5 per cent for reactions (14) to (16) at conditions mentioned above. Methane break-through increases with pressure but decreases with increasing temperature and increasing steam/carbon ratio.

The efficiency of conversion in a reformer is contingent on the use of a sulphur-free feedstock to prevent poisoning and rapid deactivation of the catalyst. For that reason, reformers employ sulphur guards such as activated carbon absorbent.

In the Midrex reformer, the reducer-reactor off-gas used in reforming may acquire sulphur from the iron oxide feed. This sulphur may be removed by first using the gas to cool the DRI product which absorbs the trace amount of sulphur involved. Because of high purity fuel and additional precautions for sulphur, DR processes employing reformers produce a very low sulphur product.

Regarding the reformer energy balance, reations (14) to (16) are endothermic and take place at elevated temperature, 850 to 1000°C (1550 to 1850°F). The required energy is supplied by recuperation from the flue gas in a convection section of the reformer and by radiant burners which heat the outside of the catalyst-filled tubes. For one-step steam reforming, the methane is proportioned, about 40 per cent for fuel and 60 per cent for process gas. However, the DR reducer-reactor off-gas which contains combustible carbon monoxide and hydrogen gases may substitute for a portion of the total amount of the fuel required.

Partial Oxidation for Gasification of Hydrocarbons - The partial oxidation of fuels, especially coal or oil, is effected in gasifiers by reaction with a gas containing a high percentage of oxygen:

$$C_nH_m + n/2\ O_2 = n\ CO + m/2\ H_2 \quad (17)$$

Compared to the reformer reactions, partial oxidation produces less gas per unit of hydrocarbon. For example, a unit of methane gives four units of gas in reaction (14) compared to three units of gas in reaction (17). Nevertheless, while additional fuel is needed to sustain the reformer reactions (14) to (16), reaction (17) of the gasifier is exothermic. Furthermore, some excess oxygen is required to soot formation. The resulting formation of carbon dioxide and steam provides even more energy to the system.

The high energy level of partial combustion processes allows the use of steam or recyled off-gas from the reducer-reactor to replace a part of the gaseous oxygen to increase gas production, and to moderate the temperature of the gas produced. The gas may be enriched by (1) passing it through a bed of hot coke or by (2) mixing it with processed rich gas from the reducer-reactor. In the latter case, installed equipment is used to condense moisture and remove CO_2 from the reducer-reactor off-gas. Because of the smaller amount of hydrogen derived from steam, partial oxidation processes produce a gas with a lower hydrogen to carbon monoxide ratio than steam reforming of natural gas. Furthemore, the process employs fuels of higher molecular weight containing more carbon than methane. Example ratios of hydrogen to carbon monoxide in partial-oxidation gaseifier gas vary from about 0.4 to 1.2 in fuels ranging from bituminous coal to light oil.

The various gaseifiers employ alternative concepts comprising entrained beds, fluidized beds, packed beds, partial combustion burners and electric plasma.

Various equipment members are protected by a water cooling system which is incorporated into the steam plant to recover the energy. The units may produce a liquid slag or a dry ash dust which must be separated from the gas cyclones. Limestone may be mixed with sulphur-bearing fuel to effect desulphurization in the gasifier. In another method of desulphurization, the product gas may be passed through a bed of dolomite.

It is desirable to perform the gas cleaning steps while the gasifier gas is hot. This saves fuel associated with reheating the gas and precludes carbon deposition which may occur at intermediate temperatures in the gas reheater. In an alternative to gas desulphurization, the DRI absorbs the sulphur in the reducer-reactor, and desulphurization is performed in the subsequent steelmaking operation (2).

ANNEX 8

ROTARY KILN PROCESS DESCRIPTION

ANNEX 8 - Rotary Kiln Process Description (2 - Section 4).

The rotary kiln is a versatile furnace that finds wide-spread use in the production of DRI. The furnace is designed to use hydrocarbon fuels in the iron oxide reduction chamber without prior gasification. Although oil and natural gas are used, the primary fuel source is coal which is the least expensive form of energy in many locations.

The rotary kiln furnace is a revolving horizontal cylinder comprising a shell with an internal refractory lining. Seals at each end join the rotating cylinder to the stationary equipment for adding materials and discharging product from the furnace. The furnace is tilted at an angle of 3 to 4 per cent from the horizontal toward the discharge end. The burden travels through the rotary kiln by rotation of the kiln and gravity. Rotary kilns for DRI vary in shell diameter from 3.5 to 5.0 metres (11.5 to 19.7 feet) and in length 50 to 125 metres (164 to 410 feet).

In rotary-kiln processes, coal, flux (if required) and iron oxide are metered into high end of the inclined kiln. The burden first passes through a preheating zone where coal devolatization occurs, flux is calcined, and the chage is heated to the operating temperature for reduction.In the reduction zone iron oxide is reduced by carbon monoxide. Reduction by carbon monoxide is the predominant reaction because, at the elevated bed temperature, part of the carbom dioxide reacts with the carbon in the coal by the Boudouard reaction. Chemical reactions, other than those cited, occur within the kiln bed but these are beyond the scope of this discussion.

A portion of the process heat is usually provided by a burner located at the solids discharge end of the rotary kiln. In an coal DR process, pulverized coal may be supplied to the burner. Fuel oil and natural gas, however, are viable alternatives. The burner operates with a deficiency of air to maintain a reducing atmosphere in the kiln. Additional process heat is supplied by combustion of the volatile matter of the coal and of the carbon monoxide emerging from the kiln bed. Combustion air is supplied through ports spaced along the length of the rotary kiln. The air flow is controlled to maintain a uniform temperature profile in the reduction zone and a neutral or slightly reducing atmosphere above the bed. The kiln gas flows countercurrent to the flow of solids.

The combustion of gases transfers energy to the bed and sustains the preheating, calcination, and reduction of the solids. Radiation from the gases and refractory walls is the most important mechanism for heat transfer to the bed.

However, convection from the gases and from superheated refractories as they rotate under the bed augment the heat transfer. Because radiant heat transfer predominates, the heat transfer is more efficient in the product end of the kiln where the temperature is higher.

Preheating of solids at the feed end accounts for a substantial amount of kiln length because of lower temperature and lower efficiency. In that regard the productivity of a rotary kiln is increased by preheating the iron oxide feed or by underbed injection of air for combustion of coal charged with the iron oxide feed or fluid hydrocarbons that are injected simultaneously. Rotary kilns that employ the concept of underbed injection of fuel utilize a valved manifold system which rotates with the shell. Other methods of increasing energy utilization comprise coal feeding mechanisms which inject part of the coal axially upstream at the product end or admit part of the coal through devices installed on the shell. Both of these methods ensure that most of the volatiles are released in a section of the kiln which is hot enough to sustain ignition.

The main components in the flowsheets of these rotary-kiln systems are similar, consisting of a solids-feed system, the rotary kiln, a product cooler, screens, magnetic separators, and off-gas cleaners. The basic technology for rotary-kiln reduction emphasizes the importance of correct selection of raw materials.

The iron oxide feed (lump ore or pellets) should fulfill certain requirements regarding chemical composition, size distribution and behavior under reducing conditions in the rotary kiln. The feed should have a high iron content (preferably close to 67 per cent for hematite ores), and correspondingly the gangue content should be low, so that costs for further processing in the electric furnace are kept as low as possible. Sulphur and phosphorus contents should also be low. The minimum size of feed ore should be controlled also, preferably at about plus 5mm. Besides being elutriated from the kiln, fine ore contributes to the operating problem of accretion build-up (ringing) in the kiln. Reduced fines in the product also reoxidize more rapidly. Reductibility of the ore, a measure of the time required to achieve a desired degree of metallization under a standard set of conditions, exerts a strong influence on the throughput capacity of the kiln. The behavior of the ore under reducing conditions is important, especially with regard to swelling, which is experienced in some feeds, and the subsequent decrepitation of such materials in kiln travel.

In the selection of coals, important factors are reactivity, volatile-matter content, sulphur content, ash content, and ash-softening temperature. Coal reactivity is indicative of the coal's reduction potencial. With increased reactivity, the throughput rate of the rotary kiln can be expected to increase within certain limits, as influenced by the complexity of the multiple reactions that take place.

A higher coal reactivity allows the bed to operate at lower temperature which enhances heat transfer. In coal selection for DR processes, consideration should be given to the fact that the volatile-matter content generally increases with reactivity. However, this concept has its limitations, because coals with a high volatile-matter content will generate more gas than can be used in the process for reduction and fuel. Therefore, for overall heat economy, the recovery of the sensible and chemical heat contained in the waste gas would have to be considered. In general, a low-sulphur-content coal is preferred as it prevents sulphur pick-up by the DRI. Dolomitic limestone is used as a scavenger for sulphur, but has the adverse effects of increasing the heat load for calcining the flux and of decreasing the throughput rate by occupying kiln space that would otherwise be used by the process reactants. Since coal ash is also a non-reactant material that takes up kiln space, a coal with low ash content is desirable. A high ash-softening temperature is also desirable to prevent, or at least minimize, the build-up of accretions in the kiln.

The solids discharged from the rotary kiln are cooled, then screened and separated magnetically. DRI fines are briquetted and used together with the normalsized DRI in steelmaking. A carbon char is separated and recycled to the rotary kiln to increase fuel efficiency. The tailings in the product comprise the ash and the lime which contains the sulphur.

The hot waste gas from the kiln contains dust and volatile-matter and must be cleaned. The gas contains considerable sensible and chemical energy which can be recovered for credit. However, several first-generation coal-based DR plants do not recuperate heat. In practice, the heavy fines are usually settled out in a gravity separation chamber that can also serve as an afterburner. The waste gas is then cooled and cleaned before being released to the atmosphere. Dust from the settling chamber is transported to a waste disposal area (2).

ANNEX 9

KINLOR METOR PROCESS DESCRIPTION

ANNEX 9 - Kinglor Metor Process Description (2 - Section 4) and Table 7.

The Kinglor-Metor process is based on the concept of producing iron continuously by heating a mixture of ore and coal in an externally-fired rectangular shaft or retort. Earlier attempts to implement this concept failed because the reduction reactions are highly endothermic and the production was severely limited by the slow rate of heat flow into the charge through the retort walls which were made of firebrick. Kinglor-Metor overcomes these limitations by constructing the walls of the retorts with highly conductive silicon carbide and by burning some of the carbon monoxide generated during reduction with air in a preheating zone in the upper part of the retort. Figure 14-17 shows a schematic flowsheet of the process.

A pilot plant comprising two reactors was installed at Buttrio, Italy by Danieli & Cie., SpA and started operations in 1973. The reactors are essentially vertical shafts of conical shape about 11 metres (33 feet) high with a top diameter of 0.4 metre (1.3 feet) and bottom diameter 0.7 metre (2.3 feet). The energy consumption is claimed to be about 16 million kilojoules per metric ton (13.8 million Btu per ton) of DRI including recovery of 0.5 million kilojoules per metric ton (0.4 million Btu per net ton) of DRI from the reactor off-gas. The pilot-plant operations demonstrated the process to be simple to construct, easy to operate, and flexible with respect to feed and reductant requirements.

A commercial plant capable of producing 40.000 metric tons (44.000 net tons) per year has been installed by Ferriere Arvedi & Cie., SpA in Cremona, Italy. The plant consists of two identical 20.000 metric tons (22.000 net tons) per year modules. Each module contains six vertical retorts 13 metres (43 feet) high, 12.5 metres (41 feet) long, and 3 metres (8.8 feet) wide. At this plant, ore and coal are fed continuously into a silicon-carbide reactor that is heated to about 1.100°C (2.010°F) with natural gas radiant burners. Solid fuel requirements of about 8.5 kilojoules per metric ton (7.4 million Btu per net ton) of DRI and gaseous-fuel requirements of about 7.9 kilojoules per metric ton (6.8 million Btu per net ton) are claimed for the process. A plant has also been installed in Burma.

ANNEX 10

MIDREX PROCESS DESCRIPTION

ANNEX 10- MIDREX Process Description (2 - Section 3).

MIDREX Process - The MIDREX Process was developed by Surface Combustion Division of Midland-Ross Corporation in the mid-1960's. The MIDREX Division became a subsidiary of Korf Industries in 1974. MIDREX was subsequently acquired by Kobe Steel, Ltd. in 1983. The first commercial MIDREX plant was installed near Portland, Oregon and started production in 1969. The plant included two shaft reduction furnaces of 3,4 metre (11,2 feet) inside diameter and had a total capacity of 300.000 metric tons (330.000 net tons) per year. The average consumption of this early plant was about 15 million kilojoules per metric ton (12,9 million Btu per net ton) of DRI. Many difficult engineering and operating problems were solved during the first several years of operation of this plant that contributed significantly to the design, construction and operation of larger MIDREX plants throughout the world during the 1970's.

The MIDREX DR plants comprise the 4.88 metre (16 foot) inside diameter MIDREX Series 400 and the 5.5 metre (18 foot) inside diameter Series 600-shaft furnace modules. The number of the series originally designated the DRI capacity in thousands of metric tons per year. However, the Series 600 modules may be installed at reduced capacity with the possibility of uprating as more reformer capacity is added at a later date

By 1983, more than twenty Midrex modules were installed having a total capacity of about 9 million metric tons per year (9.9 million net tons per year); however, not all of this capacity is operating. Future construction is expected in the Middle East, Oceania, and the Soviet Union where supplies of natural gas are available.

The MIDREX DR flowsheet is shown on figure 14-2. The main components of the process are the DR shaft furnace, the gas reformer, and the cooling-gas system. Solid and gas flow are monitored so that the process variables can be controlled within operating limits. The temperature and composition of each gas stream to the shaft furnace are controlled within specification limits to maintain optimum bed temperature for reduction, degree of metallization, carbonization level (Fe_xC content), and to ensure the most efficient utilization of the reducing gas.

The DR furnace is a steel vessel with an internal refractory lining in the reducing zone. The charge solids flow continuously into the top of the furnace through seal legs. The reduction furnace is designed for uniform mass movement of the burden by gravity feed, through the preheat, reduction, and cooling zones of the furnace. The cooled DRI is continuouly discharged through seal legs at the bottom of the furnace. The use of seal legs for feeding and discharging solids eliminates the need for complex lock hoppers.

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Sergio W.G.SCHERER | 26.01.88 | SHEET 9 OF 9

COMPARATIVE EVALUATION OF NEWLY DEVELOPED
TECHNOLOGIES FOR APPLICATION IN MINI STEEL PLANTS

Inert gas is injected into the seal legs to prevent escape of process gases. On discharge from the shaft, the DRI is screened for removal of fines. Special precautions are undertaken to minimize any danger of spontaneous igniton of the pyrophoric DRI product during extended storage or shipment. Either the patented Midrex CHEMAIRE process or a hot briquetted iron process may be employed to protect the DRI. The reduced fines are finally briquetted to make them a usable DRI product.

Reducing process gas, about 95 per cent combined hydrogen plus carbon monoxide, enters the reducing furnace through a bustle pipe and ports located at the bottom of the reduction zone. The reducing gas temperature ranges between 760 and 927°C (1.400 and 1.700°F). The reducing gas flows countercurrent to the descending solids. Iron oxide reduction takes place according to reactions (1) to (6).

The partially spent reducing top gas, containing about 70 per cent carbon monoxide plus hydrogen, flows an outlet pipe located near the top of the DR furnace into the top-gas scrubber where it is cooled and scrubbed to remove dust particles. The largest portion of the gas is recompressed, enriched with natural gas, preheated to about 400°C (750°F), and piped into into the reformed tubes. In the catalyst tubes, the gas mixture is reformer to carbon monoxide and hydrogen according to reactions (15) and (16). The hot reformed gas (over 900°C or 1.650°F) which has been restored to about 95 per cent carbon monoxide plus hydrogen is then recycled to the DR furnace.

The excess top gas provides fuel for the burners in the reformer. Hot flue gas from the reformer is used in the heat recuperators to preheat combustion air for the reformer burners and also to preheat the process gas before reforming. The addition of heat recuperators to these gas streams has enhanced process efficiency, helping to decrease annual fuel usage to a reported low figure of 11.4 to 11.6 million kilojoules per metric ton of DRI (9.8 to 10.0 million Btu per met ton).

Cooling gases flow countercurrent to the burden in the cooling zone of the shaft furnace. The gas then leaves at the top of the cooling zone and flows through the cooling-gas scrubber. The cleaned and cooled gas is compressed, passed through a demister, and is recycled to the cooling zone.

An alternative flowsheet uses cold shaft furnace top gas for cooling prior to its introduction into the reformer. Thus the DRI absorbs sulphur in the top gas that came from the raw materials. This helps to prevent sulphur poisoning of the catalyst (2).