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CHARCOAL IRONMAKING.*

A TECHNICAL AND ECONOMIC REVIEW OF BRAZILIAN EXPERIENCE.

prepared by

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SUMMARY

This UNIDO document is a comprehensive study of up-to-date practice in the manufacture of pig iron, for foundries and steelmaking, using charcoal as fuel in blast furnaces.

Most of the detailed information is derived from modern Brazilian experience since that country is the world leader in charcoal iron making and currently produces more than 4,000,000 tons/year. Experience from other major producers of charcoal blown iron is also included.

The most important conclusion of the study is that a charcoal based ironmaking industry can be economically started on a modest scale in many countries provided adequate wood supplies and suitable iron ore are available and that a proper programme of reforestation is installed.

Such an industry, commencing initially at 10 - 50,000 tons/year output, with investment costs of about US $140/ton, can form the basis of a future large and flourishing iron and steel industry. This actually occured in Brazil over the past 40 years.

The document is divided into four sections.

Section 1

Outlines the main features, economics and advantages of making pig iron with charcoal under Brazilian conditions. The importance of reforestation is stressed for a continuous future supply of charcoal. The considerable cost advantages of charcoal compared with metallurgical coke at the present time permits the small scale manufacture of high grade pig iron at prices substantially below those existing in developed countries.

Section 2.

Considers in detail the technology of forest operations, reforestation and charcoal production in simple kilns.

Section 3.

Considers the practical operation of small blast furnaces using charcoal. Blast furnace plant design is also discussed.

Section 4.

Includes data derived from other countries making charcoal blown pig iron. Details are also given of the plant operation and design provided by the main Brazilian charcoal iron making and engineering companies.

SOMMAIRE

Ce document, préparé par ONUDI, est une étude complète de la fabrication de fonte, pour fonderies et aciéries, utilisant le charbon de bois comme combustible.

La plupart des informations détaillées sont tirées de l'expérience moderne du Brésil qui occupe aujourd'hui la première position dans la fabrication de fonte fabriquée à base de charbon de bois. Sa production actuelle est supérieure à 4,000,000 t/an. L'expérience d'autres producteurs importants de fonte à base de charbon de bois est également rapportée.

La conclusion la plus importante de l'étude est que dans de nombreux pays, la fabrication de fonte utilisant le charbon de bois peut être rentable pour autant que l'on dispose d'un approvisionnement convenable de minerai de fer et de bois et qu'un programme de reboisement soit lancé simultanément.

Une telle industrie, avec une production initiale de 10,000 - 50,000 t/an (coût d'investissement moyen - 140 US$/tonne) peut former la base d'une importante et florissante industrie sidérurgique. C'est ce qui s'est passé en fait au Brésil depuis 40 ans.

Le document est divisé en quatre parties:

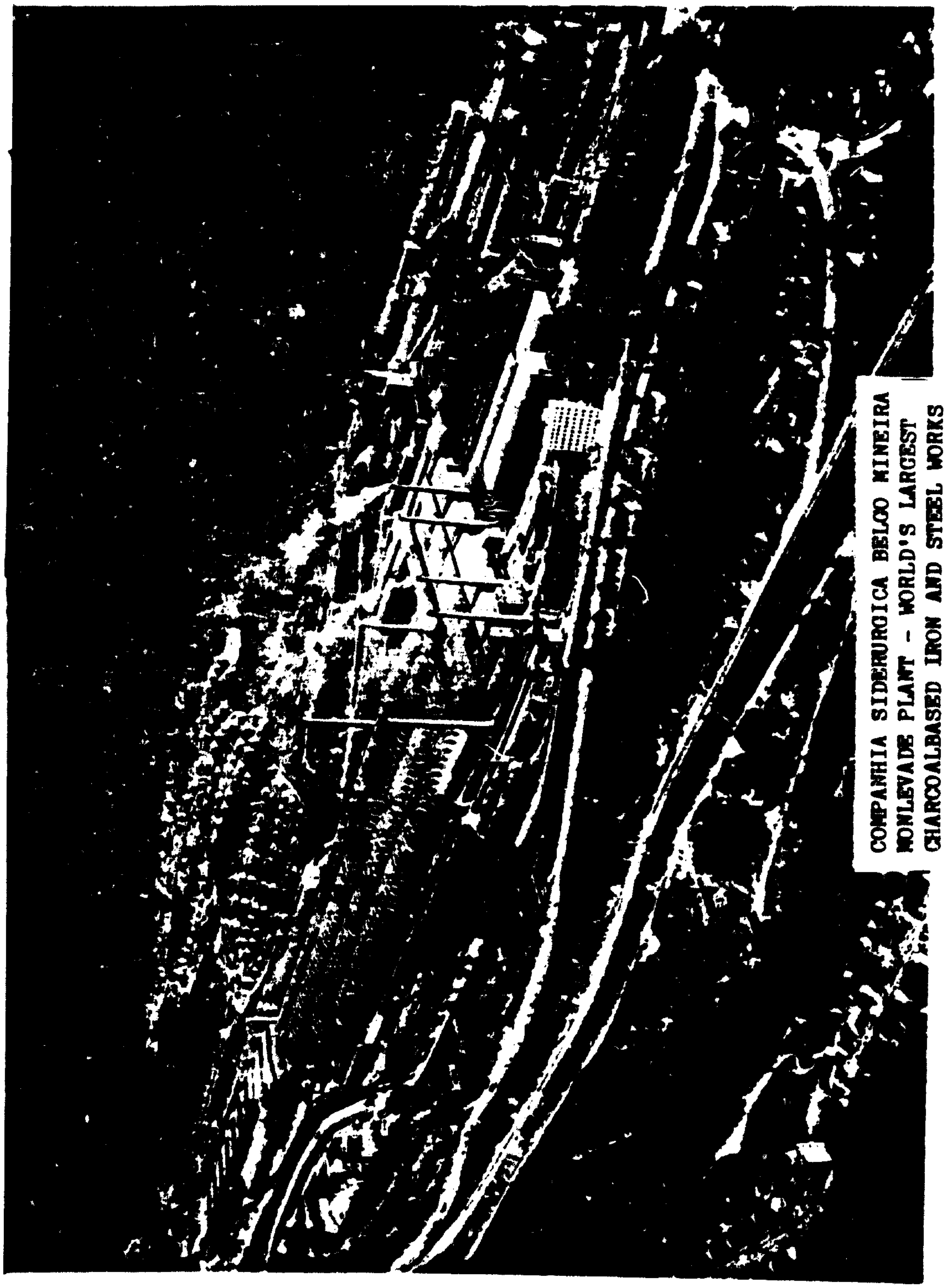
Partie 1: Indications des caractéristiques principales, la situation économique, et les avantages de fabriquer la fonte à base de charbon de bois au Brésil. L'importance de la reforestation pour assurer, un approvisionnement continu de charbon de bois est soulignée.

La grande différence de prix en faveur du charbon de bois, comparé au coke, permet la fabrication de fonte de haute qualité à échelle moyenne à des prix souvent inférieurs à ceux qui existent dans les pays industrialisés.

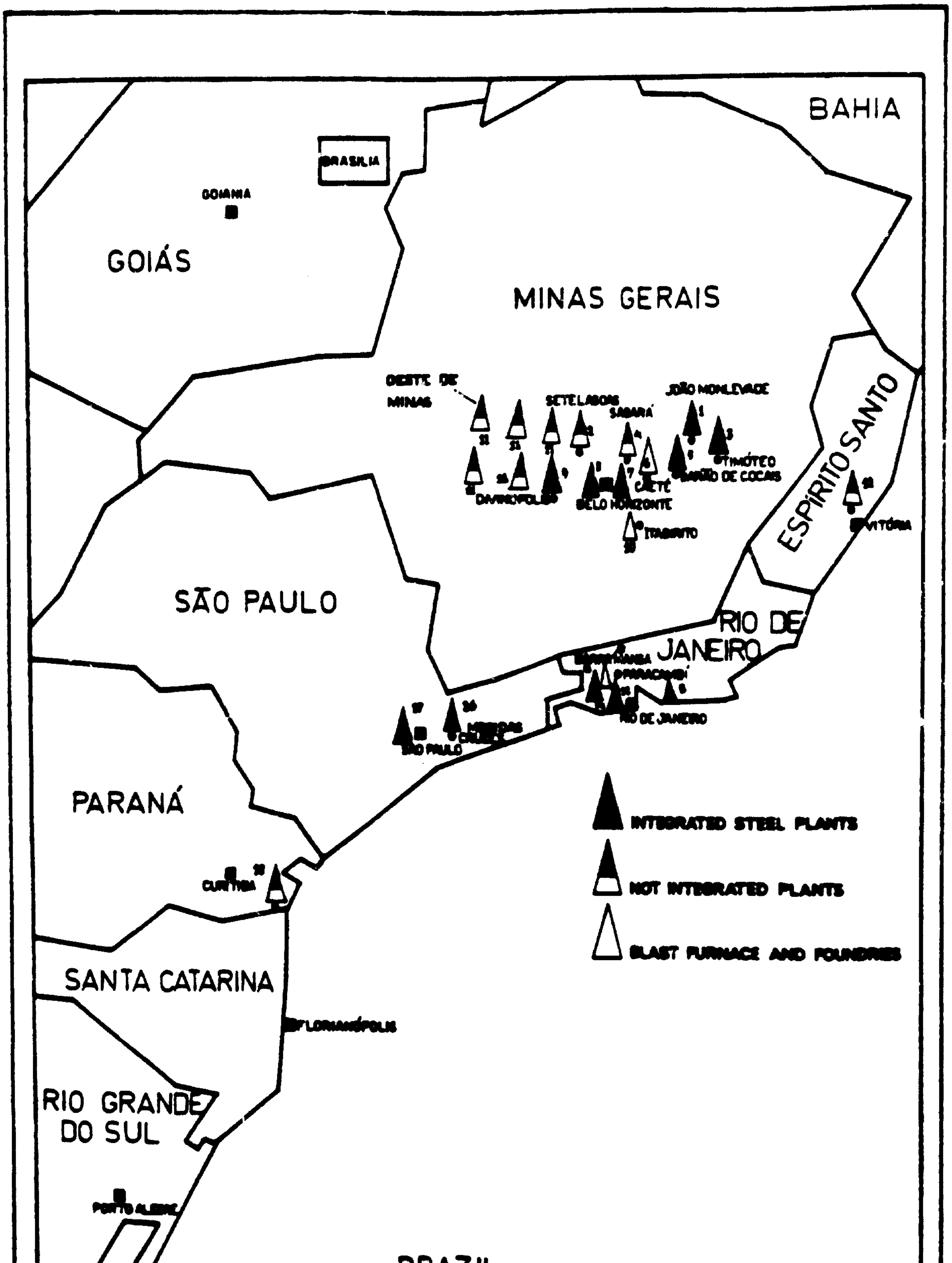
Partie 2. Etude approfondie de la technologie d'exploitation des forêts, de reforestation et de production de charbon de bois en fours simples.

Partie 3. Etude de l'opération de petits hauts fourneaux à base de charbon de bois. Discussion de la conception des hauts fourneaux.

Partie 4. Eléments d'information obtenus d'autres pays où l'on fabrique de la fonte à base de charbon de bois. Renseignements détaillés d'opération et de construction fournis par les principales usines et sociétés d'engineering Brésiliennes.



COMPANHIA SIDERURGICA BELGO MINEIRA
MONLEVADE PLANT - WORLD'S LARGEST
CHARCOALBASED IRON AND STEEL WORKS



BRAZIL

CHARCOAL BLAST FURNACE PLANTS_YEAR 1975

FOREWORD

In the course of its technical assistance and promotional activities, the United Nations Industrial Development Organisation (UNIDO) recognised the importance of the charcoal based iron and steel technology for a number of developing countries. Accordingly, in 1975 it was decided to bring this technology to the attention of developing countries that have the necessary conditions for establishing small or medium size iron and steel plants based on charcoal as renewable natural resource.

Accordingly, the Head of the Metallurgical Industries Section of UNIDO, Mr. L.C. Corrêa da Silva, requested the Associacão Brasileira de Metais (ABM - Brazilian Society for Metals), to provide the necessary information for a study on the subject. The ABM supported the idea of UNIDO to disseminate information on the charcoal based iron and steel industry, based on Brasilian experience. The Brasilian charcoal based iron and steel companies disclosed all relevant information for the preparation of a comprehensive report. Our thanks are particularly due to the Directors of the ABM and the Brasilian charcoal based iron and steel companies, especially to the Companhia Siderurgica Belgo Mineira, CIMETAL, ACESITA and Companhia Ferro Brasileira, who so generously provided detailed and invaluable information on the operation of their charcoal production and iron and steel making facilities.

Great credit is due to Mr. Henri Meyers (Companhia Siderurgica Belgo Mineira) who has dedicated his extensive experience in Brasilian charcoal based iron and steel industry to the project. This is reflected in the document entirely prepared by him for the benefit of the developing countries.

Our thanks are due also to Mr. Rodney Jennings (United Kingdom) who assisted with technical editing of the text and collating of the technical data.

CONTENTS

SECTION 2

THE TECHNOLOGY OF REFORESTATION AND CHARCOAL PRODUCTION IN BRAZIL

SECTION 3

OPERATIONAL PRACTICE OF CHARCOAL BASED IRONMAKING.

SECTION 4

EXPERIENCE IN OTHER COUNTRIES, ALTERNATIVE CHARCOAL TECHNOLOGIES AND DETAILS OF BRAZILIAN CHARCOAL BASED WORKS AND ENGINEERING FACILITIES

FIGURES

T A B L E S

I N T R O D U C T I O N

The present document describes the technical and economic aspects of the charcoal based iron and steel industry as it has developed and is being practiced in Brasil. Experience in other countries, like Argentina, Australia, Sweden is also included.

The paper is intended for the guidance of developing countries that have the necessary conditions for using this technology based on renewable resources.

In the course of 50 years experience, Brasil has developed its own charcoal based iron and steel industry. Its main, remarkable, features are:-

1. The annual output of pig iron is very considerable: 4,000,000 tons in 1976 and 1977.
2. This tonnage was economically produced in many small and medium sized works varying in output from 50,000 tons to 800,000 tons per year.
3. Practically all the companies are in private ownership requiring no appreciable support or subsidy from the Brasilian state.
4. These works produce all the pig iron needed for the Brasilian cast iron industry and practically all pig iron needed for the non-flat steel products sector (bars, sections, tube, wire, etc.)
5. The equipment for iron making is generally simpler in design and the specific investment costs (dollars/ton) are substantially lower than those necessary for coke based blast furnace plants.
6. The industry is rapidly progressing towards self-sufficiency in charcoal resources through reforestation.
7. The charcoal based companies have developed and expanded over the years from very small beginnings and formed the basis of the present important iron and steel industry in Brasil.

However, it must be stated that a charcoal based iron and steel industry has certain fundamental limitations - for example -

1. Charcoal production, including correct reforestation, is labour intensive. This work provides a good source of steady employment for a rural population but the costs of charcoal production, which today are lower than for metallurgical coke in Brasil, are closely related to the salaries of rural workers. The once important Swedish charcoal based iron and steel industry came to an end because of major increases in rural labour costs.

2. Charcoal production must be accompanied by a correct programme of reforestation suited to the location. However, for economic reasons, such reforestation must inevitably make appreciable changes in the environment by the planting of new species of trees (usually eucalyptus) in place of the original virgin forests.

3. The permissable maximum extent of such new forests will depend upon local conditions. This may limit the scale of charcoal ironmaking in a particular region.

4. The technique of charcoal blast furnace operations differs from normal coke based ironmaking. For instance charcoal is weaker than coke and is more easily crushed. This factor limits the size and capacity of charcoal blast furnaces. Nowadays these have reached 1,000 t/day output but cannot compare with the largest coke based furnace outputs now above 10,000 t/day.

Bearing in mind the above advantages and limitations, the Brasilian example is worth being followed by countries which are in a developing stage and have the necessary conditions for using this technology, principally a suitable climate and forest resources. A number of Brasilian charcoal based iron and steel companies are able to offer their know-how to interested countries.

The extraordinary development of charcoal ironmaking in Brasil is due to the fact that the country's resources of good metallurgical coal are scarce. At the other hand the country had, until recent time, vast natural forest reserves. Charcoal was therefore the natural choice for reducing iron ores in the blast furnace. In the course of many years a technology based on charcoal was developed and improved in the country, principally in the State of Minas Gerais, where most of the charcoal blast furnaces and steel plants are located.

During World War II, when maritime communications between Brasil and the rest of the world were difficult and importation of steel products practically impossible, the charcoal based iron and steel industry gave proof of much vigor, imagination and resourcefulness. Many iron and steel products indispensable to the Brasilian economy were, during those years produced by the industry, for instance railway rails, ammunition for guns, components for armaments, machinery parts, iron pipe.

Until 1950 the charcoal based iron and steel industry represented the only domestic source of supply for the manufacturing industry of a vast variety of iron and steel products. During the first 10 years of the existence of the automobile industry, from 1956 to 1966, the charcoal based iron and steel industry supplied all the necessary steel for chassis, wheels, springs, bolts, forged components and the necessary foundry iron for the engines. Today all centrifugally cast iron pipe manufactured in the country is produced from charcoal blown iron. Most of the country's foundries are supplied with charcoal blown iron which, also, in times of scarcity of scrap or coke blown pig iron, serves as a substitute and complement of these materials which are indispensable to the steel re-melters. An important amount of charcoal blown pig iron is exported and thus contributes to the balance of the Brasilian foreign trade. Charcoal pig iron has inherent proven excellent qualities which are transmitted to the iron and steel products derived from it. It therefore represents a natural raw material for the manufacture of high grade iron and steel products.

Brasilian commercial prices of charcoal have been very favourable compared with metallurgical coke. Prices CIF blast furnace plant (1977) were:

Charcoal (corrected to 85 % carbon content) - US$ 70/ton.
Equivalent metallurgical coke - US$ 130/ton.

Due to the advantageous cost of charcoal, the Brasilian charcoal pig iron is produced at a lower cost than coke blown pig iron produced in Brasil, the USA and the European Common Market.

For present Brasilian conditions, the investment costs for land, forestation and charcoal manufacture is also much lower than for a coal mine and a coke plant.

Cost of land, forestation and kilns etc. (1977) US$ 84/ton charcoal (corrected to 85 % carbon content).

Cost of coke plant (excluding coal mine) reportedly upto (1977) US$ 130/ton of equivalent coke.

The Brazilian production of charcoal pig iron in 1976 was four million metric tons, representing 50% of the total production of pig iron. The production of steel derived from charcoal blown pig iron was 2.6 million tons, representing 30% of the total for Brazil. The Government recognises the great importance of the charcoal based iron and steel industry for the Brazilian economy and has confidence in the soundness of the industry which directly employed 54,000 people in 1976 with sales worth 1,350 million US$. This confidence has increased as a result of the world energy crisis. Consequently the Government Planning Agency (CONSIDER) have assigned an expansion of the charcoal based steel industry to reach a pig iron production of eight million tons/year by 1985 which will provide 17% of the hot metal required by the steel production at that date.

The production units of the charcoal based iron and steel industry are small or medium sised due to the peculiar qualities of the fuel. As a consequence, the plants are also small to medium sized and do not require the large human concentrations that are frequent in the large coke based steel plants. The human problems are therefore easier to control. The largest charcoal based steel plant in the world, the Monlevade plant, employs only 4,000 people and the town of Monlevade has 30,000 inhabitants. Natural forests represent still the most important supplier of wood with approx. 80% of the total consumed wood. However, man planted forests are gradually taking the place of the natural forests.

The eucalyptus tree of Australian origin is the only tree species planted for charcoal purposes. It regenerates naturally at least three times in a cycle of 20 to 22 years. Caribbean pine and eucalyptus are planted for pulp and paper manufacture. Reforestation has taken a great impulse since 1966 because of the mandatory replacement of eight trees for each cubic meter of consumed charcoal. Tax incentives have eased the financial burden of reforestation. A total of 2,500,000 hectares have been planted in the country, 70% being eucalyptus trees. Brasil presently ranks fourth in the world in reforestation, after China, USSR and the USA.

500,000 hectares per year, approximately, are currently being reforested and the goal is to achieve 600,000 ha per year. The Government, through its agency, the Brazilian Institute for Forest Development, has fixed the following mandatory deadline for the execution of the reforestation projects by the charcoal based iron and steel industry: 50% self-sufficiency in man-planted forests to be reached by 1985 and 100% by 1995.

The two largest Brazilian charcoal based steel companies, Belgo Mineira and Acesita, as well as a few other companies, have already reached 40% of selfsufficiency in eucalyptus wood. These companies had started re-forestation long before the mandatory replacement regulations came into effect. The activities of reforestation and charcoal manufacture have for Brasil an important socio-economic aspect. Frequently whole families are occupied in these activities, receiving a family income. Another advantage is that the families can work together and are not disrupted.

In 1976 500,000 people were employed in re-forestation and charcoal manufacture in Brasil. Charcoal is manufactured in thousands of small beehive brick kilns which are located in groups of batteries as close as possible to the forests to minimise wood transportation costs. The kilns are periodically dismantled and rebuilt closer to the forests. No by-products are recovered. The kilns are very cheap, simple to operate, and give good yields of wood to charcoal, of good quality of charcoal when properly operated and well supervised. Some improvements to the existing kilns are being made with success.

With the recent trend for the planting of large eucalyptus forests permitting the centralisation of the activities during many years, and large scale mechanisation of the operations, it is possible that in the future larger charcoal kilns or maybe furnaces with the recovery of some by-products will be introduced. One drawback of this type of operation is represented by the high cost of investment which is similar to that for a coking plant of the same size.

It is thus important to remember that Brasilian conditions for charcoal ironmaking cannot be compared with European conditions. It is likely that conditions and prices similar to those in Brasil will be found in a number of other developing countries.

The special qualities of charcoal blown blast furnace pig iron, when made from suitable iron ores, present considerable advantages in a developing country where an iron and steel industry is newly founded. For example metal quality control is much easier.

The possibilities of using a charcoal based, so called,"Direct Reduction" process should be approached very cautiously by developing countries. The problems associated with such relatively new technology can be avoided by using the classic blast furnace process.

Finally a long term programme for the development of a complete and integrated iron and steel industry can be suitably founded on an initial modest investment for charcoal ironmaking.

First stage - 50,000 t/yr ironmaking for iron castings etc.

Second stage - 100,000 - 200,000 t/yr ironmaking for castings plus LD steelmaking for small non-flat products.

Third stage - 500,000 - 1,000,000 t/yr ironmaking for castings, export, plus LD steelmaking for a wide range of non-flat products and special steels.

Explanation of Special Terms used in Forestry and Charcoal Manufacture

1. 1 stere of wood (1 st)
   It is the volume of log shaped, manually piled, wood of following dimensions: length 1 m, width 1 m, height 1 m.

2. 1 cu metre (m^3) of charcoal
   It is the volume of loosely heaped charcoal filling a container dimensioned: length 1 m, width 1 m, height 1 m.

3. 1 hectare (ha)
   It is a land measurement of 10,000 m^2.
   1 sq. kilometre equals 100 ha.

4. 1 st. of wood requires 5 1/2 eucalyptus trees 7 to 8 years old.

5. 1 cu m charcoal (m^3) requires 2.2 st of eucalyptus wood on average.
   Better figures are being obtained recently.

6. 1 ha of land is planted with 1666 eucalyptus trees set at 3 m x 2 m.
   A figure of 1700 is used for simplicity.

7. Practical bulk density of Brasilian charcoal with, 15% moisture, 250 kgs/m^3.

8. Firewood is wood naturally dried for 3 months, also called seasoned, prior to being charged into the kilns.

9. Adrin
   Is a trade name for a hetachlor chemical product used as insecticide, principally against termites. It is used as a powder in the soil prepared for seedlings at the rate of 10 grams per plant.

SECTION I

THE MAIN FEATURES, ECONOMICS AND ADVANTAGES OF THE BRAZILIAN CHARCOAL BASED IRON AND STEEL INDUSTRY

1. GENERAL CONSIDERATIONS

Since iron was first made in the world charcoal has been the traditional reductant for the smelting of iron from ore and was used almost universally in the small blast furnaces and other reducing furnaces up to the eighteenth century when metallurgical coke was introduced as an alternative.

Today charcoal is still used for ironmaking in blast furnaces in a number of countries. The world leader in this activity is Brazil where a large proportion of a flourishing iron and steel industry is successfully based on charcoal smelted iron.

Charcoal and charcoal iron making was a natural solution to the scarcity of iron and steel products in Brazil for the following reasons:

Absence of fossil fuels. (coal and oil)
Large quantities of wood from vast virgin forests.
Abundant supply of rich and pure iron ores.
Good supply of water power.
The necessary entrepreneurial spirit and the experience in mining and similar activities.
A labor force trained in these activities.

Until 1946, when National Steel Company started production, all iron and steel produced in Brazil was charcoal based.

During that period many small and medium steel products manufacturing plants were started. Their owners got confidence in a guaranteed and regular supply of the necessary, mostly small amounts of steel available from local sources, without having to go through the costly and complicated channel of steel import from other countries. Some of the products whose manufacturing was started at that period, were:

Iron foundry products: Sanitation ware.

Steel products: Nails, wire fences for pasture land, horseshoes and their nails, bolts, nuts, welding electrodes, reinforcing bars.

It was during the 5 years of the War (1939 - 1945), when imports became practically impossible, that the charcoal based iron and steel industry became of the greatest importance for the Brazilian economy. As a consequence, the industry made great efforts in increasing the quantity of the steel supply, in improving its quality and in manufacturing new and diversified steel products. The country became to a great extent self-supporting in several steel products and was able, not only to maintain a reasonable stability of its industrial activity, but even to expand it. Some of the most important new products which were manufactured during the War were:

(a) Railway rails in 1943, which enabled Brazil to maintain and even to extend its internal railway communication system, a measure which was of the utmost importance to the country.

(b) Steel billets for the manufacturing of gunshells of the caliber 40 mm, 75 mm, 88 mm, 105 mm, 155 mm.

(c) Steel billets for the manufacturing of locomotive and railway car axles, spare parts for the maintenance of all kind of existing machinery, e.g. sugar cane mills.

At the War's end in 1945, the Brazilian charcoal iron and steel industry, and the manufacturing industry supplied by it, had attained a solid experience and the necessary self confidence in its own possibilities. They were prepared for the industrial "take-off" which was to follow soon after and which consisted in the start of the first coke based steel works at Volta Redonda.

However, this did not mean the beginning of the decline of the charcoal based iron and steel industry. On the contrary, it meant further expansion of the activity. The coke and charcoal based iron and steel works became complementary and not competitive. The first specialized in commercial steels of heavy sections and wide flat products and the latter in carbon and alloy steels both flat and non-flat. The following examples show that the impact of the charcoal iron and steel indnstry on the Brazilian economy continues. Firstly, the construction of the new capital, Brasilia, from 1956 to 1961, required thousands of tons of reinforcing bars, welded tubing, iron pipe, which were all supplied by the charcoal based iron and steel industry. The expansion of the capital still continues and still requires the same products.

Secondly, the automotive industry, which started indigenous automobile production in 1956, was supplied for the first ten years with practically all the foundry iron for engines, brake drums, etc. and all the steel for chassis, wheels, springs, bolts, nuts, etc. made solely from charcoal based iron.

The charcoal based iron and steel industry in Brazil continues its expansion and modernization. Due to the natural evolution of the country, and the companies, some products have been gradually substituted by newer ones. A certain degree of specialization in products is taking place among the companies. This measure has had a favorable influence on operational costs and production output.

The reasons for this trend are:

(a) The excellent proven, and well known, physical and chemical qualities of charcoal pig iron and the products derived from it: e.g. cast iron, cast steel, rolled steel. These qualities give the industry the natural means for manufacturing quality products.

(b) Due to the small and medium sizes of the production units in charcoal based iron and steel works they cannot compete in quantities with large coke based steel plants. They have, therefore, a complementary function to the production programs of high tonnages of normal steels coming from the coke based plants by producing small and medium quantities of high grade products.

Thus even today in Brazil, which now operates a very large scale iron and steel industry, the charcoal based sector shows a dynamic attitude to the future and will maintain a large share of the market, principally in quality steel products. Table I shows the scale of this activity in the past, present and as projected in the future.

Objections are frequently made against a charcoal based iron and steel industry.

Firstly, that charcoal manufacturing is a predatory activity, causing the depletion of the natural forests and, consequently, being harmful to the environment. Secondly, that the wood should be used for nobler purposes than charcoal, because the usually rustic carbonization methods do not recover the by-products. Instead of charcoal production

TABLE I

SURVEY OF BRAZILIAN IRON AND STEEL PRODUCTION 1925 - 1986 (IN 1000 MT)

	1925	1930	1940	1945	1950	1955	1960	1965	1970	1975	1976	ESTIMATED FIGURES 1980	ESTIMATED FIGURES 1986
TOTAL PIG IRON	30	35	180	260	740	1100	1900	2500	4200	7000	8000	15000	30000
CHARCOAL PIG IRON	30	35	180	260	400	500	1100	1100	1900	3600	4000	5500	8000
% OF BRAZILIAN TOTAL	100%	100%	100%	100%	55%	45%	60%	45%	45%	50%	50%	35%	25%
CHARCOAL PIG IRON FOR FOUNDRIES & EXPORT.	5	10	20	30	50	50	300	300	700	1600	2000	2500	3000
COKE PIG IRON *	-	-	-	-	340	600	800	1400	2300	3400	4000	9500	22000
TOTAL STEEL PRODUCTION (COKE-CHARCOAL-SCRAP) ..	20	30	170	260	800	1200	2000	3000	5400	8300	9200	18000	37000
CHARCOAL BASED STEEL PRODUCTION	20	30	170	260	400	600	1000	1000	1500	2300	2600	3500	6500
% OF TOTAL STEEL	100%	100%	100%	100%	50%	50%	50%	33%	28%	27%	28%	20%	17%
NUMBER OF CHARCOAL BLAST FURNACES	6	8	12	15	16	20	90	90	120	134	139	160	190

* 1950 NATIONAL STEEL COMPANY IN OPERATION (COKE)
1955 MANNESMANN PLANT IN OPERATION : COKE AT THE BEGINNING, LATER CHARCOAL + SCRAP
1965 USIMINAS AND COSIPA IN OPERATION (COKE)
1980 AÇOMINAS AND MENDES JUNIOR IN OPERATION (COKE)
1975 - 1986 : GREAT EXPANSION OF THE BRAZILIAN STEEL INDUSTRY, PRINCIPALLY COKE BASED PLANTS.

it is proposed that the wood be used as timber, for building material, for chemical products, for pulp and paper industry. The ideal would be of course to use the wood completely, without any loss.

The argument that charcoal manufacturing causes the destruction of forests is not borne out by the solid evidence of Brazilian and Swedish experience over many generations.

Brazil: The most important charcoal producing and consuming area of the country is the State of Minas Gerais.

The statistical data established by the Secretary of Agriculture of this State, by the Brazilian Institute of Geography and Statistics, by the Brazilian Steel Institute, and the estimations made by Brazilian charcoal and forest experts, give the following figures for 1970:

Charcoal pig iron production	1,623,365 t	
Charcoal consumption (4 m^3/t pig iron, 1970)	6,493,460 m^3	
Corresponding wood consumption:		% OF TOTAL
(Yield 2:1)	12,986,920 steres	= 35%
Timber for building, furniture, railway sleepers	2,000,000 steres	= 5%
Wood as fuel for domestic rural households	19,357,000 steres	= 50%
Timber and wood destroyed by fires on farming and pasture land (estimated)	4,000,000 steres	= 10%
Total:	38,343,920 steres	= 100%

Note: 1 stere= 1 cubic metre of wood.

The most important single consumer of wood was, and still is, represented by the rural households which consume in the average two steres, or cubic metres, of wood per capita and per year.

In the cities bottled gas is almost exclusively used.

Besides the household consumption, which can reasonably well be estimated by statistics, there is an important forest destroying element, which is difficult to measure by statistics. These are the farmers who transform bush and forest land into agricultural and pasture land. This practice, mostly done by fire, has been usual for many years and has been responsible, in a large part, for destroying the once extensive forests. It has, in the last years, come under control through Government action, but is still practiced in the more remote regions of the country. It is a very agreeable aspect now to observe exactly in the regions around the charcoal blast furnace plants, extensive man planted forests, many of them as a consequence of Government incentives to forest planting.

These incentives include legal obligation (since 1965) of forest replacement for all wood consumers and for charcoal consumers, obligation to plant eight trees per cubic meter of consumed charcoal.

Tax incentives since 1966 for reforestation projects as a rebate, up to 25%, on the amount due as income tax.

<u>Sweden:</u> This country, where the coniferous and other trees are felled at the age of fifty years, sustained continuously for many decades, upto the end of the last War, an iron and steel industry producing yearly between 300,000 and 600,000 tons of charcoal pig iron, without exhaustion of its large pine and spruce forests. The charcoal consumed by that industry represented in 1945 (the last year of World War II) only 5% of its total yearly timber and wood harvest which was 58 million m^3. The charcoal production that year, was five million cubic meters and the iron and steel industry consumed 30% of it. 70% of the charcoal produced was used in gas production.

The Swedish charcoal based industry declined not through exhaustion of its forests, but because it became uneconomic through increased labour costs and the increase in the price of wood for pulp and paper, combined with the availability of good, cheap, coking coal from other countries, principally Germany.

The progress of a country depends largely on a steel industry and in the absence of local good metallurgical coking coal it must be remembered that charcoal is easy to manufacture and as a reductant for iron ore often gives very good results in the blast furnace, at low cost.

It is a well known fact that the establishment of large scale, heavily concentrated, coke based steelworks, like other similar industries, attracts large numbers of rural workers with their families contributing to the up-rooting of the former social-economic equilibrium and causing social unstability with all its negative consequences. One serious problem is the housing of such large numbers of workers.

The charcoal based activities on the other hand are always on a small or medium scale, consist of mining, forestry, charcoal manufacture, transportation, iron and steel manufacture.

The activities related to the charcoal based iron and steel industry are scattered over vast areas. In Minas Gerais state in Brazil, approximately 150,000 sq. km are occupied with charcoal production activities. As a consequence, the related industrial population has a low density. 30,000 people are occupied in forestry and 40,000 in charcoal manufacture, by the iron and steel companies. A further 400,000 are employed by the numerous reforestation companies in Brazil. The largest charcoal based iron and steel plant in the world, the Monlevade plant, only employs 4,000 employees and the town of Monlevade has only 30,000 people.

The charcoal related activities represent a strong stimulus for fixing people in their own rural environment. Frequently whole families take part in these activities, each family member being able to work and to receive a fixed salary which is a factor of great importance for the economic stability and material progress of the individual and the family.

It can be frequently observed that, whilst the men are busy in the forests or at the charcoal kilns, the women work in tree nurseries and tree planting and simultaneously attend to their family rural property. There are also seasonal occupations. During seeding and harvesting season, the whole family does agricultural work and, after the conclusion of it, turns to the charcoal activity. As a consequence, the family receives pay when most necessary, enabling them to buy indispensable household things and to improve their standard of living.

Thus charcoal related activities contribute to fixing the rural population whilst giving them better material conditions. This aspect is always emphasized by the Brazilian Government and private authorities. Another important influence of the charcoal manufacture consists in the pioneering work of the iron and steel companies and the reforestation companies in underdeveloped and isolated regions of the states of Minas Gerais, Bahia, Espirito Santo, which have mostly a poor population. The activity centers of these companies with their meticulous and organised systems, their schools, hospitals, their teachers and supervisors, represent, for large regions, centers of instruction, for mental and material progress and stimulation.

One of the accompanying aspects has been the creation of small private maintenance and equipment industries to serve the charcoal activities.

2. CHARCOAL VERSUS COKE PRICES

At the present time in Brasil (1977) charcoal based pig iron manufacture is substantially cheaper than coke based pig iron on account of the lower cost of charcoal.

However, the price difference is very sensitive to the international price of coking coal from which Brazilian coke is mostly made. Price variations of the two fuels in Brazil and the USA and common market countries in the years 1965 - 77 are shown in figure 1. When comparing charcoal and metallurgical coke prices, it must be taken in consideration that charcoal has an average fixed carbon

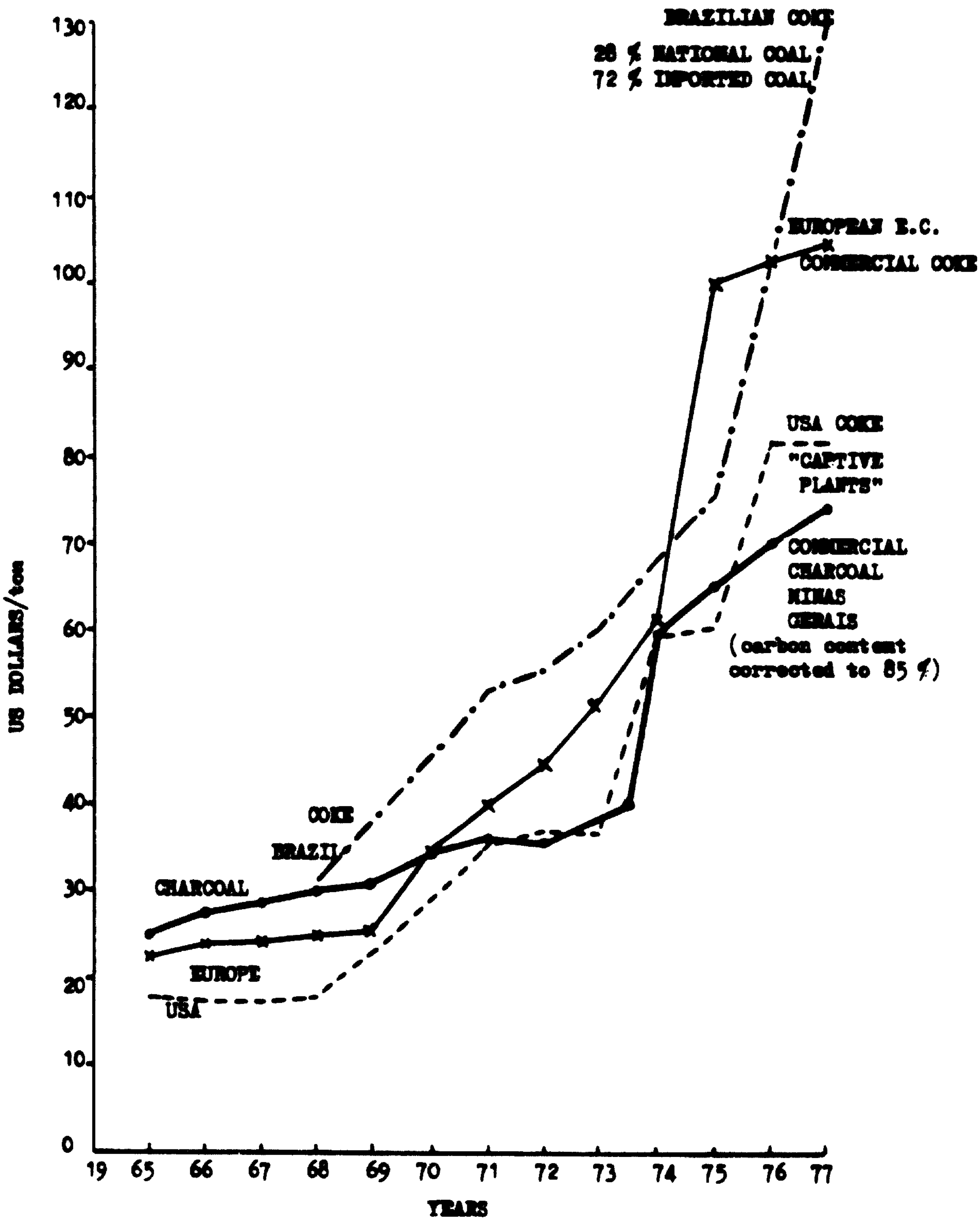


Figure 1 CHARCOAL AND COKE PRICES/ton
CIF BLAST FURNACE PLANTS 1965-1977.

Note: "Captive" coke plants are owned by iron and steel companies. These plants produce 90 % of all US coke. Commercial coke prices are higher.

content of 70% against 85% for coke. The resulting necessary correction is:

Corrected charcoal cost:

$$\frac{56.30 \times 85}{70} = \text{US\$ } 68.40 \text{ per metric ton}$$

This figure is still lower than present world coke prices. In comparing coke and charcoal prices it would be prudent to use EEC commercial coke prices rather than the current Brasilian prices shown in Figure 1.

It must be emphasised that a very important item in the composition of charcoal costs is the transportation. It frequently represents as much as the cost of fire wood at the kilns. Some plants receive charcoal by truck at distances of 600 and more km and in this case transportation costs can amount to US$ 6/t. This shows the importance of the distance from charcoal supply to the iron and steel plants. It also shows that it is necessary to make a correct choice as to distances from the plants when buying land for reforestation and to study the transportation means, principally the possibility of railway transportation, or water transportation. When comparing costs it must be remembered and taken into consideration, that a great part of the commercial charcoal sold in Minas Gerais is produced as a result of the transformation of brushland into farm and pasture land, the charcoal being considered as a by-product. Its cost does therefore not include the costs of reforestation.

However in estimating the general costs of producing charcoal for iron and steelmaking on a long term basis, the complete costs of land purchase, reforestation, charcoal manufacture and transport to the works should be included.

Under Brasilian conditions these costs can be summarised as follows:

(a) Land price

A nominal value of US$100/hectare has been used for calculation. It should be remembered, that under those conditions land cost has little influence on the cost of reforestation.

(b) Reforestation

The costs of afforestation with eucalyptus trees are shown in Table II. The trees are planted from seedlings and are first cut after eight years. Six or seven years later they are re-cut and after a further six or seven years are re-cut for a second time. This gives a total cropping cycle of 20 - 22 years after which time the stumps are uprooted and new trees planted.

In a highly mechanised operation the expense per hectare during the first year of a reforestation project represent 50% of the total expenses of the complete cycle of 20 to 22 years which is US$ 500 of a total expense of US$ 1,000 . The expenses during the first of the three cycles represent US$700 or 70% of the total rotation time of 20 to 22 years. For manual reforestation, the expenses during the first year represent US$800 or 60% of the total expenses of US$1,300. Salary for rural workers in 1977 were US$80 per month.

The cost of salaries has been included for the first implant and three years maintenance.

The resulting final cost of forestry for the three cycles is US$4.99 per cubic m of charcoal (equivalent to US$19.96 t), when using a maximum of mechanization. This corresponds approximately to 30% of the 1977 commercial price of charcoal.
The tax incentives have not been considered, as they have been decreasing in the course of the last years and may in the future become insignificant. However in 1977 they still represent a saving of 17,5%.

It is assumed that, after the third felling, the eucalyptus forest must be replanted. No figures are yet available for Brazilian conditions for the period after the third felling. In some regions of South Africa the eucalyptus trees are reported to regenerate five times over a 50 years period.

TABLE II COSTS OF FORESTRY OPERATION IN BRAZIL WITH EUCALYPTUS TREES (excluding tax incentives)

WITH MAXIMUM MECHANISATION

1 CYCLE AND YEARS	2 TOTAL YIELD STERES /HA.	3 INCRE-ASE/YR ST./YR /HA.	4 LAND COST US$/ HA.	5 EQUIP-COST US$/ HA.	6 LABOUR/ HA. PLANT-ING US$/HECTARE	7 MAIN-TENANCE	8 TOTAL PER HECTARE	9 COSTS PER STERE	10 US$ PER M3 CH.
PLANTING	176	22	100	200	200	-	500	-	-
2 - 8 YRS GROWTH			-	100	-	100	200	-	-
FIRST CUT AFTER 8 YR	176	22	100	300	200	100	700	3.94	8.74
SECOND CUT AFTER 6-7YR REGENERATION	152	22.25	-	65	-	85	150	0.98	2.15
THIRD CUT AFTER 6-7YR REGENERATION	112	16-19	-	65	-	85	150	1.34	2.95
TOTAL 20-22 YRS	440	20-22	100	430	200	270	1,000	2.27	4.99

ALL OPERATIONS MANUAL

FIRST 8 YRS	176	22	100	100	600	800	4.34	9.99
SECOND 6 - 7 YRS	152	22-25	-	50	200	250	1.64	3.61
THIRD 6 - 7 YRS	112	16-19	-	50	200	250	2.23	4.91
TOTAL 20 - 22 YRS	440	20-22	100	200	1,000	1,300	2.95	6.49

Notes: 1. Costs include land, preparation of soil, roads, tree nurseries tree planting and maintenance.

2. Cost/Stere (column 9) = column 8/column 2.

3. M3 ch.= m^3 charcoal produced from 2.2 St. of wood.

4. It is assumed that after third felling, the eucalyptus forests must be replanted. No figures yet available for Brasilian conditions after third felling.

In some regions of South Africa eucalyptus trees are reported to regenerate five times over 50 years period.

(c) Felling and Transport of Wood from Reforested Eucalyptus to charcoal kilns.

It is assumed that:

For tree felling, wood transportation to the roadside and the kilns, half of the services are carried out mechanically and half manually, that the roads are of average quality, that the distance to the kilns is five km, that the monthly salary of the rural workers is US$80 (1977) and of the supervision US$ 120.

Table III - Costs of tree felling and transport

		US$/st.
a.	Tree felling and wood piling: 10 men for 1000 st per month	0.800
b.	Transportation to kilns: 3.3 men for 1000 st per month	0.264
c.	Supervision: 1 " "	0.120
d.	Other costs: (Administration)	0.15
	(social overhead)	0.70
	Total per st. of wood at kilns	2.034

Equivalent cost/m^3 charcoal = 4.47

(The costs from naturally re-grown forest can be estimated at between 1.75 and 2.10 US$/st).

(d) Charcoal Manufacture and Transportation

In Brasil simple brick built beehive kilns are used. These are five metres in diameter and are grouped in batteries of seven upto a maximum of 35 at one site near the forest area (maximum five km distance). There is no recovery of by-products.

The handling of wood and charcoal at kiln site is manual. From kiln site to iron and steelworks transport is by truck or railway - 450 kms is maximum economic limit for trucks and 600 km for rail transport.

TABLE IV - Costs of charcoal manufacture and transport
Seven kiln battery producing 463 m^3 charcoal/month

			Cost/m^3 charcoal
Labour:	1 charcoal burner	100 US$/month	0.22
Cost:	1 helper	80 US$/month	0.17
Capital:	7 x 700 = 4.900 US$ amortised over 4 yrs.		
Cost:	$\frac{4.900}{463 \times 12 \times 4}$ =		0.22
	Cost of charcoal manufacture =		0.61
Transport to iron and steel works 600 kms rail at 0.06 US$/km or 450 kms road at 0.10 US$/km			4.00

3. TOTAL COST OF CHARCOAL CIF IRON AND STEEL WORKS

The total costs of charcoal CIF iron and steel works include appropriate investment cost charges up to arrival point at blast furnace plant - Details of investment costs are given in Table VIII.

TABLE V

	with maximum mechanisation US$/m^3	all operations manual US$/m^3
1. Forestry (Table II)	4.99	6.49
2. Felling, transport (Table III)	4.47	4.47
3. Charcoal manufacture (Table IV)	0.61	0.61
4. Transport to iron and steel works (Table IV)	4.00	4.00
Total cost of charcoal at works	14.07	15.57

This is equivalent to US$ 56.30 and 62.30/ton charcoal respectively. The present (1977) average commercial price of charcoal, CIF steel plants of Minas Gerais, is: US$ 60/ton.

4. DIRECT COSTS OF LOW SILICON PIG IRON PRODUCTION USING CHARCOAL

Three scales of pig iron production can be considered:

(a) Small to medium size: 50,000 to 150,000 t/year using the simplest equipment not integrated to steelmaking.

(b) Medium size: 150,000 to 200,000 t/year using a more elaborate equipment integrated with steelmaking.

(c) Large size: 500,000 to 700,000 t/year using most sophisticated equipment fully integrated with steelmaking.

Direct costs exclude financial, administrative, commercial and depreciation of capital investment.

It is assumed that the product will be delivered as hot, liquid, metal ready and suitable for steelmaking or pig casting.

Tables VI and VII show the direct costs of iron making in the above three scales of plants together with a comparison of costs for a coke based plant of similar large size under European conditions.

<u>Conditions of operation</u>

(a) Small (50,000 t/year) to medium (150,000 t/year) not integrated charcoal blast furnace plants.
Product: Low Si pig iron cast in casting machines.
Productivity: 500 t/man/year.
Iron ore: Supplied by railway from privately operated mines.
Charcoal: Supplied by truck from privately produced sources.
Plant efficiency: Average.
Plant equipment: Simple design and operation.
Blast heating by metallic recuperators.
No secondary gas cleaning system.
Materials handling: Manual with some mechanisation.

(b) Medium sized (150,000 to 200,000 t/year) integrated charcoal blast furnace plants producing hot metal for steelmaking.
Product: Low-Si iron for steelmaking.
Productivity: 500 t/man/year.

Iron ore: From own mine, transported by truck at a short distance. (10 to 20 km).

Charcoal: Supplied by truck and railway from own and private sources.

Plant efficiency: Good.

Plant equipment: Simple design and operation.
Blast heating by stoves.
Secondary, wet, gas cleaning system

Materials handling: Mostly mechanised, yet simple methods.

Cooling water: No water treatment.

(c) Large sized - (500,000 t to 700,000 t/year) - integrated charcoal blast furnace plants producing hot metal for steel-making.

Productivity: 1,500 t/man/year.

Iron ore: Own mine, railway transportation.

Sinter: Partial use of self-fluxing sinter.

Charcoal: 50 % own operation, 50 % from private sources.
Railway and truck transportation.

Plant equipment: Modern, yet unsophisticated.

Plant efficiency: High.

Materials handling: Mechanisation.

Operational methods: Oil injection, oxygen enrichment of blast, high furnace productivity, and intensive operation.

TABLE VI DIRECT COSTS OF LOW SILICON PIG IRON PRODUCTION USING CHARCOAL IN BRAZIL IN SMALL AND MEDIUM SCALE PLANTS

ITEM	UNIT	SMALL SCALE PLANT "a"			MEDIUM SCALE PLANT "b"		
		cost/unit US$	consumpt. of units/ t pig iron	cost/t pig iron US$	cost/unit US$	consumpt. of units/ t pig iron	cost/t pig iron US$
Charcoal	cu m (tons)	14.0	4.00 (1.00)	56.00	14.0	3.30 (0.82)	46.20
Iron ore	tons	8.5	1.650	14.02	7.0	1.650	11.55
Manganse ore	tons	27.0	0.030	0.82	27.0	0.030	0.82
Limestone	tons	4.0	0.100	0.40	6.0	0.100	0.60
Silica	tons	2.0	0.060	0.12	2.0	0.060	0.12
Fuel oil	tons	60.0	0.005	0.30	60.0	0.005	0.30
Electricity	kwh	0.02	60	1.20	0.02	65	1.30
Water	m3	0.05	5	0.25	0.03	12	0.36
Refractories	kg	0.14	1.7	0.24	0.14	1.7	0.24
Spares and Tuyeres	US$	-	-	0.10	-	-	0.20
Direct Labour	US$	-	-	6.00	-	-	6.00
Indirect Labour	US$	-	-	1.50	-	-	1.50
TOTAL	US$			80.95			69.19

Note: 1. Labour costs include 42 % social overheads.

2. No credit is given for value of surplus blast furnace top gas. In integrated plant this is usually sold to steel plant etc. at an agreed internal price which reduces the net cost of iron making.

TABLE VII DIRECT COSTS OF LOW SILICON PIG IRON PRODUCTION USING CHARCOAL IN BRAZIL IN LARGE PLANT COMPARED WITH COSTS FOR SIMILAR COKE BASED PLANT IN EUROPE

ITEM	UNIT	LARGE SCALE PLANT "c"			LARGE SCALE PLANT COKE BASED IN EUROPE		
		cost/unit US$	consumpt. of units/ t pig iron	cost/t pig iron US$	cost/unit US$	consumpt. of units/ t pig iron	cost/t pig iron US$
Charcoal	cu m	14.0	2.60	36.40			
	(tons)	-	(0.65)	-			
Coke	tons	-	-	-	100.00	0.550	55.0
ch. Fines	cu m	14.0	0.40	5.60	-	-	-
	(tons)	-	(0.10)	-			
Iron ore	tons	6.0	0.900	5.40	25.00	1.650	41.25
Sinter	tons	9.0	0.800	7.20	-	-	-
Manganese Ore	tons	27.0	0.010	0.27	45.00	0.010	0.45
Limestone	tons	10.0	0.020	0.20	10.00	0.200	1.00
Dolomite	tons	14.0	0.030	0.42	14.00	0.030	0.42
Silica	tons	2.0	0.050	0.10	-	-	-
Oxygen	Nm3	0.02	50	1.00	0.02	50	1.00
Fuel Oil	tons	60	0.040	2.40	100	0.050	5.00
Electricity	kwh	0.02	80	1.60	0.02	80	1.60
Water	m3	0.01	60	0.60	0.01	60	0.60
Refractories	kg	0.14	2	0.28	0.14	2	0.28
Spares + Tuyere	US$	-	-	0.20	-	-	0.20
Direct Labour	US$	-	-	3.00	-	-	6.00
Indirect Labour	US$	-	-	1.00	-	-	2.20
TOTAL	US$			65.67			115.00

Note: 1. Brazilian Labour includes 42 % social overheads.

2. In European plant coke consumption rate is rather high as it is assumed that no sinter is used and all limestone is fed to blast furnace.

3. No gas credits are included - see note 2 of Table VI.

5. COMPARISON OF COSTS BETWEEN CHARCOAL AND COKE BASED IRONMAKING

(a) Brazilian charcoal blown pig iron has lower costs than coke blown.

(b) Charcoal is the single most important item, representing more than the sum of all the other raw materials and additions.

(c) Charcoal quality, its cost at the kilns, transportation costs, specific blast furnace rates have therefore the greatest influence on the final pig iron costs.

(d) Charcoal blast furnace plants having their own iron ore mines and own charcoal manufacturing facilities, are at a great advantage.

(e) Plants with good operational efficiency and high intensity of operation have lower costs than others with lower efficiency.

(f) Comparative costs of ironmaking using metallurgical coke under EEC conditions in scale C plant show that, under Brazilian conditions, charcoal based pig iron is appreciably cheaper even when allowance is made for increased costs of hematite iron ore, etc. in Europe compared with the same ores in Brazil.

6. INVESTMENT COSTS FOR CHARCOAL BASED IRONMAKING PLANT AND RELATED CHARCOAL MANUFACTURING

(a) Investment costs for charcoal manufacture

The investment costs for charcoal manufacture related to ironmaking plants of various types and capacities are summarised in Table VIII. Full details of all cost items are given in Section 3.1.2. These costs include new trees, felling equipment, transport equipment, kilns, etc., as well as equipment for charcoal storage, hauling, screening up to the blast furnace bins. Equipment for truck maintenenace and charcoal quality control at the iron works is also included.

It must be noted that the amounts of charcoal produced include a 10 % allowance for fines screened out at the iron works and which cannot be used directly in the blast furnaces.

The production of these fines appreciably increases the scale of charcoal manufacture necessary to match various outputs of pig iron,

For cost comparison with a metallurgical coke plant it is necessary to make a correlation relating to the lower fixed carbon content of the charcoal i.e. to multiply charcoal plant investment cost by $\frac{85}{70} = 1.21$.

It is assumed that all charcoal has a bulk density of 250 kg/m^3.

(b) Investment costs for charcoal blast furnace plants

The investment costs will depend largely on the type of equipment chosen. This can vary from the simplest to the most advanced design depending on local conditions and requirements and particularly on the scale of ironmaking.

To estimate installation and investment costs as accurately as possible it is therefore necessary to consider various sizes and types of plant separately.

(i) A small non integrated ironmaking plant - simplest, current, approved, efficient design and operation, operational costs as shown in sector "a" of Table VI - A combination of manual handling and mechanization. Simple but fair conditions for storing and handling raw materials, etc.

Examples: 50,000 t/yr pig iron production.
One blast furnace, 150 t/day, about 3 m hearth diameter with hoist charging, dry gas cleaning, 4 "Glendon" metallic recuperators (blast temperature 500°C), blowers, iron ore yards, stock house, screens, bins, scales. Facilities for charcoal handling, storing and screening. Including operational buildings and foundations.

(ii) Medium sized plant integrated with steelmaking

Advanced but conventional design and operation, Operational costs as shown in section "b" of Table VI. Good conditions for storing and handling raw materials. All operations mechanized. Minimum necessary instrumentation.

Example: 100,000 t/yr pig iron production.
Two blast furnaces, each 150 t/day, about 3 m hearth diameter, with hoist charging, wet gas cleaning, five Cowper stoves (blast temperature 900°C), blowers, iron ore yards, stock house, screens, bins, scales, facilities for charcoal handling, storing and screening. Including operational buildings and foundations.

(iii) Large scale plant integrated with steelmaking

Modern, advanced design and operation. Equipment permitting the use of all modern operational techniques. Lowest possible charcoal rate. Operational costs as shown in section "c" of Table VII.

Example: 250,000 t/yr of pig iron production.
One blast furnace, 700 t/day, 6 - 7 m hearth diameter, with hoist or skip charging, advanced wet gas cleaning, three Cowper stoves (blast temperature 1,000°C), blowers, recirculation of cooling water, iron ore yard, stock house, screens, bins, scales, facilities for charcoal handling, storing and screening. Including operational buildings and foundations.

Table VIII. Investment Costs for Charcoal Manufacture, Transport, Storage, etc., Up to Blast Furnace Bins.

Capacity of Charcoal Plant in m^3/yr. - including 10% fines - 6 mm	40,000	170,000 "a"	700,000 "b"	1,700,000 "c"
Charcoal consumption rate in blast furnace (m³/t.iron) including 10% fines	3.60 + .40 = 4.00	3.60 + .40 = 4.00	3.00 + .30 = 3.30	2.60 + .40 = 3.00
Related output of pig iron plant t/yr	10,000	42,500	210,000	566,000
Items of Charcoal Plant		Investment Cost in US Dollars		
1. Reforestation and tree felling - Cost of new trees and felling equipment	330,000	1,340,000	4,900,000	12,200,000
2. Wood transport to kilns - tractors and carts	40,000	220,000	850,000	2,150,000
3. Carbonization - beehive kilns	50,000	200,000	800,000	2,000,000
4. Intermediate storage - buildings etc.	-	100,000	300,000	700,000
5. Charcoal transport to iron making plants - trucks, excluding railway	50,000	340,000	1,200,000	4,000,000
Investment cost - up to iron making plant (items 1-5)	470,000	2,200,000	8,050,000	21,050,000
6. Unloading, storage, screening plant, etc., at ironmaking plant	150,000	620,000	1,400,000	5,000,000
7. Reception and quality control	50,000	50,000	150,000	250,000
8. Maintenance shops for trucks	100,000	200,000	1,000,000	3,000,000
US Dollars Total Investment	770,000	3,070,000	10,600,000	29,300,000
Investment cost/m³ charcoal	19.2	18.1	15.1	17.2
Investment cost/t. charcoal (at 250 kg/m³ and corrected to 85% fixed carbon) for comparison with metallurgical coke	93.5	87.7	73.5	83.7
Investment cost/m³ charcoal (items 1-5 above only) up to arrival at ironmaking plant (see also table V).	11.7	12.9	11.5	12.4

It should be noted that the investment cost figures/t charcoal do <u>not</u> vary appreciably with the scale of plant and that a medium sized plant (700,000 m^3/yr) has the cheapest unit costs as the largest plants have more mechanization. This relative constancy of unit costs arises from the small unit sizes of kilns, trucks, trees, etc. used in charcoal manufacture.

At present the investment costs of a coke oven plant, under European conditions of 500,000 t/yr capacity, would be 65,000,000 US$ or US$ 130 t/yr. This could be compared with about US$ 84 for a similar size of charcoal plant.

Furthermore the investment costs/t/yr for a coke oven will increase very substantially if the input is small - less than 500,000 t/yr. Whereas the investment costs per ton/yr for a charcoal manufacturing plant are substantially independent of output and thus are favourable to small outputs.

Thus, it can be stated that the investments/t/yr of charcoal, are much lower than for a coke oven plant. An important aspect when comparing the two types of installation is the fact that the charcoal kilns and many other items can be totally built locally which is not the case for a coke plant. For countries in a developing state, the manufacture of charcoal represents a very economical and simple solution, allowing the application of a maximum of local resources.

It is conceded that the comparison has been oversimplified, as in a coke oven plant with recovery of by-products, the part of the investment for the chemical equipment is important. The correct comparison would be between a charcoal plant with recovery of by-products but no figures are available. On the other hand, the necessary investment figure for the coal mining has been omitted in the comparison whilst the forestry has been included in the investment for charcoal. When comparing the value of land for forestry and that of a coal mine, it can be said that the value of land generally increases with time, whilst the value of a coal mine has a tendency to decrease as a result of its natural continuous depletion. One is renewable, the other an exhaustible, source of energy.

Table IX. **Investment Costs for Charcoal Based Ironmaking Plants Delivered and Erected in Receiving Country**

Ironmaking capacity and type of plant	50,000 t/yr type 'A'	100,000 t/yr type 'B'	250,000 t/yr type 'C'
Investment costs itemised	US $	US $	US $
1. Cost of complete plant in Brasil	3,000,000	6,800,000	15,400,000
2. Engineering costs (7½% of 1)	215,000	500,000	1,150,000
3. Packing of equipment, shipment overseas, location, erection, etc. (20% of 1)	600,000	1,360,000	3,080,000
4. Contingencies (5% of 1 + 2)	160,000	365,000	970,000
Total Cost	3,975,000	9,025,000	22,500,000
Investment cost/t. pig iron	US $80.	US $90.	US$ 82.

Table X. **Total Investment Costs/t. Pig Iron for a Complete Charcoal Based Ironmaking Industry Starting with Reforestation and Ending with Liquid Pig Iron**

Ironmaking capacity and type of plant	50,000 t/yr type 'A'	100,000 t/yr type 'B'	250,000 t/yr type 'C'
Itemised investment costs/ t. pig iron	US $	US $	US $
1. Ironmaking plant (see table IX)	80	90	82
2. Charcoal making and delivery (items 1-5 of table VIII)			
(a) US $12.9 x 4.0m^3/t. pig iron	51.6		
(b) US $11.5 x 3.30m^3/t. " "		38.00	
(c) US $12.4 x 3.00m^3/t " "			37.2
Total Investment Cost/t. Pig iron	131.6	128.00	119.2

Note: 1. These costs do not include land purchase for the works and forest. The forest land cost is however included in the direct charcoal making costs.

2. Also excluded are in plant transportation costs and general infrasturecture costs.

3. The ironmaking capacities quoted in tables IX and X for plant types A, B and C do not exactly match those quoted in table VIII, a, b and c, but the resulting differences in investment costs per ton iron are negligable.

(c) Conclusion to investment cost analysis

The difference in iron making investment costs between plants types (A) and (B) table X - US \$10/ton more for plant (B) - arises mainly from the difference in blast heating by metallic recuperators or cowper stoves. However, there is a saving in specific charcoal consumption in plant (B) amounting to 0.70 m^3/t pig iron (see also table VI). Through this reduced charcoal usage the investment costs for related charcoal manufacture is reduced by about US \$13/ton of iron. Thus the overall investment costs for pig iron manufacture from reforested charcoal (table X) is about US \$3/ton. less for plant B than for plant A. In addition there are savings in direct costs, shown in Table VI, amounting to about US\$10/ton of iron for plant B.

The investment figures for the small and medium sized ironmaking plants of simple design, types "A" and "B" are modest and will therefore not represent a heavy financial burden on the economic possibilities of developing countries.

As the equipment are of simple design, it may be possible to manufacture part of them in the destination countries which are generally in an initial stage of industrialisation. Examples of such equipment are iron castings and structural steel work.

This fact does not necessarily represent a saving in costs but it is nevertheless relevant as it develops confidence and experience in local resources and possibilities.

7. ORGANISATION OF THE CHARCOAL BASED IRON AND STEEL INDUSTRY IN BRAZIL

The industry is characterised by its great variety of enterprises, all of them small or medium sized. In 1976 the industry produced 25 % of the total iron and steel products on the Brazilian market divided as follows:

65 % of cold drawn carbon bars and wire
100 % of seamless tubing
50 % of alloy steels and stainless steels
100 % of centrifugally cast iron pipes
90 % of iron and steel castings
50 % of steel forgings

The industry consists of three principal groups:

a. The integrated steel producers
b. The non integrated pig iron producers
c. The iron producers integrated with pipe and foundry products.

Principal data on the existing companies are given at the end of this section.

(a) The integrated charcoal based steel producers

There are 10 companies founded between 1920 and 1950. Eight are private and public companies and two publicly owned and controlled by the Government.

Industrial steel production varies from 50,000 ingot tons/yr to 800,000 t/yr and three companies, Acesita, Belgo Mineira and Mannesmann are each gradually expanding their production to 1,000,000 t/yr.

Pig iron production. In 1976 1,700,000 tons were produced in 28 blast furnaces and three electric reduction furnaces.

The pig iron production of the integrated companies is now insufficient for their steel production. The deficit of metal (quantity of approx. 500,000 t/year) is covered by supply from the non-integrated charcoal pig iron producers and, to a small extent, by scrap. Most steel producers are increasing their pig iron production capacity to become independent of outside sources of supply.

Charcoal supply. The more important steel companies have subsidiaries which produce part of the needed charcoal. Another part is bought from independent suppliers or from contractors producing under company supervision. The trend is to produce an increasing proportion of charcoal by the subsidiaries to control price, production and quality.

Reforestation. The larger companies do their own reforestation through the above mentioned subsidiaries, in part with tax incentives. The smaller companies sometimes pay specialised reforestation companies for this activity. These companies work exclusively on tax incentives from private people and from companies.

Mining. The large companies have their own ore mines and operate through subsidiaries. The smaller companies do the mining directly or buy the iron ore from independent mines. All the mining is open pit.

Steel production. In 1976 - 2,600,000 ingot tons, 30 % of Brazil's total. 40 % is produced in small (20 - 60 t) basic open hearth furnaces; this tonnage is decreasing. 40 % is produced in basic oxygen vessels (20 - 45 t) of LD type; this tonnage is increasing with the use of larger vessels. 20 % is produced in electric arc furnaces (20 - 40 t capacity).

Expansion plans. All the charcoal based steel companies have plans to expand their production capacities, following the guidelines of the "Master Plan for the steel industry", laid out by CONSIDER, which is the Government Planning Agency for the steel and non ferrous metals industry. These plans majorly aim at increasing pig iron production and in reaching self-sufficiency in charcoal supply.

Measures to meet these aims include:

(i) Modernisation and mechanisation of charcoal production methods.

- To improve charcoal yield from wood.
- To improve charcoal quality, increasing fixed carbon content to 75 %.
- To improve kiln productivity.
- To reduce charcoal costs, or at least to control them.

(ii) Improvement in blast furnace performance and productivity.

- By improved burden preparation - more sinter
- By increased blast temperature
- By oxygen blast enrichment
- By injection of fuel (e.g. charcoal) through blast furnace tuyeres
- By high top pressure

(iii) Installation of new major equipment.

New sinterplants to give 80 - 100 % sinter burdens resulting in lowered charcoal rate and increase in iron output.
New, larger, blast furnaces to increase outputs beyond present maximum of about 700 t/day.
New larger Cowper stoves to increase blast temperatures from 850°C to 1,150°C resulting in reduced charcoal rate.

(iv) The use of direct reduction processes using charcoal fines, the resulting sponge iron to be used as additional metal supply for electric arc furnaces.

(b) The non integrated charcoal based iron producers.

There are 60 companies, mostly family enterprises having capital of less than US$ 300,000.

Pig iron production. In 1976 - 2,000,000 t, 25 % of Brasils total, produced in 91 blast furnaces. These vary from 30 to 200 t/day capacity but 70 % produce less than 80 t/day.

Charcoal supply. Due to the rapid increase in numbers of blast furnaces charcoal supplies, have, sometimes, become critical and are of utmost importance. During periods of scarcity charcoal prices have temporary increased 40 or 50 %.
Most charcoal comes from the brush region and is supplied by independent producers. The large companies, e.g. Cimetal, partly buy charcoal and partly produce it. The trend is to increase their own production. Practically all the charcoal is transported by trucks distances of 100 to 400 kms and the average distance transported today is probably more than 300 kms.

Forestry. Since 1966, when legal mandatory reforestation was introduced together with tax incentives for this activity, the pig iron producers had reforested a total of 160,000 ha by 1976. This area is insufficient and is now being increased with the help of an assistance programme and tax incentives.

Charcoal quality. This is irregular and frequently poor as the charcoal is produced by thousands of small, independent, manufacturers with little operational technology and poor supervision. Progress in this field has been difficult and therefore slow. The moisture varies with the season of the year, from 10 to 30 %. Lately moisture content has become controlled through the general use of plastic or canvas tarpaulins during truck transportation and by the use of covered coal houses for storage before transportation to the blast furnace plants.

The generally accepted minimum charcoal size is 10 mm; however, some companies accept six mm. About 15 - 20 % of fines less than six to 10 mm are screened out of the charcoal at the blast furnaces. These fines, at present, are hardly used for any purpose.

Mining. The ore for the Minas Gerais blast furnaces is supplied by 30 small and medium private owned mining companies which produce between 1,000 t and 15,000 t of ore per month. The mining installations are simple but efficient. All ore is transported by trucks and the distances from the mines vary from 10 to 100 km. At least one company does its own ore transport. Most use independent transporters. The Siderama blast furnace plant of Manaus, Amazonia, is located on the Amazon river and intends to bring ore by boat for a distance of a few miles.

Products. This group of iron makers produces most of the iron consumed by the Brazilian foundry industry, with exception of three iron pipe foundries and the Esperança plant which produce their own liquid iron. The captive foundries of the Government controlled coke based steel plants are supplied with coke blast pig iron. The group supplies approximately 500,000 t/yr of iron to the integrated charcoal and coke based steel industry, whose own blast furnace production is either insufficient or temporarily reduced during furnace shut-downs for relining or other reasons.

In consequence of an efficient Government planning for the economic development of the country, the capital goods industry, including the steel industry, is continuously growing and requiring ever increasing amounts of foundry iron. For countries like Brazil, in a phase of industrial expansion, it is generally estimated that the demand of cast iron and steel castings corresponds roughly to 10 % of the yearly crude steel production. This figure includes the consumption of castings by the iron and steel industry itself, like ingot molds and stools, slag pots, rolls and spare parts. The capital goods industry is also a large consumer of castings for its industrial activities: Such as mechanical and electrical equipment manufacturing, automobile and tractor manufacturing, the mining equipment industry, as well as the mines, the construction industry and the shipbuilding yards. All such iron and steel castings are made in Brazil.

The Brazilian scrap based steel remelters - electric and open-hearth- with a steel production capacity of two million tons per year, suffer from a periodic deficiency of scrap, which, in times of scarcity and consequently high prices, is complemented by charcoal blown pig iron.

The resulting domestic pig iron demand will thus rise to 1.8 million tons per year in 1980 and 2.0 million tons per year by 1982. To this must be added the export of pig iron. This has fluctuated during the last 10 years between 100,000 and 800,000 tons per year. At certain periods the export has been curtailed and even suspended by the Government because of strong increase of the domestic demand. At other periods, e.g. 1975 - 1976 - 1977, due to the international situation of the steel industry, the pig iron external demand in the highly industrialized countries has diminished substantially.

Despite these fluctuations the experience over many years has shown that in normal times there is a regular export market of 600,000 to 800,000 tons per year. It is also important, in order to guarantee a steady and regular export market, to create a good customer service with warehouses in the foreign countries. At least one pig iron producer and exporter has done this with success. Thus total pig iron demand will rise to 2,500,000 t by 1980 and 3,000,000 to by 1985.

(c) Charcoal based iron founders of pipe and foundry products

There are three companies producing cast iron pipes and one foundry. All the companies produce their own molten iron. Total pig iron production in 1976 was 430,000 tons of which 200,000 tons was cast iron pipes in diameters from 90 to 900 mm.

Large scale production of centrifugally cast iron pipe started in Brazil in 1935 with the Ferro Brasileiro plant at Caeté, Minas Gerais. Cast iron pipe is of great importance in the development of the country as an indispensable sanitary element for the water supply and sewer system of towns and cities.

Beside the centrifugally cast pipe, the companies cast all the necessary hydraulic pipe accessories, connections, cocks, hydrant valves. The foundries also cast engine blocks for the automobile and shipbuilding yards, sanitary ware, ingot moulds and stools for the steel industry.

Since 1970 an ever increasing amount of the pipe production is made of nodular, or ductile, iron which has a much higher strength, better elasticity and ductility than ordinary grey iron. A certain amount of the pipe production is regularly exported, mostly to the USA and to countries of Latin America.

8. BRAZILIAN IRON AND STEEL ENTERPRISES AND PLANTS (1977)

TABLE XI

Plant Location	Number and capacity of B.F.	Pig Iron Production t/yr	Iron or Steel Foundry t/yr	Steel plants and ingot steel t/yr
1. Companhia Siderurgica Belgo-Mineira, 30 % ARBED Luxembourg, 70 % Brazilian public 45,000 shareholders. Founded 1920				
Sabará Minas Gerais	2 x 150 t/day	100,000	Iron 20,000 Steel 6,000	60,000 2x20 t open hearth to be shut down
Monlevade Minas Gerais	1 x 200 t/day 3 x 450 " 1 x 800 " Under construction	500,000	-	220,000-O.H.4x42 t Probably to be changed to 1x60 t electric 520,000- 2x42t LD 800,000- Being gradually expanded to 1,000,000
Total		600,000 to be increased to 800,000t by 1979		
2. CIMETAL - 59 % Private 41 % Public. Founded 1969				
Sete Lagoas Minas Gerais	1 x 80 t/day 2 x200 t/day			- -
Itauna Minas Gerais	7 x 60-120 t/day			-
Neiva Victoria State of Espirito Santo	2 x200 t/day	400,000 100,000		-
Bavão de Cocais Minas Gerais	2 x150 t/day 1 x 250 t/day being erected			60,000 - OH 2 x 30t 20 t LD vessel being erected Production being increased to 240,000
3. ACESITA - 70 % Banco de Brasil 30 % Public. Founded 1944				
Tomóteo Minas Geraie	1 x 450 t/day 1 x 150 t/day Electric Reduction Furnace (17,500kva Total 1977 1 x 900 t/day under construction Total (1978)	150,000 50,000 200,000 300,000 500,000	Iron 15,000	120,000 - 3 Electric Arc 20,000 - 1x20t Bessemer 180,000 - 1 x 30t LD 320,000 Being increased to 700,000 Future expansion to 1,000,000

Plant Location	Number and capacity of B.F.	Pig iron production t/yr	Iron or Steel Foundry t/yr	Steel plants and ingot steel t/yr
4. Companhia Ferro Brasileiro - Itau Bank and public. Founded 1931				
Caeté Minas Gerais	1 x 100 t/day 1 x 140 t/day 1 x 250 t/day	160,000	90,000 centrifugally spun cast pipes 20,000 Iron casting	-
5. Companhia Siderurgica Mannesmann 70 % Mannesmann Germany, 30 % Brazilian public. Founded 1952				
Barreiro Belo Horizonte Minas Gerais	1 x 700 t/day (Designed for coke but using charcoal 2 x 200 t/day Electric reduction furnaces (17,500 KVA)	220,000 150,000 370,000	-	260,000 Electric arc furnaces with in-plant and 420,000 bought scrap 680,000 2 x 30 t LD capacity being increased to 1,000,000
6. Laferma. Family owned. Founded 1953				
Cidade Industrial Belo Horizonte Minas Gerais	1 x 150 t/day	60,000		40,000 1 x 25 t O.H
7. Pains Private - Brazilian and German (Korf) plus Brazilian Public. Founded 1953				
Divinopolis Minas Gerais	5 - from 25 to 140 t/day	150,000	-	150,000 3x40 t O.H. to be changed to 1x40 t L.D. and 1x35 t Electric Expansion planned to 250,000
8. Usina Esperança - Family owned. Founded 1900				
Itabirito Minas Gerais	4 - from 60 to 150 t/day	130,000	Iron: 10,000 Steel 5,000	-
9. Companhia Barbará. Private. Saint Gobain - Pont à Mousson - France and Brazilian Private and Public. Founded 1937				
Barra Mansa Rio de Janeiro	2 x 200 t/day Future expansion 200 t/day Electric Reduction furnace (33,000 Kva)	110,000 Expansion to 130,000	100,000 centrifugally spun cast pipes 10,000 Iron castings Total expansion to 130,000	-

Plant Location	Number and capacity of B.F.	Pig iron production t/yr	Iron or Steel Foundry t/yr	Steel plants and ingot steel t/yr
10. Siderurgica Barra Mansa Family owned. Founded 1936				
Barra Mansa Rio de Janeiro	2 x 120/160 t/day 1 x 110 in Minas Gerais 1 x 600 Projected	140,000 To be increased to 350.000	-	230,000 4x25 t O.H. 2x12 t LD To be increased to 500,000
11. Siderurgica Lanari - Private and Public. Founded 1953				
Paracambi Rio de Janeiro	1 x 150 t/day	50,000		50,000 1 x 40 t O.H.
12. Siderurgica Mogi das Cruses (COSIM). Founded 1940. Since 1967 it is a subsidiary of National Steel Co. controlled by Siderbras.				
Mogi das Cruses São Paulo	2 x 150 t/day 1 x 400 t/day coke furnace occasionally operated or charcoal	200,000	-	300,000 5x60 t O.H. 1x 8 t 1x 1 t Electric
13. Aliperti - Family owned. Founded 1924.				
São Paulo Capital	2 x 170/300 t/day	170,000	-	300,000 4x25/30 /40/65 O.H. 1x22 Electric arc
14. Thyssen Fundipoes S.A. (Formerly Montana) German.- Founded 1968				
Matozinhos Minas Gerais	2 x 100 t/day	70,000	24,000 centrifugally spun cast iron pipes - 6000 Iron Castings	-
15. Sixty Mostly Small Family Owned Companies. Founded 1937/1975				
Mostly in Western part of Minas Gerais One in Manaus One in Corunabá Three in Espirito Santo	91 x 30/100 t/day	2,400,000	a few foundries. Pig iron sold for steel plants foundries and export.	
Total 75 Companies Mostly in Minas Gerais	139 x 30/700 t/day 3. Reduction Furnaces	4,000,000 Expansion in 1985 up to 8,000,000		2,600,000 Being expanded by 1986 up to 6,500,000

SECTION 2

THE TECHNOLOGY OF REFORESTATION AND CHARCOAL PRODUCTION IN BRAZIL.

1. CHARCOAL PRODUCTION

(a) General considerations

This basic activity is the most important and difficult part of the charcoal based iron and steel industry. Unlike the activities of coal mining and the manufacture of metallurgical coke, which are always concentrated on a small area, the activities related to the manufacture of charcoal, as practiced in Brasil and specifically in the States of Minas Gerais, Bahia and Espirito Santo, occupy an area of approximately 200,000 sq. km. 3.5 million tons per year of charcoal are produced on this area. This quantity may be illustrated as a coal or, better a coke field, spread out over an enormous extension with a seam thickness of one cm and a capacity to supply five million tons per year of charcoal during one century.

Apart from the larger well organised charcoal manufacturing centers operated by the integrated steel companies, the charcoal is produced by hundreds of independent suppliers, in thousands of beehive brick kilns. Some of the difficulties encountered, which are mostly a result of the continuously growing demand of charcoal by the iron and steel industry, are: Many of the charcoal producing regions opened in the course of the last years are situated in poor parts of the country, at ever increasing distances from the iron and steel plants. The steel companies have to make the necessary basic improvements like housing, medical care and schools, before installing charcoal production centers.

In certain regions, with important seasonal rainfalls, the charcoal production activities are reduced during the height of the rainy season, due to the difficulties of forest activities, charcoal manufacture and transportation.

The small independent charcoal suppliers, as well as the rural labour occupied in the charcoal related activities, have generally a poor educational background and little knowledge of the art of charcoal manufacturing. As a consequence, the average operational practice is rudimentary and the charcoal quality is not the best suited for blast furnace operation. Technical progress in charcoal manufacturing has been slow and little improvemente have been made.

The most important iron and steel companies are well aware of these facts and are making great efforts to improve the existing conditions. The Federal and State Authorities are also very interested in the problems. Several Government sponsored research studies have been made, containing practical suggestions for improvements.

Some of the measures gradually being taken by the iron and steel companies are:

Large scale mechanized reforestation activities.

Choice of the best suitable seeds for each region.

Trend to produce all the necessary charcoal by the iron and steel companies themselves.

Training of labour and good supervision.

Concentration of the operations of charcoal manufacture in fewer spots than at present to allow an industrialisation of the activities.

Improvement of yields through better operation.

Research and experimentation work in forestation and charcoal manufacture.

As a consequence of the growing needs for charcoal by the iron and steel industry, the rapid changing of some local conditions and the action of the Government, it can be foreseen that the charcoal manufacturing activity is entering a phase when old fashioned practices will give way to properly planned methods. Although all these problems apply to Brazil and, more specifically to the three above mentioned States, they may also be applied to any other country having similar climatic, social and economic conditions.

(b) Natural Forests

Virgin Forests

These forests represented, until 30 years ago, the principal suppliers of charcoal. As the initial yield of wood per hectare was very high,- 300 to 400 steres - and the total required charcoal quantities were modest compared to the present consumption, there was a wide-spread opinion among the managers of the iron and steel companies that these forests and their successors, the naturally regrown forests, would allow a permanent charcoal supply for the steel mills. However, in a few decades, these large forests were depleted. An example are the once vast virgin forests of the Rio Doce Valley in the State of Minas Gerais, where some important charcoal based iron and steel plants are located.

This depletion was partly the result of a poorly organised charcoal production activity, but principally through the undiscriminate destruction by fires which were set by the farmers and cattle raisers in order to clear the ground as fast as possible from cumbersome fallen tree trunks and underbrush and to prepare it for farm and pasture land. The ashes also represent a good natural fertiliser.

Occupation of the land by these activities was of primary importance and charcoal manufacturing was a secondary activity. As a consequence of the rapid extinction of the native virgin forests, the managers of the iron and steel companies realised as soon as the 1940-1950 decade, that they could no longer rely on the virgin forests and their successors as a permanent charcoal supply.

The remaining virgin forests in the State of Minas Gerais cover an area of 50 000 km2 and are now either protected by Law as State Natural Parks, or owned by persons who are not willing to fell them for the manufacture of charcoal. The Atlantic Mountain Range of the State of Espirito Santo running parallel to the Atlantic Ocean as well as parts of South Bahia are still covered with extensive virgin forests. Some of these forests are being gradually used for lumber and charcoal and the land transformed into eucalyptus woods for charcoal and pulp manufacture. Some land is being used for farm and pasture activities.

The virgin forests which still exist in the southern part of the State of Goias have been supplying recently great quantities of charcoal produced as the result of the gradual transformation of these forests into farm and pasture land. It is expected that this region will supply during a few years three million cubic m of charcoal per year. Some very large agrarian projects are being undertaken in that region with the financial assistance of the Government banks. Beside supplying wood for charcoal, the virgin forests supplied lumber for construction purposes. All the iron and steel companies operated their own saw mills which transformed the great logs into building material for their steel mills and their housing projects. Some of this timber was also sold. In many plants, until the present day, one can observe well conserved and still useful buildings, like rolling mill bays, maintenance shops, offices, built with the timber extracted 30 and more years ago from their virgin forests and sawed in their own sawmills.

Virgin forests can be very useful on condition that the forest operations are executed with much foresight and planning. The best logs should be removed to the sawmills, the inferior quality trees only transformed into charcoal. The Swedish example is very instructive in that respect.

Naturally regrown forests. (second growth forests)

Forests regrow naturally without the interference of man when the conditions are right. It is most important to prevent damaging fires, or at least to keep them under control. The cycle of regrowth in Minas Gerais is around 15 years and the wood yield varies between 100 and 200 steres per ha. It is of course a very simple and cheap undertaking.

In Minas Gerais the natural regrown, second growth forests still supply 30 % of all the charcoal consumed in that State.

Principally the largest of the charcoal based iron and steel companies make a very good use of the regrown forests which are situated in the vicinity of the iron and steel plants, in the so-called "Metallurgical Zone", south and east from Belo Horisonte and in the before mentioned Rio Doce Valley. These areas being close to the plants, offer the advantage of a very cheap railway and highway transportation. They are, therefore, treated with special care by the companies which protect them during the regrowing cycle.

The brush wood (Savanna forests)

The vegetation of the brush wood is characterized by the short and tortuous aspect of the tree species, whose trunks are covered with a thick bark. The leaves are very thick. The tree diameters vary between eight and 20 cm. The brush wood country covers 140,000 sq.km of the total surface of the State of Minas Gerais, which is 590,000 sq.km, and 1,700,000 sq.km of the total surface of Brazil, which is 8,500,000 sq.km., representing thus 20 % of the total country. It is a vegetation well adapted to the dry savannas of certain parts of Brazil. In Minas Gerais the brush wood areas are located in the northern and western portion of the State, having no rains during four to five months periods.

To-day the brush woods are the most important supplier of charcoal for the iron and steel industry, producing 60 % of the total charcoal. They also represent the only important wood reserve for manufacturing charcoal during the next 10 years.

The wood yields are very variable, between 70 and 200 steres/ha. Due to the tortuous shape of the trees, the thick bark and the small log diameters, the yield wood to charcoal is low, approx. three to 3.5 steres/m3 of charcoal. Average, three steres.

For some time past, due to the importance of the brush wood as charcoal supplier and charcoal reserve for the future, and also for its possiblities as future farm- and pasture land, the Government has demonstrated a high interest in the region and has created some incentives for the same.

An important aspect is the natural regeneration of the brush wood. Studies, observations and experiments are being undertaken in order to know the conditions which most favour the natural regrowth of the brush wood. Much research work must still be done in order to get a better knowledge of these conditions and to make use of them for a faster regeneration of the brush forests.

The following table shows the increase of wood yield and the total yield of some naturally regenerated brush:

Table XII

Age in years	5	10	15	20	25	30	35	40
Total average yield stere/ha	16	67	108	140	158	195	208	210
Cycles in Years	0/5	5/10	10/15	15/20	20/25	25/30	30/35	35/40
Increase of average yield steres/ha/yr	3.2	10.2	8	7.2	5.6	4.6	2.2	1.3

The table shows that the cycle or rotation time should be at least 10 years and not exceed 20 years because after this period, the yield decreases sharply. It seems that the ideal rotation time or cycle should be about 15 years, when the brush wood will yield an average of 108 steres/ha.

Some successful very large projects with eucalyptus reforesting in former brushland are now being executed by several of the larger charcoal based iron and steel companies principally Belgo Mineira and Acesita. Brushland is still the cheapest available land in Brazil at US$ 40-80/ha. Brushland is relatively flat or ondulated and therefore offers fair conditions for intensive mechanization of the operations of land preparation, tree planting, wood cutting and transportation. These projects are all executed with the help of special tax incentives which are much higher for the brushland areas than for other areas. The distances from these areas which are being reforested to the iron and steel plants vary between 200 and 500 km. For the more remote areas some railway transport is being used.

2. REFORESTATION BY ARTIFICIAL, MAN MADE, FORESTS

As early as 1940 the charcoal based iron and steel companies, particularly the larger ones, began reforestation.

Among the reasons for this were:

(i) Progressive depletion of the once large forest reserves located in the vicinity of the plants.

(ii) Deceptively slow natural regeneration of the forests.

(iii) Continuous increase in distance of charcoal supply and, consequently, of the charcoal price.

(iv) Necessity for continuity, regularity, reliability and independence of charcoal supply.

(v) Necessity of price control.

(vi) Necessity of quality control.

(vii) Increasing scarcity of rural labour in the vicinity of the iron and steel plants. People preferred to work in the plants which offered better wages and living conditions.

(viii) Increasing of wages and social overheads in the rural areas and therefore necessity for mechanisation of the forest and charcoal activities.

(a) <u>Government action</u>

Despite the need for reforestation implementation would have been slow and restricted to work by the larger steel companies if the Government had not taken direct action through the following measures.

(i) Legal obligation of forest renewal.

Since 1965 all charcoal consumers must reforest eight trees for each m3 of consumed charcoal. Other wood consumers must also reforest.

(ii) Since 1966 tax incentives in the form of tax credits.

Those credits are:

Individuals can reduce their income taxes up to 20 % and companies up to 25 %, subtracting the amounts invested the year before in reforestation projects. These figures are presently (1977) being revised. The reforestation projects may be executed by the iron and steel companies or by specialised independent companies. The following deadlines have been fixed for the reforestation projects:

By 1985 all wood and charcoal consuming industries must be 50 % self-sufficient in their supply of wood from man made forests.

By 1995 they must be 100 % self-sufficient from these forests. The reforestation projects with tax incentives must be officially approved by the Brazilian Institute of Forest Development which has fixed a series of standards for them. Some of them are: In order to preserve the indigeneous tree species and vegetation, 20 % of the original vegetation cover must be maintained. Of the total planted trees, one percent must be of a native tree species.

(b) The importance of forestation for Minas Gerais and Brazil

The two Government actions had a most important impact on the volume of reforestation in the State of Minas Gerais and in the whole country, as the following figures of the Brazilian Institute of Forest Development, IBDF, demonstrate:

Table XIII Reforestation in Brazil 1950-1976

Period	Reforested area in Minas Gerais	Total reforested area in Brazil
1950 -1966	100,000 ha	350,000 ha
1967 - 1976	365,000 ha	2,150,000 ha
Total planted area	465,000 ha mostly eucalyptus	2,500,000 ha 70 % eucalyptus

Planned plantation in 1978 for charcoal, pulp and paper industries are:

Minas Gerais: . . . . . 156,000 ha (-90 % eucalyptus)
São Paulo: . . . . 26,000 ha
Paraná: . . . . 51,000 ha
Bahia: . . . . 35,000 ha
Mato Grosso: . . . . . . 40,000 ha
Other States: . . . . . 192,000 ha

Total Brazil 1978: . . 500,000 ha (-70 % eucalyptus)

This yearly figure will soon be increased to 600,000 ha.

Thanks to the recent great progress in the reforestation activity, Brazil now ranks fourth in the world in reforestation.

1. China: . . . . 5,000,000 ha/year.
2. U.S.S.R.: . . . . 2,500,000 ha/year.
3. U.S.A.: . . . . 800,000 ha/year.
4. Brazil: . . . . 500,000 ha/year. Soon to be increased to 600,000 ha/year.

The needed reforested area for 100 % self-sufficiency is calculated on the following basis:

Blast furnace charcoal rate: . . . . 3 m3/t of pig iron.
Ratio wood to charcoal: . . . . 2 st/m3.
Ratio wood per ton of pig iron: . . . . 6 st.
Forest yield of wood/ha/year: . . . . 20 stores.

Total necessary reforested area per t/year of pig iron:

$$\frac{6}{20} = 0.3 \text{ ha}$$

Considering the mandatory maintenance of 20 % of the original cover of vegetation and non-planted areas covered by roads and other non-productive surfaces, the theoretical figure must be multiplied by 1.25.

Total necessary reforested area per t/year of pig iron:

$$0.3 \times 1.25 = 0.375 \text{ ha}$$

For the State of Minas Gerais, which produces 80 % of the total Brazilian charcoal pig iron:

Year	Iron output	Necessary reforested area
1980	4,400,000 t	1,650,000 ha
1986	6,400,000 t	2,400,000 ha

Taking in consideration the total reforested area of Minas Gerais in 1976 of 465,000 ha and the yearly(since 1978)reforested area of 156,000 ha, 90 % of which is represented by eucalyptus forests for charcoal manufacturing purposes, it can be forecast that the mandatory selfsufficiency of 50 % in 1985 and 100 % in 1995 will be reached.

Although in Minas Gerais the yield of eucalyptus forests does, on the average, not yet reach 20 st/ha/year, being closer to 15 st, it is expected that in the near future yields of 25 st will be obtained due to a better choice of the seeds, better soil treatment, principally through fertilizing and better forest maintenance. In the State of São Paulo yields of 25 and 30 st/ha/year are common.

There existed, until recent times, some doubts as to the capability of some of the small non-integrated producers of pig iron to reach the fixed reforestation quotas, There have been delays in their reforestation programmes due, mostly, to financial difficulties. The State of Minas Gerais, through its Program of Assistance to that industry is helping these companies to overcome their difficulties so that they can comply with their legal obligations which are, also, eased by the tax incentives.

(c) **The Eucalyptus tree**

Nowadays the eucalyptus represents the only tree species used in reforestation for charcoal purposes. The reason for this is its rusticity, adaptability to a great variety of climates, soils and altitudes, its rapid development and high yield, its resistance to pests and diseases, its good regenerative capacity after having been felled at least three times in seven years cycles and its excellent raw material for charcoal. These qualities have no competitors among the other native trees, some of which have been tried in reforestation projects some 30 and 40 years ago. The eucalyptus tree has also good qualities as building material and for poles, which are generally chemically treated in order to increase the resistance against rotting.

Some Brazilian native trees of the leguminous family give excellent results as to charcoal quality, but the drawback has always been the slow regenerative development of these trees once they have been felled. All these projects have therefore been abandoned.

However, all the best species of native trees are regularly planted, preferably in ravines and groves, among the large eucalyptus forests. Beside representing a reserve of indigenous trees for the future generations, they constitute a natural barrier against diseases and pests and help to maintain the ecological equilibrium.

Frequently clusters of naturally grown trees are spared from being cut and left growing. They represent a protection against the drying out of the natural water resources. (See also: Government regulations as to natural species.)

Nevertheless, even considering the good qualities of the eucalyptus genus, it is necessary to make the correct choice of the species and varieties in accordance with the origin of the seeds which are used and the climatic conditions of the regions to be reforested. Other important factors to be observed are:

The period at the beginning of the rainy season when the trees are planted. The treatment of the soil before plantation and during the forest growing period. The fertilizing of the soil. The preventions against diseases, pests and fires.

From the hundreds of existing **eucalyptus** species, the following have given the best results as to fast growth, resistance to diseases and pests and good yields:

Eucalyptus grandis, saligna, alba, paniculata, teretiocornis, citriodora, maculata and microcorys.

The trees are planted at altitudes varying from the sea level to 1400 m. Although some of the chosen **eucalyptus** species are sometimes not the best suited as to charcoal quality, for example Eucalyptus grandis, they are nevertheless intensively planted due to their high yields of wood per ha and year. The best charcoal quality is obtained from **eucalyptus** paniculata and citriodora.

The best suited **eucalyptus** species depends much on local conditions and is being continuously researched by the Forestation Departments of the Government, the Agricultural Universities, the more important iron and steel companies and the **specialized forestation** companies. As a result of the continuous studies, a **reforestation** map of the State of Minas Gerais has been established, dividing the State into 10 **zones according to the characteristics** of the topography, soils, climatic and pluvial conditions. For each zone, the best suited eucalyptus (and pine species for pulp and paper) have been indicated. Sometimes, in Brazil, the intensive reforestation programs with **eucalyptus** trees are criticized for drying out the soil, loss of soil fertility and decrease in the fauna.

These criticisms have proved groundless. The chemical examination of the forest soil after several years of plantation shows an enrichment of its minerals content. As to the supposition that the eucalyptus dries out the soil, it has no scientific basis as is proven by the successful experience with **eucalyptus** forestation in countries with pluvial conditions of 300 to 700 mm per year. These countries are: **Angola,**

Argentina, Chile, Israel, Italy, Kenya, Morocco, Peru, Portugal, Rhodesia, South Africa, South Spain, Turkey, part of the USA.
It is a well known fact that these countries have scarce hydraulic reserves but nevertheless they continue to plant eucalyptus forests without depleting their scarce water resources. As to the decrease of the fauna, the contrary has happened, as the number of small deer and larger birds is increasing. However small birds sometimes find nesting difficulties in the eucalyptus trees, due to the absence of branches.

3. ORGANISATION AND OPERATION OF FORESTATION

The goal of the forestry activity is to make the iron and steel companies self sufficient in wood and charcoal supply. The smaller companies, principally the non-integrated producers of pig iron, execute their reforestation projects through independent specialised reforestation companies which have been founded in great numbers since 1967 as a consequence of the tax incentive. These companies own or rent the necessary land for the reforestation projects or plant on land owned by the iron and steel companies.

The forestry subsidiaries of the larger companies own most or all the land, from 20,000 ha for the medium sized, up to 250,000 ha for the largest companies. Sometimes land is also rented. In Minas Gerais the properties are geographically widely scattered, present a great variety of topographies, are situated at altitudes of 100 m to 1400 m and up to 700 km from the plant.

In recent years there is a trend to concentrate the forestry activities on large pieces of continuous held land. A multiple of 6000 ha, for instance 8 x 6000 = 48,000 ha, gives very advantageous and economic operations of forestation and charcoal manufacture. Each year the trees on 6,000 ha are felled but only 2,000 ha are replanted since the trees regenerate twice after cutting before replanting is necessary.

The overall planning of the forestry activity is done years in advance and each year a special and detailed plan is traced. The various operations to be executed in the course of the year are each determined three months ahead. The forestry activities extend over the whole year. They are: Growing of the seedlings, preparation of the soil, planting, maintenance etc.

(a) <u>Seeds</u>

The seeds are picked from special trees, carefully grown, protected and isolated in order to guarantee, as far as possible, the pureness of the species and, by so doing, the qualities of the future trees. Some seeds are brought from other places and even imported from other countries like Australia, South Africa.

It is always important to bring the seeds from places with a similar climate to that of the final destination. The quality of seeds is very important and continuous research work is done to determine the most suitable. Companies like Belgo Mineira and Acesita intend to produce all their own seeds of a very high purity.

(b) Tree nurseries (or seedlings)

They are located on a rectangular, flat area of approx. 30,000 m2, 200 m long x 150 m wide. The ground must previously be flattened, smoothed and cleaned from all vegetation by scraper blade machines. This surface will receive seven million plastic bags containing the seedlings. The seedlings must exceed by 40 % the theoretically needed number of plants to compensate for losses arising from frequent poor germination, loss of seedlings and the need to re-plant previously planted areas where some trees have failed.

The area for the seedlings should be chosen for its easy access by earth roads and should have sufficient water for regular sprinkling of the young seedlings, good position as to the sun and the winds, and housing for supervision and working personnel etc. It is important that the young plants be constantly watched.

The bottom layer of the soil is covered with sand or charcoal fines which have been previously pulverized with Aldrin (5 %) in order to avoid caterpillars and termites.

The mixing of earth and fertilizer for the seedlings bags is done mechanically and the plastic bags are rapidly and exactly filled at the rate of 8,000 bags/8 hours by a simple mechanical device operated by one woman.

The mixture filled bags are transferred to the seedling area, put on the ground sprinkled with water and sown with a special seedling horn which drops five to seven seeds into each bag. The seeds are then covered with a thin layer of sand and finally cut rice straw. 15 days after germination, a fungicide is given, the healthiest seedlings selected and the bottom of the bags cut open. To obtain best results and faster growing, it will be necessary to make one or two more selections. After 45 to 75 days, the young shoots are ready to be planted in the field.

(c) Preparation of the field and planting

If the field operations are mechanised, the land is cleared of its vegetation cover by two caterpillar bulldozers which drag a steel chain between them, 100 m long and weighing 150 kg per linear meter.

The torn-out stumps, after drying, are removed by caterpillars equipped with scraper blades. The stumps are used for charcoal production. The operations which follow are:

Deep plowing, harrowing, subdivision of the field in rectangles, making sufficient tracks for future forest operations, such as hauling the wood and easy access in case of fire. Recently it has become usual to gravel the principal access roads as they must be used during many years and at all seasons.

The planting of the young trees, immediately followed by watering (sprinkling), is done just before the start of the rainy season.

Where the terrain does not allow the use of caterpillars, the operation of removing the tree stumps is done by gratings, first roughing, then final grating. Where no mechanisation is possible, due to the nature of the terrain or unavailability of machines, all operations are executed manually.

Nowadays the plant spacing is 3 x 2 m, resulting in 1,666 trees per ha, for simplification the figure of 1,700 will be adopted. Years ago, the trees were planted closer, but experience has shown that greater spacing is advantageous for better and faster development of the plants, easier mechanical maintenance and forest operations. (Starting 1978, Belgo Mineira will plant at spaces of 3 x 1.5m = 2,222 plants/ha. Results will be known in several years.)

Mechanical planting.

A special planting machine has been developed, patented and built by Belgo Mineira which executes the following operations: Opening of the furrow, exact addition of Aldrin in the exact spot where the seedling will be planted, distribution of the fertiliser along the furrow and dropping of the seedling. The machine, which plants 16,000 seedlings in eight hours, is operated by a total of 14 men; two men on the machine and the tractor, 12 men handling seedlings and manually closing the furrow.

Manual planting.

The seedlings are transported as far as possible by tractors or trucks and then by mule packs. The holes are made by men, the seedlings planted and the furrows covered with soil by women.

Weeding.

Where grass species predominate, a light howing must be done twice or three times a year. When grass is not present a single howing may be sufficient. These operations can be done manually. During the period of formation of the trees, it will be necessary to weed three times a year with a special tool.

During the period of maturation, weeding must be done, manually or mechanically, several times a year in order to suppress the undergrowth which impedes the good development of the trees. Sprout cutting and weeding is done 12 months after the first felling during the regrowth cycle.

Pests

Starting with the field preparation, the activities of termites must be continuously controlled and fought. This hazard is permanent and must be watched during the periods of maturation and regrowth by night guards. Caterpillars are another hazard. Best results have been obtained through biological control.

Diseases

The most common disease in tree nurseries is a fungus which attacks the seedlings. This is prevented and combated with insecticides. In the forests, the tree bark is attacked by another fungus, called "Diaporthe cubensis" which can cause poor regeneration of all eucalyptus species. The only effective remedy is to chose fungus resistant species.

Labour

Excellent results have been obtained with women for all light work, principally in tree nurseries and manual planting.

(d) The forest operations

The planning of the felling operations, as well as the selection of the forests to be cut, must be made well in advance. In Brasil the yearly felling programme starts in January and ends in December. The charcoal manufacturing programme starts three months later, that is, in April and ends in March of the next year. The process is continuous.

Each area of forest to be felled is divided in four distinct sections to allow clearing of the forest underbrush, to control the operations of gathering, hauling and drying of the logs at the nearest roadside and the operations necessary for a fast regeneration of the new forest.

The clearing of the underbrush is done 30 days before felling.

(e) The felling of the trees

This operation is done with axes or preferably with motor-saws. The trees must all fall in one direction to avoid mingling the logs which would cause additional handling work. The height of the remaining stumps should not exceed 20 centimeters. The cut must be done in besel shape to facilitate regeneration. The good results of the felling operation will depend on the following factors:

Good training and distribution of the labour force. Good clearing of the forest floor, felling of the trees in one direction, efficient tools in good condition, diameters of the trees, topography of the field, good supervision.

Recently, in very large forests, special large machines are being used experimentally which combine the felling and hauling operation of the entire trees. When harvesting the trees in the last cycle, 20 - 23 years after planting, the whole tree is pulled out with its stump. Increases of the wood yields of 15 to 20 % are reported in comparison to earlier methods.

(f) Transport of the wood to the roadside

After felling, the trees trunks are cleaned from their branches, cut on the spot into lengths or multiple of lengths of pieces suitable for charcoal manufacture, which is generally 1,30 m. Sometimes the entire poles are transported to the nearest road and cut there, but the first method is generally preferred.

The gathering of the felled trees and their removal to the roadside must be completed within 15 days maximum after the felling operation in order to not hinder the sprouting of the shoots. The efficiency of this operation will depend on various factors, the most important being the correct choice of the transportation means used in relation to the distances to the roadside, as these have a direct influence on the costs.

Transportation distances of wood and efficiency of operation

Table XIV

Distance in meters	Efficiency of Transportation	
	Arbitary Units	% increase
500 - 400	100	-
400 - 300	108	8 %
300 - 200	114	6 %
200 - 100	118	4 %
<100	120	2 %

It is necessary, for efficient transportation, to determine the exact number and correct distribution of the labour involved, keeping in mind that the personnel must be kept occupied to a maximum in accordance to the distances to be covered.

The various means of transportation of wood to the roadside are:

(i) By men hauling the logs; this is rarely used.

(ii) By mules which carry the wood in baskets; this is used on very steep slopes.

(iii) By oxen which haul entire trunks or pull carts loaded with wood.

(iv) By mechanical devices

Inclined troughs or chutes.

Tractors hauling entire trees, this is expensive.

Tractortype loading machines. These devices are suitable for flat terrain and very large industrialised operations; large investment is needed.

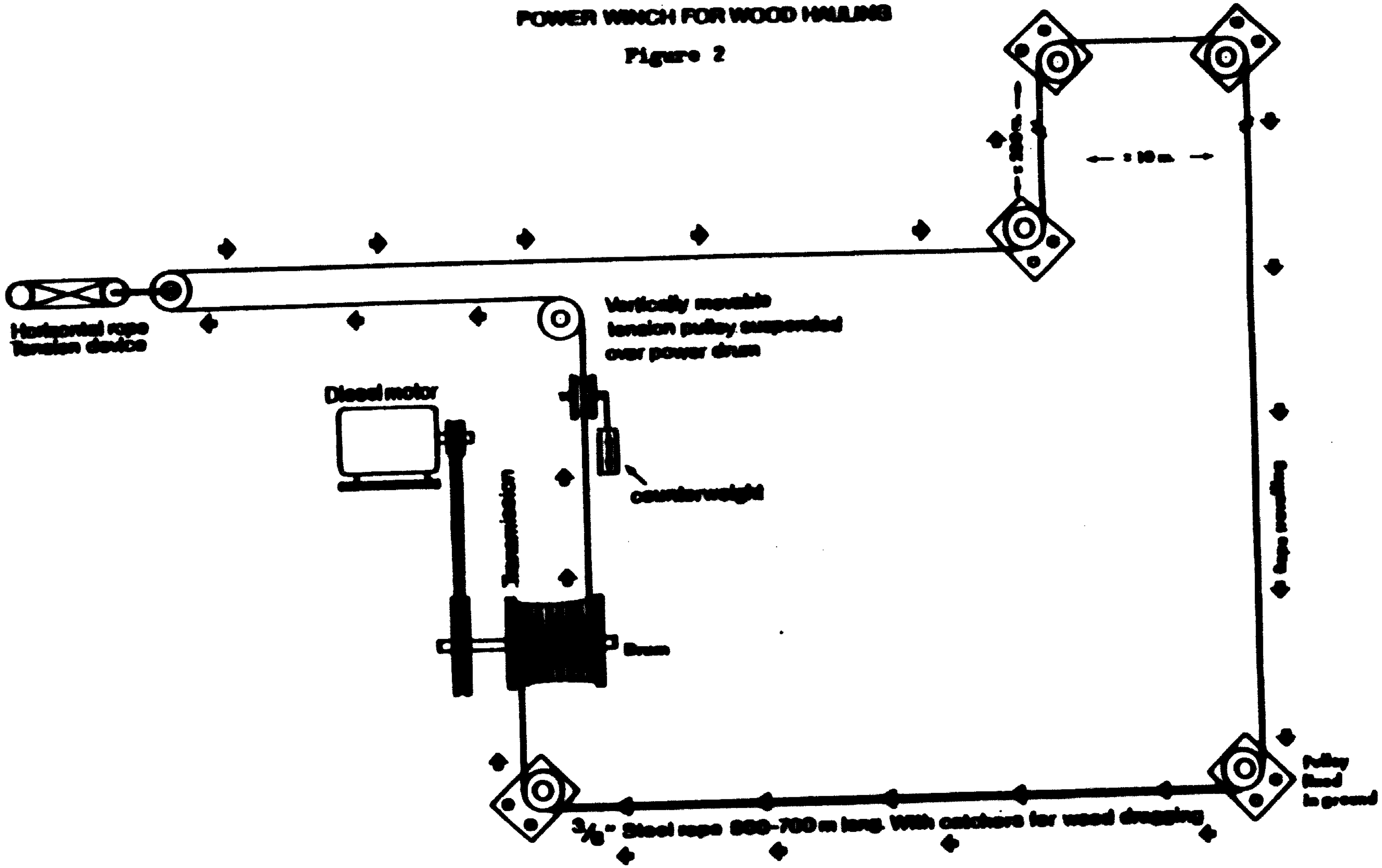
Drum winches, diesel-powered, pulling a steel rope, to which are attached, at regular intervals, by means of special catchers, bundles of tree poles, which are dragged over the ground to the roadside. This device is very simple, cheap and efficient. It can be used on all terrains with slight to steep inclination. The winch is easily moved from one place to the other. See figure 2.

Movable aerial ropeways. These are expensive, difficult to install, operate and to move from one place to an other. Their use has therefore been abandoned in the State of Minas Gerais. They remain popular in other countries with different conditions, like Australia, Germany, Austria, Switzerland.

All the above described transportation means are frequently combined. The general rule is: Simplicity, ruggedness, flexibility, efficiency.

POWER WINCH FOR WOOD HAULING

Figure 2



(g) Piling the wood

This operation may be done in the forest or, after transport, along the roadside. It is important to obtain an exact knowledge of the forest production, the forest yield and for the paying for the different operations. The supervisor must watch that the length of the wood is correct, 1.30 m, and always constant. The wood piles must have sufficient strength and have a uniform and correct height. This is important to facilitate the operations of loading and transporting the wood to the kilns after seasoning(drying). When piling the wood, gaps between the pieces must be avoided. After piling has been completed, the wood is measured and the volume indicated in steres.

Sometimes the wood is piled in the forest. This will help increase the efficiency of transport to the roadside. After measurement, the wood piles are marked with the date of felling at different spots with red, waterrepellent ink. From this point on the wood may be distinguished as firewood.

(h) Transport of the firewood to the charcoal kilns

(i) By mules when the terrain is very steep and the kilns are nearby.

(ii) By mechanical means.

a. Agricultural type tractors pulling a certain number of carts, depending on road conditions and distances.

b. By manually loaded trucks.

Transport by tractors and carts is very efficient and cheap for distances up to five km. For greater distances trucks are preferrable as they are more economical. Recently, 1977, Belgo Mineira, which used the tractor and cart method for many years switched to truck transportation which is reported to be more flexible but questionable whether it is cheaper.

For efficient transport by carts they should be used in the following proportions, depending on distance and road conditions:

3 carts: One being loaded, one being pulled, one being unloaded at the kilns.
6 carts: Two being loaded, two being pulled, two being unloaded at the kilns.
9 carts: Three " loaded, three " pulled, three " unloaded at the kilns.

Independent contractors can usefully be used for this transport thus avoiding investment in transport equipment.

(i) Natural wood drying or seasoning

Freshly felled eucalyptus trees contain from 50 % to 60 % free moisture which must be reduced to decrease transport costs and increase yield from the kilns.

The fuel consumption and the carbonising time in the kiln depend on the moisture content. To avoid the cost of transporting large quantities of undesirable moisture the wood is air dried or seasoned.

When piled in the open air between 90 and 120 days, the wood loses 30 to 35 % of its weight and 10 % volume, depending on the season. After 90 to 120 days the decrease of weight is slower, reaching 50 to 60 % after five years. In Minas Gerais wood is therefore stored for 90 days before being charged into the kilns.

(j) Wood Storage

A wood stock of about three months kiln consumption is necessary. This stock is held in the forest or at the roadside or at the charcoal kilns.

However as the forest must be cleared within 15 days after felling only 16 % of the total stock can be held in the forest.

The roadside is the most suitable place to store and dry large amounts of firewood. The width of the road must be laid out and the traffic planned accordingly.

During the dry season the amount of firewood stored at the kilns site should just be sufficient to maintain normal kiln operation. During the rainy season, when earth roads are frequently in muddy condition, it is necessary to increase the amount of firewood stocked at the kilns. Normally this should not exceed 10 % of yearly consumption.

Dried wood shrinks and for that reason the difference between the volumes of wood measured immediately after felling and the volume after three months drying amounts to between 10 - 15 %. When wood is repiled, the loss of volume through the effect of seasoning, repiling and loss of bark, amounts to between 15 - 20 %.

4. THE MANUFACTURE OF CHARCOAL

(a) The process of carbonization

Carbonisation of wood is a process of heating it at certain temperatures with little or no air. In the beginning of the heating period, the wood simply dries, but as the temperature rises, the materials making up the structure of the wood begin to decompose, yielding a certain amount of organic chemicals and leaving a residue of pure carbon.

Below 170° C, practically pure water is released. Above that temperature, wood will begin to carbonise and up to 250° partial decomposition takes place with a pyroligneous product containing acid but no alcohol. At 250 - 270°C an exothermic reaction begins and continues without requirement of heat from external sources. In all methods of carbonisation some source of heat, external or internal, must be provided normally through the combustion of part of the wood-charge to be carbonised which is the case for all kilns and the kiln type furnaces. Wood is self-carbonizing at 8.5 % moisture content if the heat of the charcoal is recovered and at 2.9 % if the heat from the charcoal is not recovered as in kiln type furnaces.

This heat must be provided to reduce the moisture to self carbonizing level, plus an allowance for losses from furnace walls etc. The carbonizing temperature determines the fixed carbon and the residual volatile matter, which are inter-related. The volatile matter is determined as the loss of weight when charcoal is heated for seven minutes at 950°C in a neutral atmosphere. Its contents decreases with temperature on a linear basis. As the volatile matter decreases, so the fixed carbon increases, and reaches a near maximum at just over 700°C.

Typical carbonisation results of laboratory tests are:

From 150° C to 200°C . . . . . 60 % Carbon
From 200° C to 280°C . . . . . 68 % Carbon
From 280° C to 380°C . . . . . 78 % Carbon
From 380° C to 500°C . . . . . 84 % Carbon

(b) Wood carbonisation in kilns

The composition of absolutely dry wood varies little with the species and on average has Carbon 50 - 55 %, Hydrogen 6 - 7 %, Oxygen 40 - 45 % with calorific value 4,200 - 4,700 Kcal/kg.

However, the chemical composition of wood is extremely complex and varies widely between the species and within each species and between trunks and branches.

One ton of wood with 30 % moisture consumes for drying and carbonization 550,000 to 600,000 Kcal. In practical operation between 15 and 20 % of the wood, depending on its moisture content and other factors, will be consumed as heat source for the carbonization process.

The heat contained in the combustion gases will, before leaving the kiln, completely dry the wood and heat it until the carbonisation process is self-supporting through the exothermic reaction, which starts at 250° to 270° C. The better the gases are conducted through the wood charge, the better their heat will be transferred to the charge, the less wood will be consumed through combustion and the higher the yield.

The yield expresses the percentage of the wood input and is related to the type of kiln, the initial moisture content, the carbonisation temperature and speed, the characteristics of the wood, its age, size, shape, volume of bark, and very important, the experience and skill of the kiln operator, called also a burner.

In the Brazilian practice of charcoal manufacture in kiln beehive furnaces, the yield is expressed by volume, rather than by weight, since volume is more easily measured. The brick beehive kiln developed in Brazil is a good example of a properly designed kiln but even so yields by volume vary from 33 to 60 %.

33 - 38 % =	3.0 - 2.6 Steres/m3	charcoal	-	Low - usually from brushwood
40 - 45 % =	2.5 - 2.2 "	"	"	Fair
46 - 50 % =	2.1 - 1.85"	"	"	Good
55 - 62 % =	1.8 - 1.6 "	"	"	Excellent practice.

Yields by weight are lower and vary between 20 - 25 % of seasoned eucalyptus wood which weighs 500 kg/st after 90 days storage.

High carbonizing temperatures reduce the residual volatile matters to such a degree as to reduce the mechanical strength of the charcoal, both characteristics being inter-related. The resulting charcoal has a high carbon content, a low density and a low mechanical strength, which latter is undesirable for blast furnace use. It is therefore necessary, when manufacturing blast furnace charcoal, to make compromise between carbon content and mechanical strength, this latter being the more emphasized quality. Therefore as a rule in Brazilian practice with kiln furnaces, the carbonization temperatures are kept low, between 380° and 420°C, and the process is conducted slowly. Another advantage of slow carbonisation is that larger pieces of wood tend to break less than in faster methods and the resulting charcoal has a better average size than when carbonizing fast.

The combination of the two factors, temperature and time, is represented by the carbonisation curve which will, when correctly applied, result in charcoal with a reasonable carbon content, a high density and a high mechanical strength.

In this respect Brazilian charcoal manufacturing practice and the quality of the resulting charcoal, are different from Swedish practice which emphasises a high carbon content, low volatile matter and resulting low tendency to self-ignition.

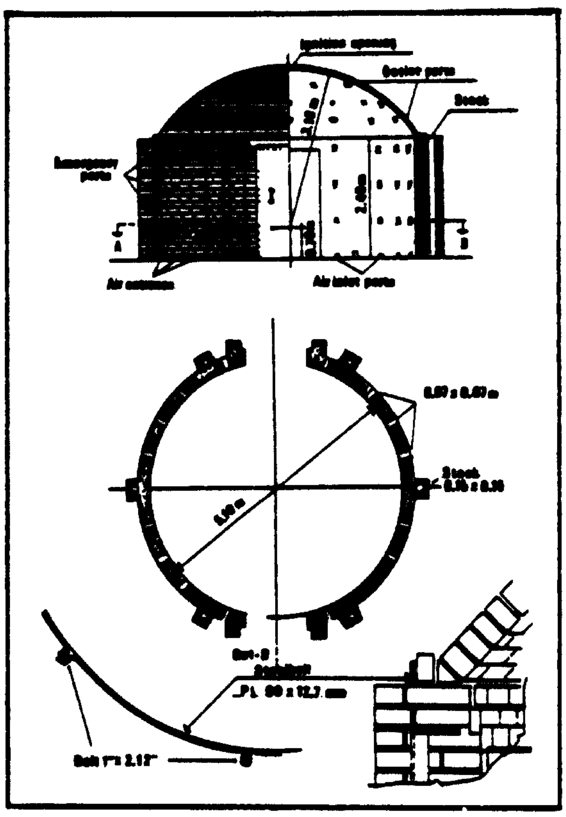
(c) Beehive charcoal kilns without recovery of by-products

There are many existing types of charcoal kilns and kiln furnaces. Either with external or internal (partial combustion of wood) heating; fixed or mobile, with batch operation or continuous.

The kilns which are operated widely and successfully in Brazil, and especially in the state of Minas Gerais are internally heated, fixed, batch type. The important iron and steel companies operate several thousand of them.

They are circular, with a domed roof, and are built of ordinary fire bricks. The circular wall is totally in contact with the outside air. This type of kiln is referred as "Beehive Brick Kiln".

Figure 3 Beehive Brick Kiln



General Data

Kiln diameter	5 m
Nominal Kiln volume	48.94 m3
Effective Kiln volume	45.31 m3
No. of air inlet ports	18
No. of smoke stacks	6
No. of outlet ports	6
No. of emergency outlet ports	50
No. of bricks required	8500

This design has the following advantages:

The gases pass through the wood charge. The heat contained in the gases is partially used in the process of wood drying and carbonisation.

Good yield, up to 62 % in volume = 1.6 st of wood/m^3 charcoal when properly operated.

Low cost, approximately US$ 700 inclusive the access roads for trucks.

Easy construction ......Two men build a kiln in eight days

Simple materials ......8,500 burnt clay bricks with only one steel band for the dome. No concrete foundations.

Long life span ....Up to six years on the same place. Can be dismantled without substantial loss of bricks and be rebuilt at another site.

Uniform carbonisation.

Uniform cooling because the walls are completely in contact with the outside air.

Short operating schedule: Approximately one week. This time could be shortened through forced cooling with fine water sprays.

Uniform control of interior combustion through 18 air inlet portholes for the entrance of the necessary combustion air.

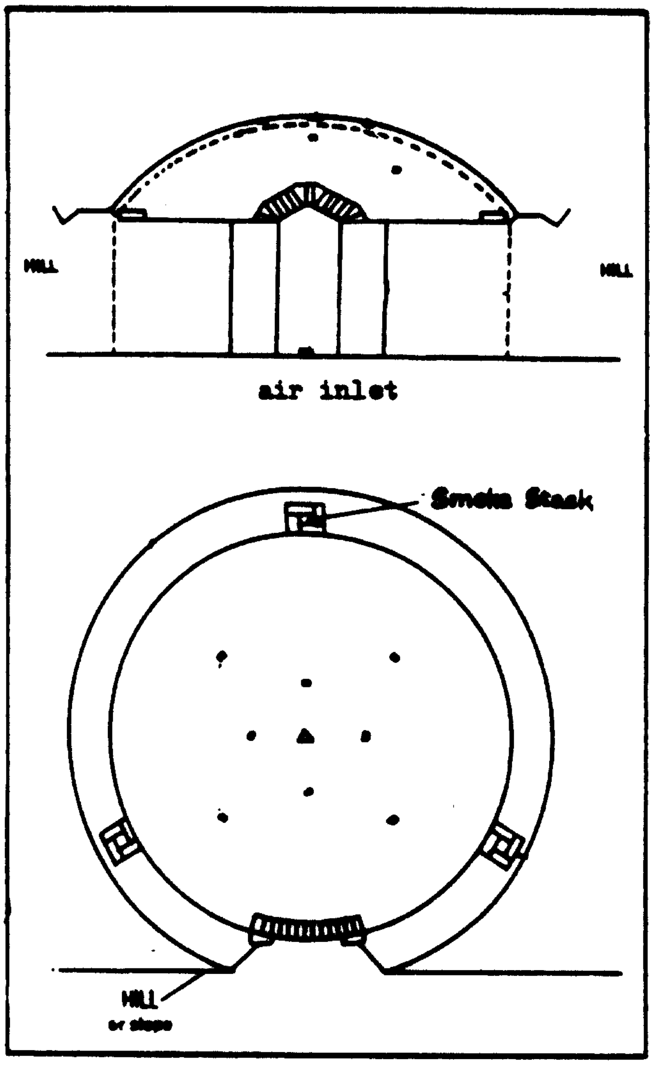
Easy and cheap maintenance, little repairs, no wall cracks, no electricity, very little water, approximately 100 liter per kiln and per batch.

Recently, 1977, large scale experiments are being made by CAF, subsidiary of Belgo Mineira, with a modified design of this kiln in which the six outside chimneys have been substituted by one center stack. The results are excellent. Patents on this design are pending. (Compare also the Swedish forest pile with outside stack).

Slope type beehive kilns

A variation of the "Beehive brick kiln" is the circular, four metre diameter kiln which is built into a slope or hill which forms the side and rear walls of the circular kiln. This type will be referred to as "Slope type kiln". It uses considerably fewer bricks.

Figure 4 Slope Type Beehive Brick Kiln



General Data
Kiln diameter 4.0 m
Nominal Kiln volume 24.8m3
Effective Kiln volume 21.6m3
No. of air inlet ports 1
No. of smoke stacks 3
No. of outlet ports 4
No. of emergency outlet ports 4
No. of bricks 2,000

Many thousands of these kilns are in operation in Minas Gerais and in Brazil. They are very popular among the small, independent charcoal producers. Their operation is somewhat easier than that of the beehive brick kilns because they have only one air-port to control against 18 for the beehive kilns. Chemical and physical composition as well as yields of charcoal produced in slope type kilns are very close to those of charcoal produced in beehive brick kilns. No significant differences between the qualities of the two charcoal types are reported.

In the future it is possible, with the increased demand for charcoal from the large iron and steel companies, that some improvements must be sought in the construction and operation of the charcoal kilns. Some of the improvements proposed are:

(i) Increase of the volume and improvement of the present kiln design. Example: Steel charging and unloading doors and central stack are already being used in large scale operation by Belgo Mineira.
(ii) Better and faster drying of the wood.
(iii) Some mechanisation of the kiln operation.
(iv) Faster cooling of the charcoal inside the kiln.

(d) Brazilian experience with other types of carbonisation furnaces

Some 20 Years ago, Belgo Mineira intended to introduce in its charcoal operation, continuous retorts, giving high yields and with the recovery of some by-product, principally tar. It was intended to adopt a continuous type furnace which had previously been successfully operated in Australia, Belgium, France. Several of these units are in operation in these countries (see Section 4.1.2). The principle of design and operation of these furnaces or retorts is to utilize hot gases as a medium for both drying and carbonising the wood as well as for cooling the charcoal. The gases are circulated countercurrent to the wood and heated by partial internal combustion. The wood, which has been previously dried in a separate retort by the hot gases, is fed continuously into the carbonising retort and charcoal is removed, also continuously, at the bottom of the retort. The duration of the complete process, from the entering into the retort until its exit as cool charcoal, is approximately half a day, as against one week for the beehive brick kilns. The intention was to install several of these retorts with an annual capacity each of 25,000 metric tons of charcoal = 100,000 cubic meters each. These vertical steel retorts were to have a diameter of 2.50 m and a height of 22 m. Each wood drier had approximately the same dimensions.

The yields were expected to be: By weight of air dried wood: 33 % (against 20 % to 25 % for kilns).

By volume of air dried wood: 66 % (against an average of 45 to 55 % for kilns).

Notwithstanding the expectancy of excellent results, well demonstrated by several practical operations in the above mentioned countries, it was decided at the time, ca. 1960, not to install these large retorts for the following reasons:

(i) Very high initial investment. 10 to 20 of these units would have been necessary, grouped at the carbonisation centers in numbers of two to four.

(ii) Delicate operation, which, at the time, would have represented a great effort for the company management and the personnel.

(iii) Necessity of the installation, at each carbonisation plant, of a large sawmill to cut the wood into pieces of approx. 30 cm length for the charging device of the driers and the retorts.

(iv) The unsurmountable difficulties of transporting economically even seasoned wood (25 - 35 % moisture) from the widely scattered natural forests to such large carbonisation plants. Because of their size these plants would have to be spaced 20 - 50 kms apart.

The limiting distance for economic transportation of fire wood is about five kms maximum, it is thus necessary to move the carbonisation centres as close as possible to the forests.

This has been successfully and economically achieved during the past decades and until the present moment, with the simple, cheap and efficient beehive kilns.

With the recent trend to large eucalyptus forests, covering continuous areas of many thousands of ha, yielding a continuous supply of regular wood quantities and allowing the mechanisation of all operations, it may well be possible that the installation of local continuous and mechanized charcoal plants will be reconsidered. Studies are now being made by private companies, and by several Government and private research centres, to examine other carbonising methods which will give better yields.

Another aspect of this question is the increase of the price of the distillation by-products since October 1973. As a consequence, carbonisation processes with recovery of by-products, or at least of some by-products, may be reconsidered in the next future. A remaining drawback is the high investment for these installations.

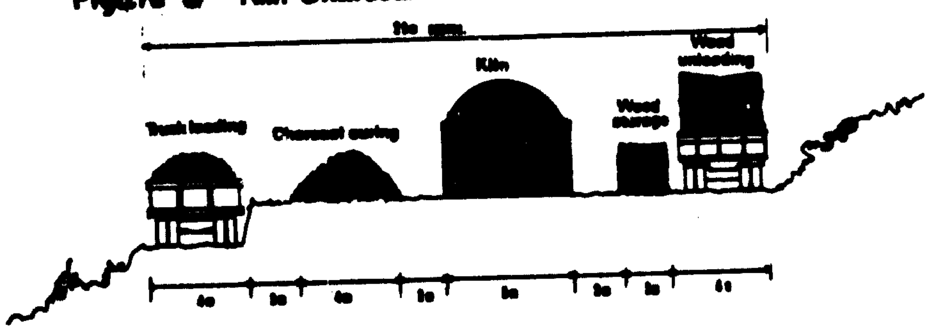
(e) <u>Charcoal production centres</u>

The beehive brick kilns are grouped in batteries of seven, 14, etc. always a multiple of seven. The slope type kilns are grouped in batteries of 14, 28 etc., always a multiple of 14.

Each battery is attended by only two men, one charcoal operator or burner and one helper.

A charcoal production centre comprises one or more batteries of kilns each complete with the infrastructure necessary for continuous operation. For example stockyard for firewood, for charcoal storage for charcoal loading facilities, access roads, water supply etc.

Figure 8 Kiln Charcoal Production Center



Operating cycle for beehive brick kilns:

Charcoal discharging and firewood charging:	8 hours
Carbonisation	96 hours
Cooling:	88 hours
Total cycle:	192 hours or eight days

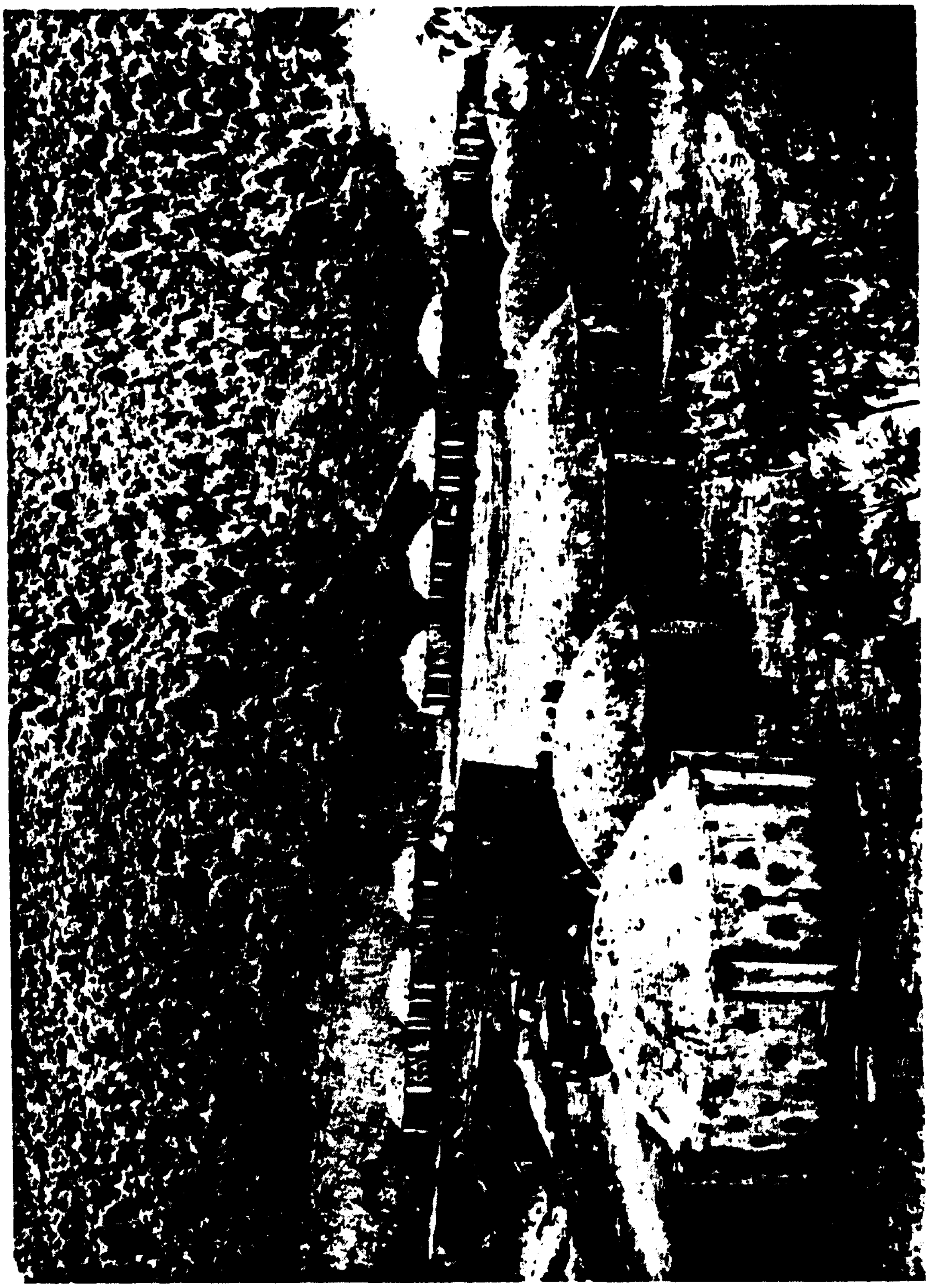


Figure 6 Typical charcoal production center

Operational cycle of a seven kiln charcoal battery

The operational cycle of each of the seven kilns starts on successive days. If kiln No. 1 is discharged and recharged (eight hours) on a Monday then Kiln No. 2 is discharged and recharged on a Tuesday etc. Kiln No. 1 will then be ready for discharging and recharging on the following Tuesday and Kiln No. 2 on the following Wednesday etc.

Sunday is a rest day on which no kiln discharging or charging is done. Kilns due to be discharged on Sunday are dealt with the following Monday. Thus the cycle recommences on a Monday for each kiln in turn after 6 weeks.

Table XV

Characteristics of Beehive and Slope Type Kilns

Type of Kiln	Volume of Firewood in steres		Ratio: Real / Nominal	Charcoal volume in m^3 per batch	Average Yield: Firewood / Charcoal
	Nominal	Real			
Beehive Brick Kiln 5 m Diameter	48.94	37.34	70%	17.8	2.1 : 1
Slopetype Kiln 4 m Diameter	24.8	17.40	60%	8.9	2.2 : 1

The above average yields are those obtained until about 1975. Since 1976, through continuous research and experiment, the improvement of operational conditions, the training of charcoal burners and better supervision, the yields of company operated kilns have continuously improved to: 1.9:1 (53%), 1.8:1 (55%) and 1.7:1 (59%). Yields of 1.6:1 (60%) are being obtained recently in routine operation (1977).

Production of a seven beehive kiln battery in 30 days $\frac{30}{8} \times 7 = 26.25$ batches - say 26 batches.

Each batch = 17.8 m^3 of charcoal.

Monthly production 17.8 x 26 = 462.8 m^3 charcoal.

and yearly production 17.8 x 26 x 12 = 5,553.6 m^3 charcoal.

(f) The operation and construction of beehive brick kilns.

Instructions

(i) Charging

First fit two logs crosswise on the inside of the discharging door. Then block up the discharging door with bricks laid without mortar. The outside of the door to be brushed with a clay slurry but only after charging has been completed.

Charging can now commence. The logs are placed vertically, the thinner pieces against the wall, the thicker ones towards the center of the kiln, where the temperature will be higher. Put the chisel-shaped bases of the logs on the kiln floor to make circulation of the gases easier. The wood piled under the dome ceiling must be placed horizontally, on top of the vertically piled floor wood. Fill up well into the dome. The wood must be piled as close together as possible, to obtain a maximum amount of material inside the kiln. Use a rather loose structure, and some kindling, close to the ignition opening to make ignition easier. If there is some deteriorated wood, this must be placed to the discharge opening as the coal produced from it will have a tendency to ignite easily so if that happens it can be rapidly removed, when discharging the kiln. Close the charging door in the same manner as has been done for the discharge door.

When the kiln is ready for ignition, all port-holes and openings must be kept open.

(ii) Ignition of kiln

Introduce through the central opening in the dome a shovelful of glowing (incandescent) coal. In the rainy season it may be necessary to help with some kerosene or used lubrication oil. Use the central opening only for ignition, as the carbonisation process must proceed from top to ottom. At the start of the ignition period, smoke will issue from the ignition opening, first white, minutes later dark coloured. This is a signal that the fire has caught. The opening must then be plugged with a brick brushed with clay slurry.

(iii) Carbonisation

Immediately after ignition, smoke issues from the outlet portholes, initially white colored, which means that the carbonisation area is increasing. The emergency outlet portholes and the ports located in the dome are now plugged.

The stacks (chimney) start smoking. The kiln operates from now on exclusively with the controlled air supplied through the airinlet portholes and on the draft of the stacks expelling the carbonisation gases.

The carbonisation process proceeds from top to bottom and also horisontally. The chimneys must be watched to ensure they work uniformly. This is achieved by controlling the draft of air entering the air inlet portholes by varying the position of a brick loosely inclined against the porthole entry.

The charcoal burner controls the carbonisation by observation of the smoke colour issuing from the stacks. Carbonisation proceeds as long as the colour is white or clear. Later, it turns to bluish and then to blue. When this colour becomes steady, the airinlet portholes must be closed.

At the end of the carbonisation the smoke becomes colourless and transparent. When, on top of the stacks, a zone of approximately 20 cm height of colourless smoke appears the chimneys are closed.

The stacks do not present simultaneously the same smoke colour even when every precaution is taken.

It is therefore, necessary to regulate, one after the other, the air inlet portholes and to close the corresponding stacks. These will continue to issue smoke some time after the airportholes have been plugged. The stacks should not be closed too soon to avoid the presence of uncarbonised pieces of firewood.

Once the stacks have been closed, the carbonisation process is terminated. After closing all openings, they must be carefully brushed with clay slurry to prevent any air entering.

(iv) Cooling the kiln

The kiln is brushed all over with several layers of clay slurry to close all openings, leaks and cracks. The number of brushings varies between three and six. The better this operation is done, the faster will be the cooling of the kiln. When leaks are not fully closed, air will continue to penetrate into the kiln, preventing the extinction of the fire, causing loss of charcoal through its combustion and an increased ash content.

(v) Unloading the kiln and curing the charcoal

The kiln is opened and the charcoal is discharged when the kiln is sufficiently cool. The burner knows the correct temperature, 60 - 70° C, by feeling the door wall with the back of his hand.

A kiln must never be opened until it is sufficiently cool to avoid spontaneous fire. Such a fire may be extinguished with water, but, in most cases, it will be necessary to close immediately the kiln. The result is always a loss of charcoal. Sufficient water, at least one barrel - 200 litres -, must be readily available before the kiln is opened. The space in front of the kiln, where the charcoal will be stored, must be clean. Fresh charcoal must never be placed on top of older charcoal. The kiln is opened rapidly. The burner will observe, by smelling the issuing gases, whether there is fire in any place and, in that case, will extinguish it with water spray.

The bricks from the door opening are put on one side not to impede the discharge operations, which are done manually with a special large fork and a basket. It is good practice to separate all uncharred pieces of wood bricks, ashes, charcoal fines and clay remnants. Uncompletely carbonized pieces of wood are separated and reloaded with the next batch. The discharged charcoal is heaped and stored in a way to allow thorough airation. This is also called curing. Fresh charcoal absorbs oxygen. This chemical reaction is accompanied by a rise in temperature which can

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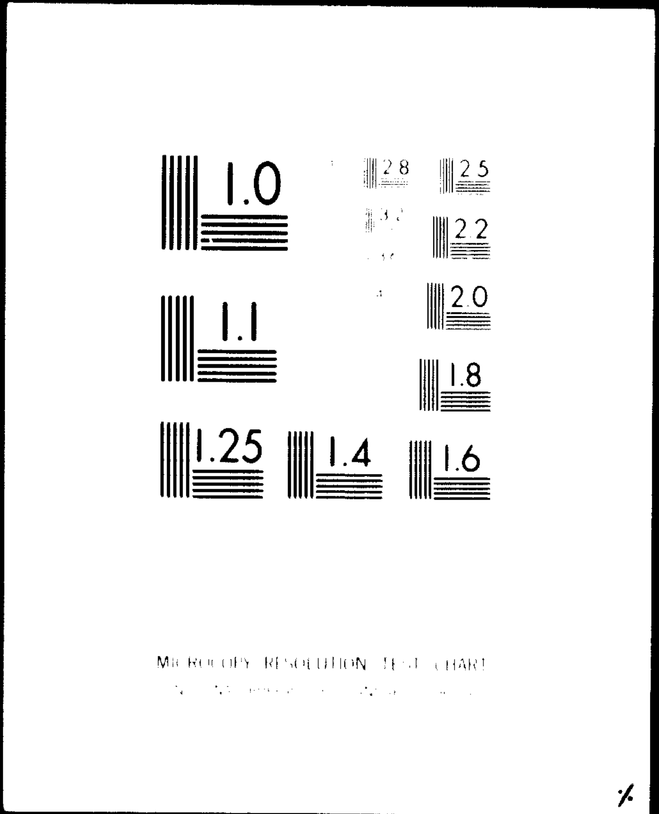

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reach a degree to cause spontaneous ignition. Therefore fresh charcoal is required to "cure" in the open air for two days before being transported to the intermediate storing houses or to the iron and steel plants. It is of course difficult to control whether this operation is always done with the necessary care. Principally at the end of the month, when charcoal operators are anxious to complete their monthly quotas of charcoal production, it frequently happens that the coal is unsufficiently cured, causing fire hasards.

During curing, the charcoal heaps should not exceed 1.50 m height or depth to permit a thorough contact between coal and outside air.

After unloading, the bottom of the kiln is cleaned. All air-ports and stacks are opened and cleared from carbonisation residues. The entire inside of the kiln becomes heavily coated with hard tar or pitch which condenses and builds up during successive charges and protects the bricks.

(vi) Carbonisation in slope type kilns

It is the same as in beehive brick kilns. The operation is simpler because there is only one air-inlet porthole to watch and to regulate.

These kilns are frequently located at places of difficult access without roads. The unloaded charcoal must be transported to the nearest road, or to a reloading place, by mule packs. To make the correct choice between the two types of kilns, the following points of comparison may be considered:

Beehive Brick Kiln	Slope Type Kiln
No special topography required.	Necessary to have a natural slope or to prepare an artificial one.
It will be frequently necessary to do some important earth moving to prepare a good sized flat area.	Very little earth movement required.
No special requirements as to the texture or composition of the soil. In case of sandy soil, the floor must be made of clay brought from another place.	The texture and composition of the soil are important. When very clayey it will crack through the effect of the carbonising heat and false air will enter. When sandy, the wall will collapse easily and retain too much heat to permit fast cooling.
Life span: a minimum of 1200 m3 of charcoal.	Life span: A minimum of 350 m^3 of charcoal.
The kiln platforms must be laid out to permit the handling of the charcoal directly into trucks, after curing. The trucks should arrive at a lower level. (See figure 5)	The kilns must be built as close as possible to the wood supply.
Maximum distance from the wood supply five km.	A few hundred meters.
Labour: Two men for each battery of seven kilns	Labour: Two men for each battery of 14 kilns.
The charcoal burners must have developed considerable skill in order to observe correctly and regulate the 18 air inlet portholes. Training of labor is recommended.	Easy operation. Only one air inlet port hole. No special training required.

(vii) <u>The construction of beehive brick kilns</u>

One seven-kiln battery requires a place with the following dimensions:
Length . . . . 70 m.
Width . . . . 25 m.

This area is necessary for the seven kilns, the storing and curing of charcoal during two days, access roads for the trucks bringing the wood, storage space for a certain amount of wood, access roads for trucks for removing the charcoal and a truck turn around area. To prepare the ground for the furnaces and the charcoal loading platform some earth moving work by caterpillar tractors will always be required. The terrain must be slightly sloped to allow the drainage of rain water. Frequently two or more kiln batteries will be grouped together in one line. This happens when the surrounding forests are vast and the available fire wood quantities at a short distance are large. The batteries will always have seven kilns and the necessary area will be a multiple of the surface given for one battery. The lay-out of a great number of batteries has the advantage of good centralisation of the operations and good supervision. The result is a good charcoal quality and good yields.

The total number of kilns at one centre is limited to 35 or 42 by the quantity of fumes coming from the chimneys. This is not harmful to health but is irritating to the eyes and lungs. Charcoal manufacturing centres should therefore be at least two kms distance from villages and their location should be considered in relation to the prevailing wind direction.

When laying out a battery the centre line of the battery is first marked on the ground. The kiln centres are eight metres apart. The centre of each kiln is marked with a two metre long pipe driven vertically into the ground. The inside circumference of the kiln is traced at a five m diameter, the outside circumference at a 5.40 m diameter.

The two, one m wide, doors are marked, as well as the foundations for the door pillars. The six chimneys are marked, the kiln foundations are marked and the excavation of the footing trench is made. The kiln foundations must extend four courses of bricks below the surface of the ground and one course of bricks over the ground. All courses must be laid carefully and level.

A 2.50 m wooden pole will be fixed horisontally on the central pipe to serve as a guide for the building of the walls. When laying the walle, leave the openings for the doors but build the pillars for them. The mortar is made of 10 parts of clay and one part of charcoal fines, which have been previously sieved. When laying the first course of bricks, leave the necessary openings for the air ports, three between each pair of chimneys, a total of 18, symmetrically distributed. Sizes of air ports are: Width: 0.10 m, Height: 0.08 m. The chimneys are raised simultaneously with the wall. The inside measures of the flues are: 0.12 m x 0.10 m. When building the kiln wall, care must be taken that the different courses of bricks be level. Use the wooden guide. After five courses of bricks, leave two emergency openings vertically above the two air inlet ports located next to the stacks. After the second layer of five courses, leave one central emergency opening. After the next five layers, leave two emergency openings located vertically above the first ones. The emergency openings are 0.07 m x 0.07 m. To each pair of stacks correspond five emergency ports. When the wall has reached 1.60 m height, put on top of the door pillars the steel angle lintels and continue to build the surrounding wall. In thie way the two door openings, 1.00 m wide and 1.60 m high, will be ready. After loading the kiln with firewood and closing the doors with bricks the burner will leave in each door - wall, one air inlet porthole at the height of the others.

The total height will be 1.80 m and the last course of bricks must be well leveled. On top of it is laid, on side, and with a minimum of mortar, one more course of bricks. Outside thie course, and against it, are laid the four segments of steel band, loosely bolted together.

Adjust by cutting, the first course of the dome bricks to the top course of wall bricks which has been laid on edge. Remove the central pipe and put in its place a picket or short stake is driven into the ground and flush with the last brick course of the foundation. To this picket will be attached the beam compass of guide length about 3.10 m for the building of the dome. This is built with a thickness of half a brick and a minimum of mortar is used. The strength of the dome ceiling is obtained through the pressure of the bricks one against the other.

At the fifth course of bricks, leave 10 emergency openings 0.07 m x 0.07 m, at the tenth course, leave another 10 openings, at the fifteenth leave six openings. At the top of the dome, leave the ignition opening, which is triangle-shaped and has 0.10 m x 0.10 m x 0.10 m. After the dome is terminated, tighten the steel band. Plaster the walls with a fine clay mortar and brush the dome with a clay slurry to close all the cracks and openings.

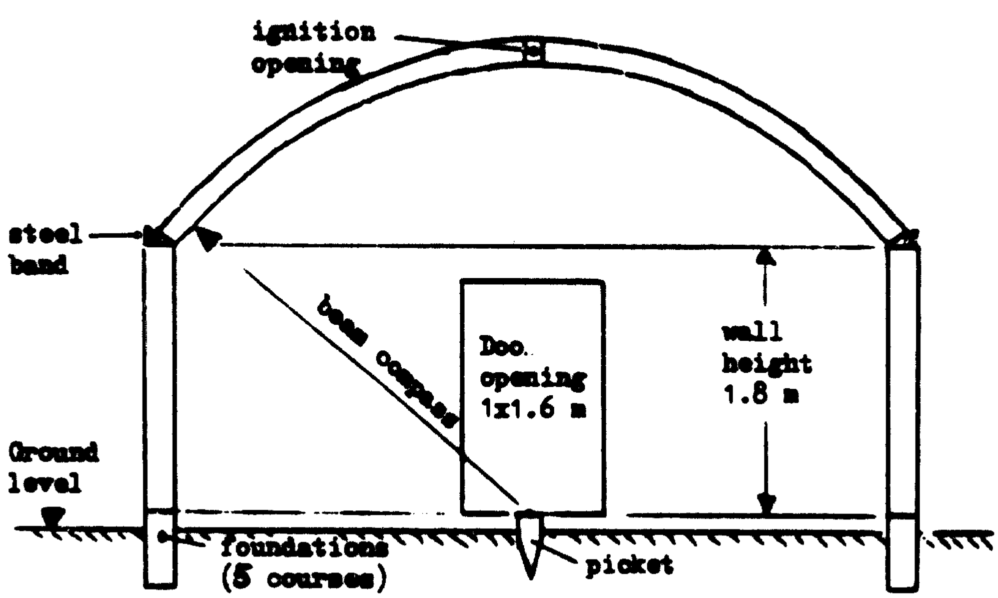


Figure 7. Section through beehive kiln showing construction techniques.

(viii) The construction of slope type kiln - four m diameter

Clean a circular surface six meter diameter at the kiln place. Mark a circle of four m diameter and excavate the kiln body with 1.40 m height, the floor being well leveled. Mark the door, width 0.60 m and the three stacks at 120° angle between them.

Excavate into the bank the openings for the door, 0.60 m wide, and the three stacks with a section of 0.35 m x 0.35 m and a height of 1.40 m. Raise the chimneys to 1.50 m height with bricks laid on edge.

Drive a picket in the center of the floor ground and attach to it the beam compass for building the arched dome. The guide length will have the exact inside height of the dome, which is 2.45 m.

If the bank or hill-height is insufficient, it will be necessary to complete the wall height with a brick wall of half brick thickness. The mortar used is the same as for the dome. The opening over the door receives a brick arch. Make around the domebase the necessary sloped incision for the domerest.

The dome is built in half brick thickness, with little mortar, made of 10 parts of clayish soil and one part of sieved charcoal fines. In the tenth course of bricks leave four emergency holes, 0.07 m x 0.07 m, symmetrically placed. After 10 more courses leave four other holes 0.08 m x 0.08 m. At the top of the dome, leave the ignition opening, 0.10 m x 0.10 m.

The arch over the door opening is built in bricks laid on their sides and bonded to the dome brick structure. Toward the kiln door an opening is made into the bank in order to facilitate the handling of the firewood. After the kiln has been loaded with wood and the door has been closed, leave at its base level the porthole for the air inlet. Excavate around the kiln the necessary water drainage trenches.

(ix) Maintenance of the kiln

Rasp periodically from the outside the excess of clay which has been formed by the successive brushes of clay slurry. This improves cooling of the charcoal.

Avoid shocks against the kiln walls, which could damage its structure. For instance: Shocks by trucks, carts, logs. The door pillars should be protected by two corner poles. Put in place and ram tight bricks which have fallen out of the walls or have become loose.

The outlet and emergency portholes must be closed with wedge shaped bricks and without mortar. Brush clay slurry on the outside. The stack flues must be carefully cleaned with a long, flexible wooden rod.

The chimneys must terminate above the dome steel band, to reduce corrosion by the fumes. (After a few years the band will always become corroded). Tighten regularly the dome steel band and change any corroded parts.

The kiln floor should always be kept level. When necessary, put in some wet clayish soil and stamp. If the soil of the kiln platform cracks, it must be closed to avoid damage to the kiln foundations, for instance through water infiltration, Keep the water drainage trenches always unobstructed.

Keep straying animals out of charcoal manufacturing center by fencing it with barbed wire or other material.

(g) Charcoal Protection and Intermediate Storage

Fresh charcoal absorbs oxygen. This chemical reaction is accompanied by a rise in temperature which can cause spontaneous ignition. Fresh charcoal must therefore be "cured" in the open air for two days before it is transported to intermediate storage houses.

Charcoal is also very porous and therefore hygroscopic and will rapidly absorb large amounts of moisture from the air and water from rainfall. (up to 50 % of its dry weight). After the curing period it must, therefore, be protected during humid and rainy periods while awaiting transportation. This is simply done by covering the coalheaps with plastic or canvas sheets, galvanised sheet or available roofing material.

70 % of the charcoal produced in Minas Gerais is transported directly by trucks from the coal manufacturing centres to the iron and steel plants and so does not require intermediate storage. The truck loads of coal are protected during the transport with tarpaulins, firmly attached to the trucksides.

Intermediate storing is necessary when large amounts of charcoal must await transportation because of sporadic, accidental or regular scarcity of transportation means, trucks, railway or, poor road conditions in remote areas. Intermediate storing of charcoal is a regular practice at railway stations. The following requirements should be observed when laying out an intermediate storage station:

It must be sufficiently large to accept the quantity of charcoal to be stored under abnormal conditions e.g. during a prolonged rainly season, or a period of scarcity of railway transportation. The storage house should be divided into sections, of approximately 2,000 m^3 each, separated by walls. It must be covered and must have sufficient facilities for easy and fast handling of the charcoal at its arrival and departure. Unloading into the storing house can be done through wooden or metallic chutes and loading of the railway cars through manually operated wooden or metallic closing traps. Belt conveyors may also be used but mechanisation should be minimized because it is expensive. The height of the heaped coal should be less than six m to avoid spontaneous ignition. Incoming coal should be dropped as little as possible (two m maximum) to reduce formation of fines. The coal should be unloaded onto a naturally formed slope of charcoal and handling should be reduced to a minimum as each movement produces some fines.

Trucks should not be allowed inside the storinghouse because of fire hazards from internal combustion engines and smoking by truck drivers. Unloading should, therefore, be done outside. The building must be well ventilated and open on all sides to give rapid and easy access from all sides in case of fire. It should have no intermediate columns across the roof span.

The building columns may be of brick, concrete or steel but the roof girders must be in steel; the roof should preferably be galvanised sheet but asbestos may be used. The floor may be brick, stone, concrete or even rammed earth. Water pipes with hose connections should be available at different points but in case of fire the best method of saving the charcoal is to push the unburnt coal out of the building with tractors equipped with shovel blades.

(h) Transport of Charcoal to Iron and Steel Plants

(i) Transportation by trucks

As mentioned before, approximately 70% of all charcoal produced in the State of Minas Gerais is transported by truck. This is a flexible and fast means of transportation, but expensive. The coal can be moved from the kilns to the iron and steel plants immediately after curing. Also little charcoal fines are produced as the number of handling are few. Most of the small pig iron producing plants have no railway connection and must rely solely on truck tranportation. Trucks are able to reach isolated kilns, located close to poor roads. The most popular truck has the following characteristics: Brazil manufactured, Mercedes Benz, Type LK 1113 Diesel engine powered, HP 145 two axles for normal road driving and a third one for fast and safe highway driving to comply with State regulations of maximum axle loading.

Carrying capacity 48 m^3. Cost (1977) US$ 18,000. Some transport companies use 60 m^3 trailers but these are not able to operate on poor roads and have a tendency to tilt over.

Transportation distances vary from a few kms to 1,000 kms to some iron and steel plants in the States of Rio de Janeiro and São Paulo. In Minas Gerais, the maximum distance is 700 km.

Many truckers prefer to carry the charcoal in burlap bags (about 25 kg/bag or 11 bags/m^3 of charcoal). This practice allows general purpose trucks to be used which, on the return journey, can carry other merchandise. Bagged charcoal is bulkier than loose charcoal which "sets" during transport with a volume loss of 2 - 5 %.

Trucks loaded with burlap bags also have a greater tendency to tilt than when loaded with lump charcoal. The unloading of the burlap bags must be done manually which is a disadvantage.

Trucks carrying lump or loose charcoal must have their side height increased to about four m total with cratetype side sheeting to give a reasonable volume corresponding to the truck capacity.

(ii) Transport by rail

All medium and large iron and steel plants have rail connections and use rail transport to the maximum because it is much cheaper.

Companies like Belgo-Mineira and Acesita transport about 40% of their charcoal by rail. Belgo Mineira also uses a cable car system.

Most railway cars have a capacity of 54 m^3. A few are 80 m^3 and recently some 100 m^3 cars have been ordered. They cost about US$ 30,000 each.

There are still some older cars in use of 20 to 30 m^3 capacity; these have flat bottoms and wide discharging doors but must be unloaded manually. However, they may also be used for other merchandise as return freight. The newer and larger cars have sloped bottoms and self-discharging doors on both sides of the track which permit a rapid discharge directly into coal bins or into the storing house. The cars are sometimes loaded at the railway station directly from trucks, but mostly from a reloading and storing place, through hand operated gates or by conveyors.

Belgo Mineira has recently started transporting charcoal by rail over distances of 700 kms in big, plastic, bagshaped containers of 3 m^3 volume. The savings in transportation costs compared with truck transport are US$ 3/t.

The plastic containers also protect the charcoal against moisture. The plastic containers are loaded by a mobile crane. The experiment may be extended to fill the containers at the charcoal kilns and so avoid handling lump charcoal between the kilns and the railway stations. Rail freight for charcoal is calculated on the basis of 300 kg per m^3 of charcoal. All handling at the loading and unloading stations is done by the iron and steel companies, which also supply all the necessary equipment and carry all expenses. The cars, however, belong to the Railway Company which is Government owned.

(iii) Aerial rope or cable-way

Since 1957 Belgo-Mineira uses an aerial cable way to move a certain proportion of the charcoal produced in one of the principal charcoal manufacturing centres in the Rio Doce region which is east of their Monlevade iorn and steel plant. The length of the cable way is 50 kms; the charcoal at 40 t/hr is carried in steel boxes of 1.4 m^3 which are suspended from the rope way and move at 10 km/hr. Another cable way transports all charcoal from the works central storage place to the blast furnace bins - a distance of 1.2 kms at 60 t/hr in boxes of 1.5 m^3 moving at 10 kms/hr.

Cableway transport can be economic and efficient but it must be operated at near full capacity, as the investment is high and its operation must be continuous to be economical.

It is therefore necessary that the supply of charcoal at the loading station be continuous and the delivered charcoal volume close to the capacity of the cableway. These conditions are seldom encountered in charcoal manufacturing.

(iv) Mule Packs

For short distances, up to 20 km, and for small quantities, transportation by mules or horses should not be discarded and has been used for many years in the State of Minas Gerais. Each mule carries two baskets of 60 kg each. Transportation speed is six km/hr. Loading and unloading are manual. Mules are now only used for intermediate transport of the charcoal to the trucks, when the kilns are located in remote places of difficult access.

(v) Water

Water transportation is not used in the State of Minas Gerais. The iron and steel plant at Manaus, Siderama, located on the Amazon river uses barges for all its iron ore and charcoal transportation, the results are not known. The projected Paraguay steel works on the Paraguay river, close to the capital of Asunción intend to transport up to 60 % of their charcoal by water.

Water transport is very cheap and should be considered when conditions are suitable.

(i) SIZES AND CATEGORIES OF CHARCOAL MANUFACTURING FACILITIES, TRANSPORT, HANDLING, STORAGE AND RECEPTION OF CHARCOAL AT BLAST FURNACES

(BASED ON EXISTING BRAZILIAN CONDITIONS)

Table XVI

Plant Category	I	II	III	IV	V	VI	VII
Charcoal manufacturing capacity m^3/year (including 10% fines)	40,000	70,000	170,000	350,000	700,000	1,000,000	1,700,000
Related capacity of ironmaking plant t/year	10,000	17,500	42,500	105,000	210,000	347,000	590,000
Number of blast furnaces (t/day)	1x40t	1x60t	1x150t	2x150t	3x200t	3x300t	4x400t
Average distance from charcoal kilns to plants	50km	50 km	100km	200km	300km	400km	600km
Transport means - wood to kilns	Tractor carts	Tractor carts	Tractor carts or trucks	Tractor carts or trucks	Tractor carts or trucks	Tractor carts or trucks	Tractor carts or trucks
" " -Charcoal to plants	$40m^3$ Trucks	$40m^3$ Trucks	$40m^3$ Trucks	2/3 trucks (50km) 1/3 railway	2/3 trucks (50km) 1/3 railway	2/3 trucks (50 km) 1/3 railway	1/2 trucks 1/2 railway
Type of handling - Reforestation	Manual	Manual	Manual	Manual	Manual and mechan.	Mechanized	Mechanized
" " -Wood felling	Axes and Motor Saws	Axes and Motor Saws	Motor Saws	Motor Saws	Motor Saws	Motor Saws	Motor Saws and Special Machines
" " -Charcoal Manufacture	Manual	Manual	Manual	Manual	Manual	Manual	Manual
" " - Intermediate Storage	Manual	Manual	Manual and Mechanized	Manual and Mechanized	Mechanized	Mechanized	Mechanized
" " -Storage at plants	Manual and Mechanized	" and Mechan.	Mechanized	Mechanized	Mechanized	Mechanized	Mechanized
Charcoal Manufacturing Capacity - t/yr (at 250 kg/m^3)	10,000	17,500	42,500	87,500	175,000	250,000	425,000

(j) EQUIPMENT DETAILS AND INVESTMENT COSTS FOR CHARCOAL MANUFACTURE, TRANSPORT, HANDLING, STORAGE AND RECEPTION AT BLAST FURNACES

Table XVII

CATEGORY	I	II	III	IV	V	VI	VII
A. REFORESTATION FOR SELF SUFFICIENCY IN 20 YEARS							
Hectars/yr planted	300	500	1,200	2,500	5,000	7,500	12,000
Trees/yr planted (1700/ha)	510,000	850,000	2,040,000	4,250,000	8,500,000	12,750,000	20,400,000
Investment for first 7-8 years (US$ 800/ha)	US$ 240,000	US$ 400,000	US$ 960,000	US$ 2,000,000	US$ 3,500,000	US$ 5,250,000	US$ 8,400,000
B. FOREST OPERATIONS							
Wood cutting and felling motor saws	30(10 spare)	60(20 sp)	120(20 sp)	250(50 sp.)	480(80 sp.)	700(100 sp.)	850(100 sp)
winches	15(2 spare)	25(5 sp)	60(10 sp)	120(20 sp.)	230(30 sp.)	350(50 sp.)	550(50 sp.)
1. Investment	US$ 90,000	US$ 160,000	US$ 380,000	US$ 760,000	US$ 1,400,000	US$ 2,160,000	US$ 3,800,000
Wood transport to kilns							
st./month	10,000	16,000	40,000	82,000	160,000	220,000	380,000
st./day/centre (Peak)	400	212	160	164	160	160	160
st./hour/centre (Peak)	50	20	16	16	16	16	16
Equipment. Tractors carts	2 + 7	4 + 10	12 + 35	25 + 80	45 + 130	65 + 210	110 + 350
or trucks (5t)	5	8	20	40	80	100	200
2. Investment	US$ 40,000	US$ 70,000	US$ 220,000	US$ 500,000	US$ 850,000	US$ 1,300,000	US$ 2,150,000
C. CARBONIZATION							
Peak Production/month(m^3)	4,500	7,200	17,500	37,500	73,000	100,000	175,000
	9x7=63	15x7=105	38x7=266	81x7=567	160x7=1.120	20x7=1.540	380x7=2.660
Charcoal centres (No.)	1	3	10	20	40	55	95
Investment	US$ 50,000	US$ 70,000	US$ 200,000	US$ 400,000	US$ 800,000	US$ 1,100,000	US$ 2,000,000
Total of Items A, B (1+2) + C	US$ 420,000	US$ 700,000	US$ 1,760,000	US$ 3,660,000	US$ 6,550,000	US$ 9,810,000	US$ 16.350,000
Investment Cost/t charcoal at 250 kg/m^3	US$42/t	US$40/t	US$41/t	US$42/t	US$38/t	US$39/t	US$38/t

Table XVII (continued)

	CATEGORY	I	II	III	IV	V	VI	VII
D.	Charcoal transport to plants $40\ m^3$ trucks	3 (1 sp.	5 (1 sp.)	20 (4 sp.)	for 2/3 transport 30(5 sp.)			
	$50\ m^3$ trucks					For 2/3 transport 60(5 sp.)	For 2/3 transp. 120 (10 sp.)	For 2/3 transp. 200 (20 sp.)
	Investment	US$ 50,000	US$ 90,000	US$ 340,000	US$ 500,000	US$ 1,200,000	US$ 2,400,000	US$ 4,000,000
E.	Charcoal Intermediate storing	not needed	not needed					
	Volume			$6{,}000m^3$	$12{,}000m^3$	$20{,}000m^3$	$30{,}000m^3$	$50{,}000m^3$
	Area			$1{,}000m^2$	$2{,}000m^2$	$3{,}000m^2$	$4{,}500m^2$	$7{,}000m^2$
	Investment	-	-	US$100,000	US$200,000	US$300,000	US$450,000	US$700,000
F.	Charcoal unloading, storing, screening at plant							
	Volume	$9{,}000m^3$	$15{,}000m^3$	$30{,}000m^3$	$50{,}000m^3$	$75{,}000m^3$	$100{,}000m^3$	$180{,}000m^3$
	Area	$1{,}500m^2$	$2{,}000m^2$	$4{,}000m^2$	$7{,}000m^2$	$10{,}000m^2$	$15{,}000m^2$	$25{,}000m^2$
	Investment	US$ 150,000	US$ 200,000	US$ 620,000	US$ 1,000,000	US$ 1,400,000	US$ 3,000,000	US$ 5,000,000
G.	Charcoal reception and Quality Control Investment	US$ 50,000	US$ 50,000	US$ 50,000	US$ 100,000	US$ 150,000	US$ 150,000	US$ 250,000
H.	Maintenance Shop for Trucks Investment	US$ 100,000	US$ 100,000	US$ 200,000	US$ 400,000	US$ 1,000,000	US$ 2,000,000	US$ 3,000,000
	US$ Total Investment-Items A-to H	770,000	1,140,000	3,070,000	5,860,000	10,600,000	17,800,000	29,400,000

SECTION 3

OPERATIONAL PRACTICE OF CHARCOAL BASED IRONMAKING

1. FUNDAMENTAL ASPECTS OF BLAST FURNACE OPERATION IN RELATION TO THE USE OF CHARCOAL.

(a) Reactivity of carbon in the blast furnace

We may define as reactivity of the carbon fuel its aptitude to react with CO_2 forming CO by the following chemical reaction:

$$C + CO_2 \longrightarrow 2\,CO$$

This reaction follows the equation of Boudouard and is shown in Figure 8.

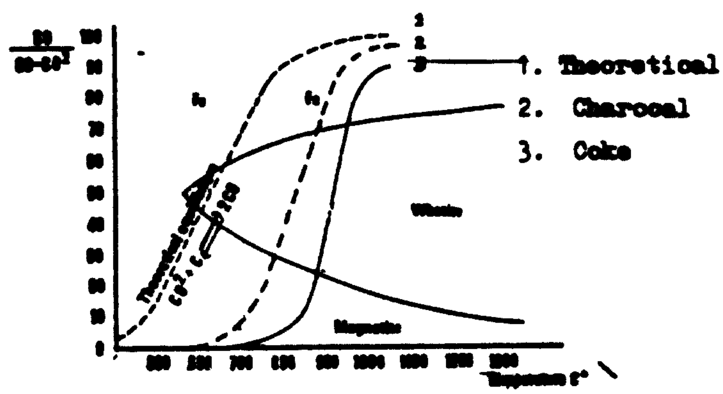


Figure 8. Theoretical equilibrium of C, CO and CO_2 and Fe and its oxides according to Boudouard . Equilibrium of Fe with coke and charcoal are also shown.

As the figure shows, the reaction is theoretically possible at low temperature but in that case the kinetics are low and in practical operation the reaction will only begin at a certain temperature, depending un the reactivity of the fuel. For usual blast furnace cokes, this temperature is situated between 900 and 1000°C; for charcoal, between 750 and 850°C. This means that charcoal is much more reactive than coke.

This is also shown in figure 9 which clearly shows the wide difference in reactivity between coke and charcoal at 800°C.

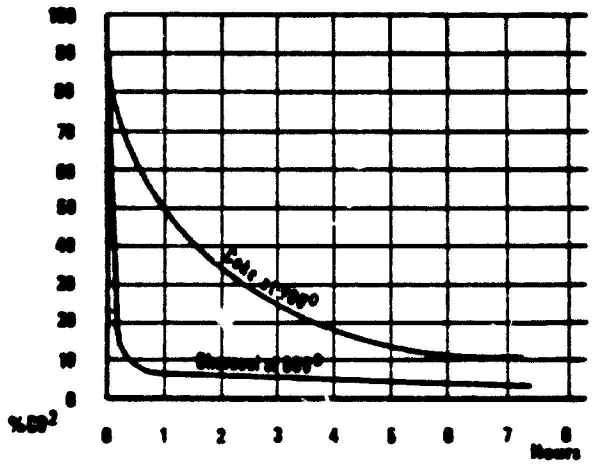


Fig. 9 Kinetics of reaction between carbon and CO_2 at 800°C for charcoal and coke.

For simplicity only the reactions of carbon with CO_2 are considered. In reality the blast furnace gas also contains H_2, from the volatile matters contained in the charcoal and humidity of the blast, which reacts with carbon in a similar way as CO_2.

$$C + H_2O \longrightarrow CO + H_2$$

The reactivity of a given type of carbon depends up to its specific surface exposed to the reducing gases, that is, its porosity. Thus charcoal because of its high porosity has a higher reactivity than coke. For practical blast furnace operation the reaction $C + CO_2 \rightleftarrows 2CO$ is very important because 15 - 20% of the total gasified carbon is, in the form of CO, produced by this reversible reaction. The main source of reducing gas being produced through the direct combustion of the carbon (charcoal) in front of the tuyeres.

(b) <u>Reduction of iron oxides by charcoal</u>

Due to the high reactivity of charcoal the upper and middle parts of the blast furnace stack have a temperature of only 750 - 850°C compared with 900 - 1000°C for coke blast furnaces. This temperature is constant for a certain "intermediate" zone of the stack.

Figure 10 shows the temperature line in this zone according to tests made by IRSID in a charcoal blast furnace at the Monlevade Plant.

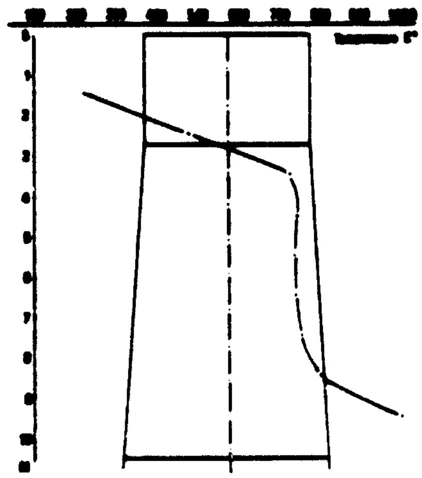


Fig. 10 Temperature line in charcoal blast furnace (IRSID).

It is in this zone that the indirect reduction of the iron oxides by the ascending gases containing CO and H_2 occurs and it can be assumed that, due to the excellent charcoal reactivity, the degree of indirect reduction and the reduction speed in this zone is high when compared with the less reactive coke. Due to this favourable characteristic of the charcoal the necessary preparation zone in the upper part of the stack can be smaller and therefore the total height of the stack can be lower than in coke blast furnaces. However, it is impossible to establish "a priori" the influence of the lower temperature in the above mentioned intermediate stack zone on the overall fuel rate because of another important influencing factor which is the decrease of the reaction kinetics of the reduction process at lower temperatures in charcoal blast furnaces. Some blast furnace experts and operators have the opinion that the use of charcoal may be especially favourable with a highly reduceable burden. A very good burden preparation works in the same direction. (Note: In the present text the blast furnace nomenclature of "indirect" and "direct" reduction is used. This must not be confused with the nomenclature used in "Direct Reduction Processes").

(c) Influence of the volatile matter

Charcoal, as manufactured by the current Brazilian practice contains approximately 25% by weight of volatile matter, mainly hydrogen and carbon monoxide. It is a generally assumed opinion that these gases take a certain part in the chemical process of reducing the iron oxides contained in the burden.

However it is difficult to judge quantitatively the influence of these gases on the reduction process since the gases volatilise at different temperatures, the CO at a lower, the H_2 at a higher, but both under 900°C.

Charcoal blast furnace gas contains 4 to 6% H_2 against 1,5 to 3% in coke blast furnace gas. A simple calculation will prove that a large amount of the H_2 contained in the volatile matter has been consumed in the process of iron ore reduction. The high content of hydrogen in the volatile matter also has an influence on the dynamics of the gaseous flow inside the blast furnace. This gas being very light, it rapidly rises and penetrates into the stock and, consequently, accelerates the reduction of the iron ore oxides.

In conclusion, it can be said that the volatile matters in the charcoal will to a certain degree improve the carbon balance of the charcoal blast furnace.

(d) <u>Kinetics of gaseous flow in the blast furnace:</u>

In practical operation a very important factor for the blast furnace productivity is the quantity of gas which can pass through the furnace without disturbing the descent of the stock. Normally, this gas quantity is proportionate to the blast (or wind) volume. The volume of wind which can be blown into a given blast furnace is ruled by the permeability in the stack which depends on the size of the burden particles, their shape, and their distribution in the furnace. The permeability of the burden has therefore a direct influence on the furnace productivity.

Charcoal has a low bulk density and it thus occupies about three quarters of the total furnace volume. The average particle is also small, a minimum of six mm is sometimes used, so that the small charcoal particles tend to be lifted when the blast pressure is high and to accumulate at the upper part of the blast furnace, forming a large impervious mass which interrupts the smooth descending movement of the stock.

Close sizing of the burden with the lowest possible average diameter of the particles and separate charging of the different charcoal and ore sizes is therefore very important in charcoal blast furnace operation to ensure a regular and sufficient voidage for the passage of the gas flow. This results in better gas solid contact thereby increasing the kinetics of the reduction reaction.

High moisture contents of the charcoal reduces the resistance to abrasion and increases the tendency for the above described trouble because, when steam is suddenly expelled from the charcoal by the effect of the high temperature, the charcoal particles explode into small pieces which are carried by the ascending gases to the blast furnace top causing irregular distribution of the gases and abrupt movements of the stock. Hence, the necessity to use charcoal with a low moisture content, preferably less than 10%. This is, however, often difficult to achieve.

(e) Slag:

In the lower part of the furnace, just over the tuyeres, the pasty mass of slag and iron may be impeded to descend smoothly through the charcoal or coke layer because of the countercurrent effect of the ascending gases. This happens when high production rates and consequently high blast volumes are used. Charcoal blast furnaces operate, for the same iron content in the burden, at much lower specific slag volumes than coke blast furnaces and therefore present less tendency to this trouble than coke blast furnaces. Slag volume for charcoal blast furnaces: 100 - 200 kg/t pig iron; slag volume for coke blast furnaces: 300 kg/t pig iron. The reason for this is that, when smelting with coke some of the sulphur it contains combines with iron to form iron sulphide which must be removed in the hearth by reduction in the presence of a highly basic slag. Coke ash has an acid composition and the necessary correction of the ratio of basic oxides, lime and magnesia to acid oxides, silica and alumina, requires the additon of a great quantity of basic fluxes.

Thus the basicity of coke blast furnace slag must be

$$\frac{CaO}{SiO_2} = 1.05 \text{ to } 1.25$$

On the other hand charcoal is practically free from sulphur and charcoal ash is of basic composition and the quantity is less than half that of coke. So the necessary addition of fluxes is therefore much smaller and the slag volume consequently also lower.

Ratio $\frac{CaO}{SiO_2}$ in charcoal blast furnace slag: 0.70 - 0.9.

(f) Time of burden travel through the blast furnace:

For the same blast furnace volume, the coke blast furnace will have a longer travel time than the charcoal furnace, due to the higher bulk density of coke, which is double that of charcoal.

Burden travel time in coke blast furnaces: .... 6–8 hours depending on intensity of operation.

Burden travel time in charcoal blast furnaces: ... 4–6 hours, depending on intensity of operation.

Due to the short burden travel time in charcoal blast furnaces, they are very sensitive to burden changes, even small ones, principally when they are operated at a high rate of production. Any necessary change in burden must therefore be carefully considered.

Some blast furnace experts have the opinion that the longer time of burden travel in the coke blast furnace and the higher temperature in the stack favour the degree of indirect reduction of the iron oxide in this zone, and that for this reason, for a given blast furnace and the same operating conditions, the coke rate per ton of pig iron must be lower than when operating with charcoal. No comparative figures between the two fuel rates for the same furnace are available in Brazil.

(g) Liquid iron temperature:

Charcoal blast furnace operate at lower hot metal temperatures than coke furnaces.

Average coke hot metal temperature	1400 to 1450°C.
Average charcoal hot metal temperature	1270 to 1350°C.

Charcoal blown hot metal for steelmaking therefore has lower Si - 0.3 to 0.4% - than coke blown hot metal - 0.6 to 0.7%. The reduction of Si is a highly heat absorbing reaction.

(h) Comparison between fuel rates of coke and charcoal per ton of pig iron:

For similar conditions of burden and operation, blast temperatures, injections of liquid or gaseous fuels, percentage of sinter in the burden and for the same grade of pig iron, the charcoal and coke ratios per ton of pig iron are similar.

Under similar conditions there are still many factors to consider, some of which favour the conditions of charcoal and other those of coke.

The principle factors are:

(i) The calorific value per kg of average dry blast furnace coke and charcoal are very similar.

(ii) Coke has a higher fixed carbon content than charcoal.

(iii) The reactivity of charcoal is higher than that of coke which favours the indirect reduction of the iron ore at lower temperatures.

(iv) The high volatile content of charcoal made in Brasilian practice probably contributes to the indirect reduction process of the iron oxides in the lower part of the stack.

(v) The average moisture content of charcoal is higher than that of coke. Moisture elimination is a heat absorbing reaction.

(vi) The higher temperature of the coke blast furnace stack may favour the kinetics of the indirect reduction which consumes less heat than the direct reduction.

(vii) The slag volume of coke fired blast furnaces is higher than that of charcoal fired blast furnaces in order to eliminate the coke sulphur and to bind the acid coke ashes. Higher slag volume requires higher fuel rates.

(viii) Charcoal blown hot metal has a lower temperature and lower Si content than similar grade coke blown hot metal and therefore consumes less heat than coke blown iron.

Notwithstanding the small capacity of charcoal blast furnaces it is interesting to note that the thermal balance of the two principal integrated charcoal based iron and steel plants in Minas Gerais show the very promising figures of 4.6 and 4.9 G.cal/t of crude steel respectively. This excellent result equals, or even surpasses, the corresponding figures of large European and Brasilian coke based iron and steel works.

2. METALLURGICAL ASPECTS OF CHARCOAL BLAST FURNACE OPERATION

Coke and charcoal blast furnaces have the same function which consists in:

(i) Removing the oxygen combined to the iron of the iron ore by a series of chemical reactions between the iron oxides and the reducing gases produced by the combustion of the furnace fuel.

(ii) Melting the materials resulting from the chemical reactions. The metal must be separated from the non-metallic ingredients contained in the iron ore, in the coal ash and in the fluxes, under the formation of a layer of molten slag. So, in a general way, the charcoal blast furnace operates by the same principle as the coke blast furnace.

The unique difference consists in the different chemical and physical qualities of the two fuels. This difference dictates the charcoal blast furnace design and its operation.

Table XVIII Composition of charcoal and of coke

	coke	charcoal (yearly average)
Fixed carbon	85-88 %	70 %
Volatile matter	1-3 %	25 %
Ash	8-10 % (Acid)	3-4 % (Basic)
Sulphur	0.7-1.2 %	-
Phosphor (as P_2O_5)	0.01-0.03 %	0.08 %
Moisture	2-4 %	10 %
Calorific value on a dry basis in Kcal/kg	6,500-7,200	6,800-7,200
Ignition temperature	600-700°C	240-250°C
Bulk density - kg/m3 (dry)	400-500	230-260
Size range mm	50-80	10-50 (average 35)
Crushing strength kg/cm2	100-150	30-40 (measured radially)
Friability or size degradation	No exact comparison is possible due to differences in testing methods. Coke is several times more resistant to size degradation than charcoal.	
Porosity	48-54 %	70-75 %

Composition of ash

	SiO_2	CaO	MgO	Fe_2O_3	Al_2O_3	S	P	Alkalis K_2O	Alkalis Na_2O	$\frac{CaO}{SiO_2}$
Coke %	40-50	2-10	1-2	8-13	30-35	0.6-1.5	0.5-0.6	0.6	0.4	0-25
Charcoal %	15-25	25-35	6-7	3-5	2-4	0.05-0.06	1-3	10-15	1-2	1.3-1.5

Composition of Charcoal Volatile Matter

CO_2 = 9 %, CO = 20 %, H_2 = 64 %, C_nH_m = 7 %

(a) Iron Ores

(i) Types of Ores

Presently most of the Brasilian charcoal blast furnaces use compact hematite high grade iron ores of the "Quadrilatero Ferriferro" district in Minas Gerais.

Composition:	Fe:	63 - 69 %
	SiO_2	0.5 - 2 %
	Al_2O_3	0.7 - 2 %
	P	Normally less than 0.1 %

Consumption of iron ore per t of pig iron: 1500 - 1600 kg.

Some blast furnace plants, usually the smaller ones, use other varieties of hematite called "itabirites", principally: "Chapinha", which means "little plate" because of its regular flat shaped appearance of 6 mm to 18 mm thickness. This iron ore has a lamellar structure, an Fe-content of 62 - 65 %, is low in P and SiO_2. Due to its good porosity and lamellar structure, its regular and low thickness, the "Chapinha" ore represents an excellent burden, requiring only screening. It ary suited to small blast furnaces. Charcoal specific rates are l[illegible].

Another variety is the "Canga" which is a hydrated hematite ore, found near the surface of the ore bodies. Its Fe-content is 55 - 60 %, the P is high, 0.15 - 0.30 %, the alumina 4 to 6 %. This type of ore is, like the preceding, easily reduced in the blast furnace. However, due to its high P content, the "Canga" ore is used in the burden in a restricted amount, usually 30 % max. One serious disadvantage of these porous iron ores is that, during the rainy season, they absorb up to 15 % moisture, causing difficulties in the blast furnace operation. Compact hematite iron ores absorb only a max. of 2 % moisture.

Nowadays they are used for economic reasons, by plants which own mines of one or the other ore types in their vicinity. Mining of these ores is very simple and easy and does not require any drilling and explosives.

Today, with the great care given to the preparation of the blast furnace burden, the more compact and less porous iron ores of the pure hematite types are currently used in most Minas Gerais and Brazilian charcoal blast furnaces. They require less charcoal and give higher blast furnace outputs than the two above mentioned qualities of iron ores.

(ii) Ore sizes

A rule of thumb is that larger sizes of ore are more difficult to smelt than smaller ones. Furnace efficiency therefore dictates an upper limit to size. There is a general trend to use as much as possible the so-called "natural pellets", a size between 6 mm and 18 mm. The ideal is to use 6 mm to 12 mm but this is difficult to obtain in large quantities because of the great losses of iron ore fines caused by the intensive crushing and screening operations.

Typical sizes of iron ore in a blast furnace burden are:

12 mm to 30 mm . . . . 50 % to 60 % of total burden, with trend to decrease

6 mm to 18 mm . . . . 40 % to 50 % with trend to increase.

Larger furnaces, 300 t/day upwards, have a tendency toward using 100 % in sizes between 6 mm to 25 mm with a tolerance of ± 5 % > 25 mm and < 6 mm. The different sizes of ore are separately charged in the bucket. This method is called "layer charging".

It is very important to screen out all the fines under 6 mm. It is best to rescreen the ore before charging it into the blast furnace bucket or skip.

Good results are obtained by washing the ore, while screening it, through a strong waterspray which eliminates adhering dust and gangue. In the rainy season, this dust and gangue is transformed in mud and the washing is still more important than when the ore is dry. Excellent blast furnace productivity results have been obtained by all these measures.

(iii) Transportation of iron ores

All the important iron and steel plants have their own mines situated at distances between 10 and 100 km from the plants and transport most of their iron ore by railway. One plant Mannesmann does some transport by an aerial cableway through a distance of approximately five km. The transportation capacity of this cableway however is small. Mining is usually operated through totally owned subsidiaries. The Monlevade plant of Belgo Mineira has its own electrified railway and brings the ore to the plant at a distance of 10 km. Most other plants use the State owned railway.

The charcoal blast furnace plants situated in the States of Rio de Janeiro and São Paulo have to bring the iron ore at distances of a few hundred km from the State of Minas Gerais.

Most of the smaller and medium charcoal blast furnace plants situated in the State of Minas Gerais do not own mines and have no railway connection and the ore is transported by trucks. Cost of transportation:

By truck for distance of 100 km	US$ 6.0/t
By state railway for distance of 100 km	US$ 1.5/t

Truck and railway costs are lower when the iron and steel companies operate their own transport system.

(iv) Ore Prices

In the Belo Horizonte area commercial prices of hematite iron ores in the above described sizes are at present (1977).

Not washed . . . . FOB Mine: US$ 7/t

Washed . . . . FOB Mine: US$ 8/t

CIF at 100 km from mine, including transport by private truck - US$ 13-14/t.

CIF at 100 km from mine, including railway transport - US$ 8.5/t.

These prices are for washed and unwashed ores and can be lower on long term contracts.

(b) Sinter

Approximately 70 % of the iron ores in Minas Gerais are mined in the form of fines and several of the more important iron and steel plants, which operate their own mines, sinter these fines and form a combined blast furnace burden of "natural iron ore pellets" and sinter. The existing sinter plants for charcoal blast furnaces are discontinuous pan type Creenawalt type units. The first one was started in 1945. Capacity of pans 300 - 500 t/day; productivity 25 - 35 t/m2/24 hrs. A continuous grate sinter machine, Lurgi design, started operation in February 1978.

Besides hematite iron ore fines, other ore types and iron bearing materials like rolling mill scale are successfully used as limited proportions of the sinter mix.

Like iron ores, the different sizes of sinter are separately charged into the blast furnace.

For example - coarse sinter 12 mm to 50 mm
fine sinter 6 mm to 9 mm

The importance of sintering is based on the following reasons:

(i) To make an economic use of the large available quantities of cheap hematite type iron ore fines sized 0.10 mm to six mm. Many mines have dumped these fines during years. Large amounts are available. Commercial price FOB (mine) US$ 5/t.

(ii) To use the charcoal fines or breeze under six mm size, which amount to 22 % of the total charcoal production.

(iii) To increase the blast furnace productivity.

(iv) To lower the charcoal rate per ton of pig iron.

(v) To get a simpler, more regular and stable blast furnace operation through the use of self-fluxing sinter which means that it contains all the necessary additions to a self-fluxing burden like: limestone or lime, granulated blast furnace slag or sand, manganese ore. Presently lime is preferred to limestone because it increases the specific sinter production and produces a sinter which is easily reduced in the blast furnace and gives a good permeability to the burden.

The influence of sinter on iron output and charcoal rate in a charcoal furnace at Monlevade with 210 t/day nominal capacity is shown in figures11 and 12.

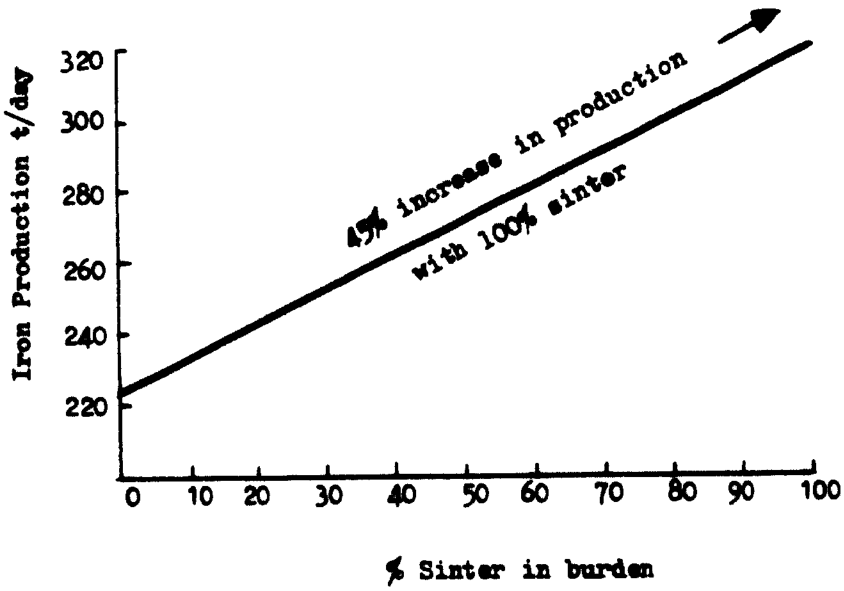


Figure 11. Influence of Sinter on blast furnace production

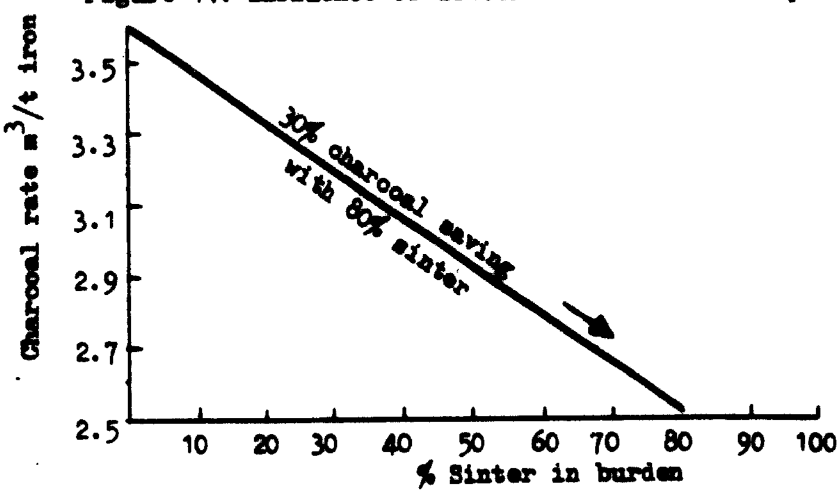


Figure 12. Influence of Sinter on charcoal rate

However, when this comparison is made between a blast furnace burden of "natural pellets" and a burden with sinter, the figures of production increase and charcoal economy are less pronounced.

(c) Limestone

As charcoal is practically sulphur free, charcoal blast furnaces operate with an acid slag with a ratio $\frac{CaO}{SiO_2}$ = 0.7 to 0.9

When the iron bearing burden is composed exclusively of hematite iron ore, the limestone addition is 90 to 110 kg per t of pig iron. When using fluxed sinter with a basicity ratio of 0.9 to one the necessary limestone addition decreases proportionately to the amount of sinter in the burden.

Large deposits of excellent limestone, minimum CaO content 54 %, exist at distances of one to 200 kms from most iron and steel plants.

Limestone is usually purchased from independent quarry owners and operators who do the crushing and screening. A few steel plants own quarries. Usual sizes: 10 to 40 mm.

Limestone prices
FOB, quarry (1977) US$ 3/t.
CIF Iron and steel plant, including 200 km truck transport US$ 9/t.

(d) Silica

Due to the high purity of the iron ores used in Brazil silica addition is required to obtain sufficient slag volume. This acid fluxing addition is usually made in form of sand and river gravel. Used open hearth silica refractory bricks can also be added. SiO_2 content of sand and gravel should be 95 % minimum.

Sizes: 10 to 30 mm.

Silica is frequently encountered in the vicinity to the iron and steel plants in rivers and quarries.

Amount of addition: 60 to 70 kg/t of pig iron when using hematite iron ore burden.

Prices: FOB quarry or river: US$ 2/t. (Practically no transportation costs).

(e) Dolomite

Dolomite, which is calcium-magnesium carbonate, is used alone or in combination with limestone by some blast furnaces, principally the larger ones. Some plants use dolomite limestone because they own quarries of this material in the vicinity of their plants. The proportion of limestone and dolomite used depends on the other constituents of the slag. Dolomite is used in order to make the slag more fluid. It is also used in the form of fines in the sinter mix.

Prices: FOB quarry: US$ 6.50/t.

CIF iron and steelworks including 200 km truck transport US$ 12/t.

(f) Manganese Ore

There exist several small mines of iron-manganese ores with 15-20 % Fe and 30-35 % Mn in the centre of the so-called "iron square" of the State of Minas Gerais, but no large ones. The available quantities are, for the moment, sufficient, but there is some concern that in the long run the manganese ore will have to be transported at great distances from other States:

When using 100 % iron ore as furnace burden 20to 50 kg/t iron of Manganese ore is added, sized 12 to 60 mm, depending on the desired manganese content of the pig iron.

When using self-fluxing sinter, the necessary manganese content is incorporated as fine ore into the sinter: 30 to 40 kg of manganese ore per t of sinter.

Prices: FOB Mine: US$ 23/t

CIF blast furnace plant including rail transport US$ 24.50/t.

3. RECEPTION, STORAGE, HANDLING AND SCREENING OF CHARCOAL AT IRON AND STEEL PLANTS

(a) Reception:

When the charcoal arrives at the iron and steel plant it has to be carefully received and checked at a special reception centre.

This control is very important and the reception centre is manned 24 hours/day.

The objects of the control are: -

(i) To control and check the arrival from various sources
(ii) To measure the received quantities
(iii) To pay for the received quantities
(iv) To sample incoming loads for chemical and physical analysis.
(v) To obtain all possible information on charcoal stocks available for the blast furnaces.

The control at the reception centre must be done with much accuracy and by men with a high sense of responsibility and honesty, otherwise the companies may suffer heavy material and financial losses. The risk of human error and cupidity is always present and charcoal is the most valuable raw material of the iron and steel plants.

At reception, the necessary papers are emitted and a copy of them given to the transporter for purpose of payment. Charcoal quantity is always expressed and paid per volume. Railway cars and trucks are measured, taking length, width and principally height, which is the only varying dimension. Nevertheless, for the purpose of double checking, it is good practice to also weigh the charcoal and scales should therefore be available, which print tickets of every received truck and railway car. Weighing charcoal is also useful for checking its specific weight and so to control its quality and moisture content.

Trucks loaded with bags are unloaded manually into a measuring box or wagon of fixed volume varying between three and five m^3. The box may be tilted onto a conveyor or directly into a bin. When a measuring wagon is used, it has generally a single or double sloped floor and side discharging doors which allow the charcoal to be directly discharged over, or into, the storage space. Coal arriving by aerial cable-way is checked, by measuring the height of charcoal in each carrying box, before tilting into the bin.

When rail cars or trucks are unloaded they should be checked for any sign of smoke or fire. Any load indicating a fire risk must be separated and never discharged into the storage space.

(b) Storage of charcoal:

A large charcoal storage place is of utmost importance in an iron and steel plant.

Charcoal manufacturing is characterised by an absence of fixed location; it is located frequently in remote places spread over a wide area and methods are relatively primitive and dependent on seasonal and human factors. There are also difficulties in transportation.

In these respects charcoal is very different from metallurgical coke which is manufactured in large quantities in a single locality and transported in whole train or ship loads to the consuming iron and steel plant.

The use of a large storage space or depot can substantially neutralise the above objectionable variables which arise in charcoal manufacture.

The storage depot has the following functions:

(i) To centralise all unloading operations
(ii) To protect the charcoal from humidity and rain
(iii) To provide buffer stock so that the blast furnace can work continuously over a long period.

The storage capacity required is directly related to the daily blast furnace output; it will vary from two weeks to two months supply dependent on the regularity of charcoal supply. Storage capacity also depends on whether the charcoal is supplied from natural or man-made forests. Generally the capacity should be 20% of the yearly consumption from native forest and 10% when supplied by artificial forests.

(iv) To neutralise the effects of irregular charcoal supply, prices and transportation, e.g. during prolonged seasonal rains. The greater and more prolonged these difficulties, the greater must be the volume of the storage deposit. At the beginning of a prolonged rainy season, for instance, the storing depot should be completely filled and at the end of it, nearly empty.

(v) To blend different qualities of charcoal for instance batches with moisture contents of 10% and 30% to result in an acceptable average of 15%.

(vi) To check the rate of consumption of charcoal

(vii) To protect it from fire, and other hazards

The storage depot should be some distance from the iron making plant, on its periphery. It should be arranged with plenty of space around it to cater for intensive truck and railway traffic without disturbing normal ironmaking plant operations.

The lay-out is, in general, similar to that of the intermediate storing deposits previously described. It is, of course, much larger, depending on the size of the iron and steel plants and varies from 5,000 to 10,000 m^3 for the small pig iron blast furnace plants, to a max. of 250,000 m^3 for the Belgo Mineira charcoal deposit at its Monlevade plant, which allows storing of two months charcoal consumption by the blast furnace.

Charcoal coming from trucks and rail cars is discharged into the storage depot by travelling belt conveyors or manually from wagons or cars with side discharge. When lump charcoal arrives by truck, it may be unloaded by a tilting device into a bin and then transported to the storage depot. The depot is filled - starting from one end and continuing lengthwise - at a steady pace to reduce the falling height of coal to a minimum and so cause less fines.

Storage height of the coal must not exceed seven m to reduce the risk of self ignition, which increases with the height. This risk is highly increased when the charcoal contains a large amount of fines, more than 10%, which, when unloading, have a tendency to segregate from the larger size charcoal and to concentrate in one spot. In very large storing places, as in Belgo Mineira, all the operations are automatic, as the quantities of charcoal to be handled are very large and sporadic unloading peaks must be taken in consideration, when trucks, railway cars and aerial transport simultaneously arrive at the storage depot.

Due to special local conditions, the Monlevade storing deposit had to be laid out with a storing height of 11 m, which must, however, be considered excessive.

The method used for empying the storage depot depends on it's design. It may be done :

(i) By travelling conveyors running in tunnels under the stored charcoal which is grabbed by special devices and thrown onto the conveyer. This is a highly mechanised operation, very efficient, but causing a high amount of fines and should only be considered for very large installations. It is also very expensive.

(ii) By mechanical bucket loaders on wheels, which load the coal into small cars or onto travelling conveyors.

(iii) Through unloading hoppers with closing traps, hinged or otherwise, In this case the storing place floor must either be elevated or the coal be stored in large bins, steel or concrete.

(iv) Manually, with forks.

A disadvantage of highly mechanised storing depot is the formation of large amounts of charcoal fines, which can amount to 10%, due to the numerous and rough handling of the coal. Small and medium sized storing depots should be made as simple as possible combining some mechanical and manual handling. The production of fines should always be kept to a minimum.

The layout of the storing depot and its operation must take account of the need for fire prevention and fire fighting. The essential measures and recommendations are:

(i) Suitable and separate location of the storing depot to allow unimpeded and fast access and circulation from all sides of all the necessary equipment and vehicles in case of fire.

(ii) Sufficient outside space to separate burning charcoal, in case of fire.

(iii) Choice of the correct uncombustible construction material. A good combination is to have concrete columns and steel roofing girders and galvanised sheet for roofing.

(iv) When the storing place is located in proximity of the blast furnaces, which is frequently the case for the pig iron plants, the roof must be well closed to prevent flying glowing embers from penetrating into the storing depot.

(v) Subdivision of the storing depot, in small compartments, by partition walls, to reduce and limit the losses in case of fire. The individual compartments should have a volume of not more than 2,000m^3 for small depots and not more than 5,000m^3 for large ones. Each compartment must allow independent access from the outside.

A good measure is to have the storing floor elevated in such a manner as to empty the compartment, in case of fire, through floor chutes or traps which unload directly into trucks or hand pushed carts driven under the floor.

(vi) Special care must be taken in the layout of the electrical wiring which must be constructed of special material. Wherever possible, the wiring should be laid outside the building.

(vii) Sufficient water pipes for fire extinguishing must be arranged so that every part of the storage depot can be reached. The correct choice of water pumps as regards capacity and pressure is essential and all electric motors for pumping etc. should have Diesel motors for standby in case of electrical failure - A water reservoir of adequate height and volume must be included.

For a storage depot of 30,000 m^3 a water volume of 350 m^3/hour is recommended at a pressure of seven kg. Each 5,000 m^3 compartment should have two connections of 150 mm diameter. Roof mounted sprinklers are also recommended. 90 sprinklers each 10 mm diameter for each 5,000 m^3 compartment.

All details should be fixed by an expert in fire fighting.

(viii) Efficient supervision and labor working in and around the storing depot. Training aginst fire hazards and in fire prevention is essential. At one plant it used to be the practice to introduce long steel rods into the heaps of stored coal, at regular intervals, and, by feeling the temperature by hand it was possible to judge whether a fire hazard existed or not. A fire starts frequently very deep inside the coal heap.

(ix) Prohibition of smoking in and close to the storing depot. Prohibition of equipment which may cause fire, e.g. welding equipment.

(x) Unloading of all charcoal trucks and railway cars outside the storing depot.

(xi) Limiting access to storage depot to authorised persons only.

(c) Screening of Charcoal:

Charcoal must be screened before charging it into the blast furnace. This is best done in a separate screening house located between the storing place and the blast furnace charcoal bins.

Screening has two functions:

(i) To eliminate the fines under eight or 10 mm; small blast furnaces may use the size from eight mm up, larger furnaces from 10 mm up. (Sometimes 12 mm to 14 mm, depending on the moisture.)

(ii) To separate the charcoal in two or preferably three sizes.

Unlike metallurgical coke, which has substantially uniform size, charcoal size is irregular and to give the blast furnace a good and uniform permeability, it must be separated in several size fractions which are separately charged into the blast furnace.

Example:

	Three sizes	Two sizes
Coarse:	+40 mm	+30 mm
Medium:	20 to 40 mm	10 to 30 mm
Fine:	8 or 10 to 20 mm	

When separating in two size fractions, the coarse one is predominant over the fine one at the ratio 3 : 2 or 2 : 1.

Screens: Double deck screens make the size separation in one simultaneous operation. These screens give good results, but are expensive.

When single screens are used, the screening operations, two or three, are made one after the other. Single screens are simple and cheap.

Some plants rescreen the charcoal fines rejected in the first screening and recover the sizes between six mm and eight mm, which are then charged separately into the blast furnaces. When charcoal is wet, more than 20% moisture, screening presents difficulties because of the obstruction of the wire mesh. A larger opening must then be used, e.g. 12 mm or 15 mm. Charcoal screens have square or rectangular openings.

(d) Storing Charcoal at the Blast Furnaces

The different sizes of charcoal are separately stored in concrete or steel bins with hinged, manually or motor-operated traps, or vibrating feeders for discharge. The charcoal storing volume required at the blast furnaces depends of the hourly charcoal consumption, the distance between the furnaces and the plant storing depot, the regularity and dependability of transportation between these two points.

A minimum of eight hours blast furnace charcoal consumption is essential. Three days consumption is a good average for large blast furnace plants.

From the bins, the charcoal may be loaded into travelling conveyors or into manually or motor-operated wheel cars which will carry the coal to the blast furnace bucket or skip. It may also be directly loaded from the bins into the blast furnace bucket which are carried to the bins. The first method is preferred.

A few blast furnaces use travelling belt conveyors up to the furnace top (Ferro Brasileiro) and have good results.

4. CHARCOAL QUALITY FOR BLAST FURNACE USE

(a) Analysis and Testing Procedures

Characteristics of charcoal as charged into Blast Furnaces in Minas Gerais - Brasil.

Table XIX

Chemical and Physical composition of charcoal Dry basis - by weight	Range Max.	Range Min.	Yearly Average	Charcoal considered good to excellent
Carbon	80%	60%	70%	75 - 80%
Ash	10%	3%	5%	3 - 4%
Volatile matter	26%	15%	25%	20 - 25%
Bulk Density - as received (kgs/m³)	330	200	260	250 - 300
Bulk Density - dry -	270	180	235	230 - 270
Average Size (mm) -as received-	60	10	35	20 - 50
Fines Content - as received (-6.35mm)	22%	10%	15%	10% max.
Moisture Content -as received-	25%	5%	10%	10% max.
Friability %				
a. Shatter test: coarse + 31.75 mm			20%	15% max.
a. Shatter test: medium - 31.75 mm to fine + 6.35 mm			6%	4% max.
b. Tumbler test: coarse + 31.75 mm			No average yearly figures available	60% max.
b. Tumbler test: medium - 31.75 mm to fine + 6.35 mm				40% max.

The ranges and yearly averages refer to charcoal used by Belgo Mineira. This is a mixture: 40% eucalyptus charcoal produced in company operated kilns and 60% heterogenous natural wood charcoal manufactured by privately operated kilns. "Good to excellent" charcoal refers to that produced from eucalyptus wood in company kilns.

Composition of Ash. Average for the State of Minas Gerais is:

SiO_2 = 15-25%; CaO = 25-35%; MgO = 6-7%; Al_2O_3 2-4%

Fe_2O_3 = 3-5%, Mn = 0.5% P (as P_2O_3) = 1-3%

Na_2O = 1-2%; K_2O = 10-15% S = 0.05 % - 0.06 %

The high proportions of alkalis is typical of charcoal ash.

Composition of volatile matter.

Measured in volume at high temperature

CO_2 = 9%, CO = 20%; H_2 = 64.0% C_nH_m = 7%

The high proportions of hydrogen and CO are typical.

To account for the wide range of charcoal qualities supplied to the steel plants it must be remembered that most of the charcoal produced in Brazil is manufactured by small, independent producers. Their production is very primitive using heterogenous woods in remote places where supervision is practically impossible.

On the other hand charcoal produced from eucalyptus wood in company operated kilns has a uniform and good composition with good chemical and physical proportions.

This type of charcoal is being manufactured in ever increasing proportion.

To control the quality of charcoal received from suppliers samples are taken from every truck and rail car. This is called "testing at reception" or testing the coal as received.

To control blast furnace operation and pig iron quality tests are made on samples taken from the charcoal charged into the furnace.

The following tests are made daily for the received coal and separately on each size fraction, coarse medium and fine charged to the blast furnace.

(i) moisture content

(ii) bulk density

(iii) average size of sample and fines content - 6.35 mm.

Manual sieving is done on square mesh sieves of 101.6 mm, 76.2 mm, 50.8 mm, 31.75 mm, 25.40 mm, 15.87 mm, 12.70 mm, 9.52 mm and 6.35 mm

After sieving the average size is calculated.

For example: For testing coarse charcoal - normally + 31.75 mm

Table XX Measurement of average charcoal size

Size Range - mm -	Av. size (1) mm	% (2)	(1) x (2)
+ 101.6	-	0.0	0.0
-101.6 + 76.2	88.9	4.2	373.38
-76.2 + 50.8	63.5	10.6	673.10
-50.8 + 31.75	41.27	38.4	1584.77
-31.75+ 25.4	28.57	25.2	719.69
-25.4 + 15.87	20.63	15.4	317.70
-15.87 +12.70	14.28	4.2	59.99
-12.70 + 9.52	11.11	1.0	11.11
- 9.52 + 6.35	7.94	0.8	6.35
- 6.35 + 0.00	3.18	0.2	0.64
		100.0	3746.75

Average size $\frac{3746.75}{100}$ = 37.46 mm

(b) The Strength of Charcoal:

Strong charcoal is of utmost importance to resist the effects of numerous handling operations in its transit from the kilns to the blast furnace. The losses, through the formation of fines, between the kilns and the blast furnace charging bucket may be 10-25% in volume. Generally, the more mechanised installations will produce more fines but the degradation of charcoal tends to stabilise itself. This can be seen in the tumbler tests when the charcoal is subjected to many hours of rolling and tumbling.

For this reason coarse graded charcoal is weaker than finer charcoal which has suffered from the effects of much handling.

For this reason the friability tests, shatter and tumbler, are made separately on coarse (+ 31.75 mm) charcoal and medium to fine (-31.75 + 6.35 mm) charcoal.

The friability tests are a means of measuring the liability of the charcoal to break into smaller pieces, when subjected to repeated handling, and so indicate the relative extent to which sized coals will decrease in size during transport and descent inside the blast furnace.

The figures in % indicate the reduction in size which the original charcoal size will have suffered during the test.

Therefore, the lower the % figure the better the charcoal. No Brazilian or International standards exist for charcoal tests and the tests used have been derived from coal and coke testing methods. They can, therefore, only be considered as practical means of estimating the physical qualities of the charcoal.

The tumbler test is considered the most important of the two friability tests. It is derived from the recommendations R-556 of the MICUM Indices of coke of the International Organization for Standarization (ISO).

10 kg of charcoal are placed in a steel test drum 1,000 mm long, 1,000 mm diameter fitted with four steel angles, fixed lengthwise inside the drum. The drum is rotated at 24 r.p.m. for one hour (total 1,400 rev.).

Charcoal is first tested at the works reception. The coal is hand sieved and only material larger than 31.75 mm is tumbler tested to avoid the fine sizes protecting the coarser pieces by their cushion effect against shocks and abrasion.

Previous to the tumbler test the new average size of the charcoal must be calculated (-as in table XX). After the tumbler test the resulting average size is again calculated.

The friability is expressed as %: -

$$100\left(1 - \frac{\text{Av. size after test}}{\text{Av. Size before test}}\right)$$

Charcoal, as charged to the blast furnace, is also tumbler tested. The three charge size fractions, coarse, medium and fine are tested separately.

Table XXI Charcoal Tumbler Testing

For example. Testing of screened coarse charge size fraction.

Size range before testing:

Size range mm	av. size (1) mm	% (2)	(1) x (2)
- 101.6 + 76.20	88.9	7.9	702.31
- 76.2 + 50.80	63.5	20.0	1270.00
- 50.8 + 31.75	41.27	72.1	2975.56
		100.0	4947.87

average size = 49.47 mm

Size range after testing:

mm	av. Size mm(1)	% (2)	(1) x (2)
- 101.6 + 76.20	88.9	0.0	-
- 76.2 + 50.80	63.5	15.4	977.90
- 50.80 + 31.75	41.27	32.2	1328.89
- 31.75 + 25.40	28.57	26.1	745.68
- 25.40 + 15.87	20.63	11.6	239.31
- 15.87 + 12.70	14.28	4.8	68.54
- 12.70 + 9.52	11.11	4.5	49.99
- 9.52 + 6.35	7.94	3.2	25.41
- 6.35 + 0.00	3.18	2.2	7.00
		100.0	3442.72

average size = 34.43

Friability % = $100 \left(1 - \frac{34.47}{49.47} \right) = 30.41$

The drop shatter test is the second friability test. This test is derived from the ASTM D-440-49 for coal and the apparatus is described in ASTM D-440-49. Test material is prepared as for tumbler test and 10 kg are dropped four times from a height of 1.83 m. The resulting average coal size is calculated after sieving and compared with size before testing as for tumbler testing.

Chemical analysis is always expressed on a dry basis.

Ash content is the remainder, after combustion at 700°C in a muffle furnace, of one gram of charcoal. Volatile matter represent the gases expelled from the charcoal when heated at 950°C for five minutes. Fixed carbon is 100 - (% ash + % volatile matter).

Crushing strength is less important for operational purposes than friability figures since the crushing strength figures do not express as well the ability of the charcoal to resist abrasion and breakage.

The crushing strength of charcoal varies greatly with the wood quality and how the carbonisation of the wood has been conducted. Wood which has been carbonized too fast will result in charcoal with many cracks and low crushing strength. The crushing strength is different when measured parallel or perpendicular (radial) to the original wood structure. The parallel strength is much greater than the radial strength. The radial strength of charcoal from heterogenous Brazilian woods varies between 25 and 50 kg/cm^2 and eucalyptus charcoal averages 30 kg/cm^2.

For comparison minimum crushing strength of blast furnace coke is more than 100 kg/cm^2. For all these reasons, the crushing strength of charcoal is not tested in the laboratory.

External aspect of charcoal is important and an experienced charcoal expert can make an accurate judgement of the quality of charcoal, both chemical and physical, from the following external observations:

A good charcoal must have brilliant black colour, be hard, have no smell and give a clear metallic sound when two pieces are knocked together.

(c) Laboratory equipment and personnel.

For undertaking the above analysis and testing a properly equipped laboratory is essential. Equipment must include, hand sieves, 50 and 100 kg balances, ball mill, stoves, muffle furnace, electric combustion furnace, gas burners, gas heated hot plates, platinum crucibles, pyrometers (up to 1,200°C), precision balances, laboratory glass ware and chemical reagents for wet analysis.

Personnel should include two chemists (technicians) for physical and chemical laboratory and one helper for preparing material.

<u>Investment costs.</u>	Building	US$
	70 m^2 for physical tests 35 m^2 for chemical tests	15,000
	Apparatus	35,000
		50,000

<u>Operational costs.</u>		US$
	Personnel costs	1,000/month
	Materials and overheads	1,000/month
	Total	US$ 2,000/month

5. OPERATIONAL TECHNIQUES FOR CHARCOAL BLAST FURNACES

(a) Blowing in

The process of starting a furnace is called "blowing in". It is carried out in four steps.

(i) Drying and heating the stoves
(ii) Drying the furnace
(iii) Filling the furnace
(iv) Blowing in the furnace.

Drying

Newly constructed or relined furnaces and stoves are carefully and slowly dried before they are put into service. The reason is to avoid as much as possible extreme thermal shock to the lining and to drive off the vast amount of water absorbed by the brick during construction and contained in the mortar used in brick laying.

For drying two methods are available depending on whether blast furnace gas from another furnace (or another combustible, gas) is available during the blowing in period.

When gas is available this can be used during the whole drying and heating cycle of the stoves and also for the initial light up of the blast furnace.

When gas is not available the stoves must be dried and heated by inserting wood and charcoal into the bottom of the stove combustion chamber. In this case stove heating can be completed by blast furnace gas as soon as this becomes available from the newly lit blast furnace.

(i) Drying and heating the stoves

Example given for 150 t/day blast furnace with three stoves, Sabará plant.

1. Start one day before preliminary drying the blast furnace.

2. Start drying with gas, or firewood and charcoal, in the bottom of the combustion chamber until the temperature in the dome reaches 200°C. Maintain this temperature during 24 hours. Stack slide valve stays open.

3. Increase dome temperature 100°C every eight hours until it has reached 700°C.

4. Isolate the stove and maintain dome temperature at 700°C by adding charcoal or gas, until the furnace is lit.

5. Total drying and preheating time: three days minimum.

(ii) Drying the blast furnace.

a. Preliminary drying.

i. Keep blast furnace bells open.
ii. Leave slag notch open, without the cast iron uncooled holder.
iii. Block all tuyeres with clay.
iv. Keep the hearth splash cooling system closed.
v. Open the cooling system of the tuyeres and the tuyere cooler castings.
vi. Shovel burning charcoal onto the hearth floor through the slag notch opening.
vii. Cover this coal layer with charcoal and firewood and start drying.
viii. Blast furnace throat temperature not to exceed 300°C.
ix. After 48 hours heating stop adding firewood and open tuyeres and tuyere elbow covers.
x. Let hearth cool and clean it out.
xi. Total time for preliminary drying: 56 hours.

b. Final drying.

i. Close blast furnace bells.

ii. Close tuyere elbows and remove any material which may clog the tuyeres.

iii. When the stove dome has reached 700°C, give a hot blast at 400°C temperature during two hours.

iv. After two hours, interrupt the hot blast and open furnace bells.

v. Increase dome temperature to 1,000°C

vi. Total cycle: about four hours minimum.

(iii) Filling the furnace.

Example given for a 150 t/day blast furnace, Sabará Plant.

a. After drying the furnace insert a two inch pipe through the iron notch into the furnace. It should stick out 0.50 m and reach the hearth center.

b. Fix the pipe to the iron notch with clay.

c. Charge into the furnace, through the slag notch or tuyere opening, coarse charcoal until the slag notch level has been reached.

A furnace of three m hearth diameter requires six m^3 of charcoal.

d. Insert the slag notch holder and the slag notch.

e. Close the slag notch or tuyere.

f. Start filling the blast furnace according to the following burden for a 150 t/day blast furnace. (See Table XXII).

g. Use separate buckets for charcoal and for iron ore and fluxes.

h. The total filling of a blast furnace having 92 m3 working volume requires 40 charges. Total time 4½ hours.

i. After 20 charges light the furnace by blast furnace gas through a tuyere, or if no gas is available, by inserting a red hot steel bar through the iron notch and blowing compressed air through the notch.

j. After the furnace has been completely filled - i.e. the stockline recorder indicates "0" - start the blower and blow at 0.5 m water gauge pressure.

k. When blast furnace gas becomes available the stove can be lit. When stove dome temperature reaches 1,000°C hot blast can be fed to the furnace.

l. Open the hearth cooling system.

m. Increase blast pressure at a rate of 0.5 m W.G. per 2 hours until final desired pressure had been reached.

Example: For final blast pressure of 3.6 m W.G. 14 hours are required.

n. Stove changes may be done at the following temperatures:
Max. temperature of dome: 1,000° C Blast temperature 600°
Min. temperature of dome: 900° C Blast temperature 500°

o. When, within approximately 3½ hours, the first molten iron appears at the taphole, it must be plugged.

p. After the completely filled furnace has received 20 more charges within approximately 5½ hours, the first tapping will be done. Take samples of iron and of slag.

q. During the first five days of blowing-in foundry pig iron with two percent silicon is produced.

r. After this initial period burdening is gradually adjusted to obtain the desired routine pig iron composition.

Table XXII Blast Furnace Burden Charges

Number of Charges	Coarse charcoal (+38 mm) m3	Hematite Iron Ore kg	Quartz kg	Manganese Ore kg	Limestone kg
10	2.2	-	-	-	-
5	2.2	250	20	5	35
5	2.2	400	20	5	40
5	2.2	500	20	5	40
5	2.2	600	15	5	30
10	2.2	700	10	5	30
Following	2.2	900	10	5	40
Charges	id	id	id	id	id

(b) Routine Operation.

Example: Two - 150 t/day blast furnaces at Sabará Belgo Mineira producing molten hot metal for O.H. furnaces

The furnaces operate continuously without shut down on three eight hour shifts.

Sequence of charges:

Iron ore and fluxes are weighed on a central scale with 2,500 kg capacity.

Charcoal is measured by volume.

Blast furnace I.: Two buckets of 2.2 m^3 volume. Each bucket carries one complete charge - "combination charging" - consisting of: Iron Ore + Fluxes + Charcoal.

Example:	Charcoal:	2 cubic m.
	Iron ore:	1,050 kg
	Limestone:	52 kg
	Quartz:	23 kg
	Manganese ore:	10 kg

Sequence of charcoal sizes: Two buckets coarse charcoal + 38 mm
Two buckets medium charcoal 20-38 mm
One bucket fine charcoal 10-20 mm

Blast furnace II.: Uses separate charging of charcoal and iron ore fluxes.

Sequence of charges:

One bucket iron ore and fluxes

One bucket charcoal

Charcoal:	1.8 cubic m.
Iron ore:	1,138 kg
Limestone:	52 kg
Quartz:	23 kg
Manganese ore:	10 kg

Sequence of charcoal sizes: The same as for blast furnace I.

Tapping: Every 2 3/4 to 3 hours up to 20 tons of hot metal tapped from each furnace.

Opening iron notch. Drilling with pneumatic drill and finally burning with oxygen lance.

Closing iron notch. By pneumatic clay gun - one per furnace.

Routine work between tappings.

Cleaning up metal and slag and repair of main runner
cooling cast iron pigs, removing pigs
Preparation of casting beds for next cast.

Casting hot metal in sand casting beds

When tap hole is open the hot metal runs down the main trough. A skimmer separates any slag and diverts it to the slag ladle. The iron runs to the casting beds, or into ladles for transport to the steel plant.

At Sabará the pigs are 850 - 1000 kg each, which are hoisted by crane. Formerly 15 - 20 kg pigs were cast, manually broken and handled.

The molds are made of special sand with 3 % bentonite as binder. Runners and molds must be carefully dried with B.F. gas.

When casting in sand hot metal temperature must be 1300° C, lower temperatures result in skull formation. Consumption of runner and mold sand, when casting 50 % of hot metal into molds, 50 kg/t.

Sampling the Iron.

At every tapping a sample of iron and of slag is taken. The iron is cast into a small steel mold and broken. (See figure 13 according to Brasilian Standard MB 573.) Care must be taken to obtain a sample which

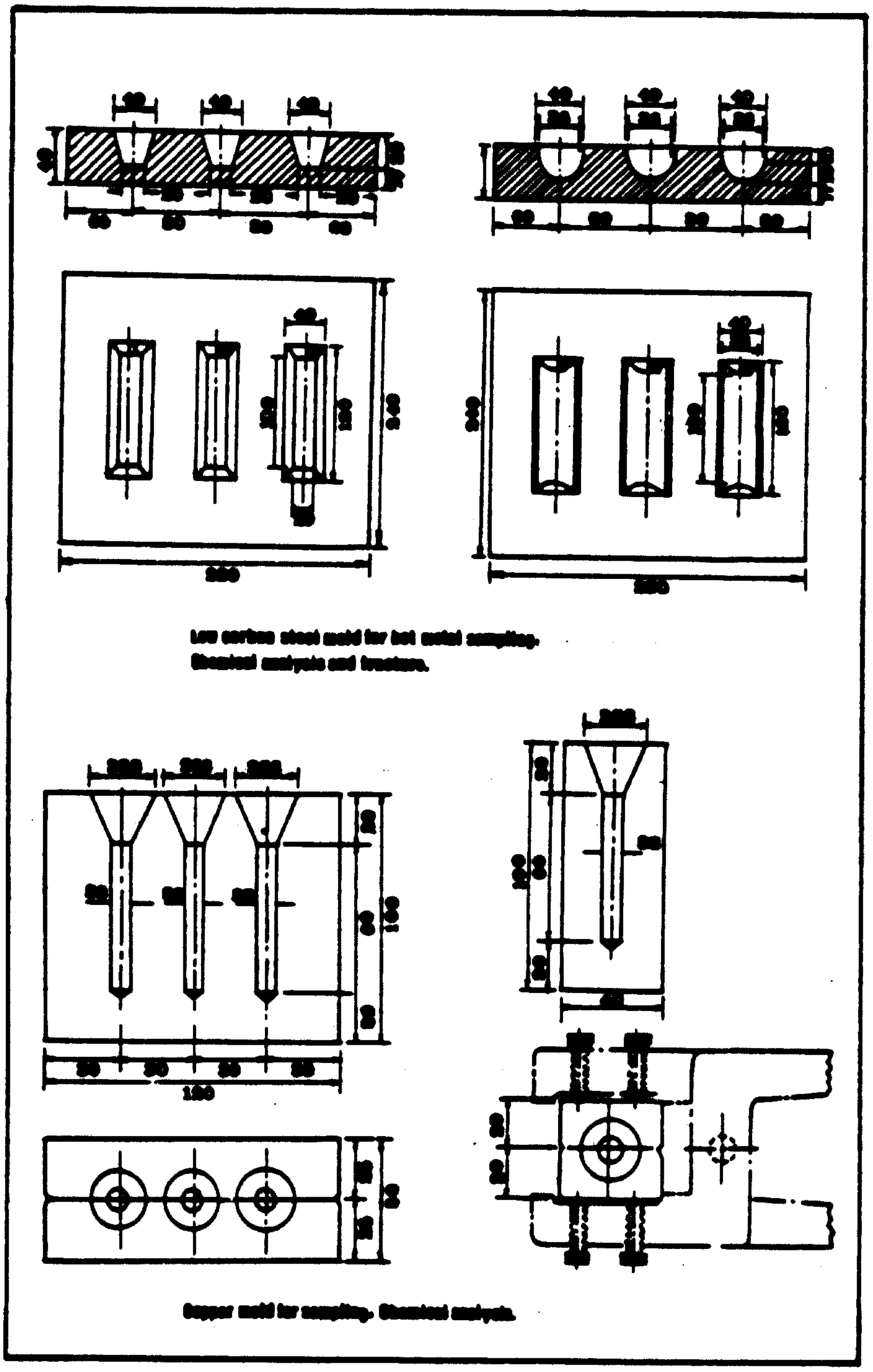


Figure 13 Brasilian Standard Molds for pig iron sampling.

is representative of the whole cast. By visual observation of the grain of the broken chilled surface and the slag colour an experienced blast furnace melter is able to make an accurate estimation of the hot metal temperature and silicon content. A sample of iron and slag of each tapping is sent to the chemical laboratory. The following elements of the iron are analysed: C, Si, Mn, P, S. It is sometimes unnecessary to analyse the slag at every tapping and once or twice a day will be sufficient.

The Monlevade plant of Belgo Mineira, Mannesmann and the Acesita plant use a vacuum spectrometer for chemical analyses. The sample is taken in a copper mold represented on fig. 13 according to Brasilian standards. At Monlevade the sample is sent to the laboratory through a pneumatic tube transportation system and the result sent back to the blast furnace by telex. Total time: five minutes against one hour for chemical analyses and transportation system.

Approximate cost of a Quantovac vacuum spectrometer US$ 100,000.

According to the Brasilian Association of Technical Standards (EB 84) the following standards have been established for charcoal pig iron.

Table XXIII

<u>A. Pig iron for steelmaking</u>: basic (B) and acid (A) process

<table>
<tr><th rowspan="3">Type</th><th rowspan="3">Silicon %</th><th colspan="3">Manganese %</th><th colspan="2">Phosphorus %</th><th colspan="2">Sulphur %</th></tr>
<tr><th colspan="3">Class Mn</th><th colspan="2">Class P</th><th colspan="2">Class S</th></tr>
<tr><th>I</th><th>II</th><th>III</th><th>I</th><th>II</th><th>I</th><th>II</th></tr>
<tr><td>GAB 1</td><td>0.50 max.</td><td rowspan="3">0.40 max.</td><td rowspan="3">0.41 to 0.80</td><td rowspan="3">0.81 to 1.20</td><td rowspan="3">0.07 1</td><td rowspan="3">0.071 to 0.100</td><td rowspan="3">0.010 max.</td><td rowspan="3">0.011 to 0.020</td></tr>
<tr><td>GAB 2</td><td>0.51 to 0.80</td></tr>
<tr><td>GAB 3</td><td>0.81 to 1.20</td></tr>
<tr><td>GAA</td><td>1.25 to 1.70</td><td colspan="3">0.40 to 0.80</td><td colspan="2">0.100 max.</td><td colspan="2">0.020 max.</td></tr>
</table>

Table XXIV

B. Pig iron for foundry iron.

Type	Silicon	Manganese %					Phosphorus %					Sulphur %
		Class Mn					Class P					Class S
		I	II	III	IV	V	I	II	III	IV	V	I
GFF 1	1,00 max											
GFF 2	1,01 to 1,50											
GFF 3	1,51 to 2,00	0,25 max.	0,26 to 0,40	0,41 to 0,60	0,61 to 1,00	1,01 min.	0,10 max	0,11 to 0,15	0,16 to 0,30	0,31 to 0,50	0,51 min.	0.025 max.
GFF 4	2,01 to 2,50											
GFF 5	2,51 to 3,00											
GFF 6	3,01 min.											

Slag and Blast Furnace Gas Analysis etc.

In charcoal blast furnace practice slag quantity is normally about 130 - 150 kg/t pig iron with a basicity ratio $\frac{CaO}{SiO_2}$ = 0.7 to 0.9.

A typical slag analysis (no dolomite in the burden) is:

CaO = 30 - 35 %; SiO_2 = 35 - 45 %; Al_2O_3 = 10 - 18 %;
MgO = 2.5 - 3.5 %; MnO = 1 - 3 %; FeO = 1 - 2 %.

A typical blast furnace gas composition is:

CO_2 = 14 - 18 %; CO = 24 - 27 %; CH_4 = 2 - 4 %.
H_2 (without oil injection) 4 - 6 %; with oil injection 10 %.

Calorific value 900 - 1,100 koal/nm^3. With high sinter burdens this decreases to 850 - 900 kcal/nm^3 due to lower charcoal rate.

Top gas temperature 100 - 200°C
Top gas pressure 200 - 300 mm w.g.

Stove operation

Many existing small to medium blast furnace plants operate with two stoves per furnace.

To increase the blast temperature and to have a better temperature regularity over the blast cycle, the general trend is towards three stoves per furnace and several plants are therefore adding a third stove to each furnace. This much reduces blast temperature fluctuations.

The newer charcoal blast furnaces all have three stoves. Another arrangement which is sometimes found is to have five stoves for two blast furnaces.

Most present stoves have manually operated valves which are sometimes being mechanized by electric motors and the entire operation time is thus reduced to a few minutes against 10 to 15 minutes for the manual changing. This practice results in higher hot blast temperatures.

The stove heating is controlled through the dome temperature which is measured by a pyrometer and recorded on an indicator. The newer type stoves are usually heated until the dome reaches 1,200°C. This temperature must not be exceeded. The resulting blast temperature will then be 900°C.

The stove temperature depends also on the quality and condition of the refractory checkerwork.

In recent years existing hot blast stoves have frequently been modified and improved with the aim of increasing the blast temperatures. This trend continues and the new large charcoal blast furnaces will operate at blast temperatures of 900 to 1,050°C against the present maximum of 850°C.

(c) Furnace operation with injection of oil or charcoal through tuyeres

With the development of higher hot blast temperatures it is possible to inject hydrocarbon fuels or pulverized charcoal fines into the blast furnace tuyeres to control the flame temperature and at the same time replace some of the charcoal.

The oil used at the Belgo Mineira Monlevade plant is of Brazilian origin and at normal temperature has a low fluidity and must be heated to 110°C to obtain sufficient fluidity. After steam heating at the boiler house the oil arrives at the blast furnaces at 90 - 100°C with a pressure of 11 kg/cm^2 in steam heated insulated piping.

At the blast furnaces it is filtered and distributed to each tuyere.

The oil is injected into each furnace through lances which penetrate into the tuyeres.

Oil consumption 40 - 45 kg/ton hot metal
Oil specification: CV = 10,200 kcal/kg
specific gravity = 0.9
composition C = 85 %; H_2= 10.4 %; S = 1.0 % (max.)
Replacement ratio: One kg oil replaces 1.6 kg charcoal

One kg oil costs US$ 0.06. One kg charcoal costs US$ 0.06. Thus one kg oil (US$ 0.06) replaces US$ 0.10 charcoal and the operation is economic even at to days oil prices. However, the most important effect is the decrease in charcoal rate.

Acesita plans to inject pulverised charcoal fines in its new 1,000 t/day blast furnace. This technique has been used for a number of years in Australia. See Section 4.1. (b).

(d) Oxygen enrichment of the blast.

When the blast air is enriched with oxygen, the flame temperature increases and more oil must be added to control the flame temperature at approx. 2000°C. For every percent of enrichment, a production rate increase of 2 - 3 % is obtained. The higher the blast temperature the smaller the gain in output.

At the Belgo Mineira blast furnaces the oxygen content of the blast is increased 4 %.

The Monlevade plant has an exceptionally favourable condition as its oxygen plant has an excess capacity and therefore the oxygen used in the enrichment of the blast has a very low cost. The resulting productivity gain of the blast furnaces is therefore obtained at a small extra cost.

(e) High pressure operation

In Section 3.1.(d) "Kinetics of gaseous flow in the blast furnace" it has been shown that one of the limiting factors in the blast furnaces operating at high wind pressures is the lifting effect that is caused by the large volume of gases blowing upward through the burden.

Many coke blast furnaces have been equipped for years with special valves in the top-gas system to increase the exit gas pressure which permits a larger amount of air to be blown. With this increase in the quantity of air blown per minute there is a corresponding increase in production rate.

Charcoal is much more sensitive than coke to the lifting effect caused by large volumes of blast and higher top pressure will therefore have a more important effect on charcoal than on coke blast furnaces.

The following results are to be expected:

Possibility of operating the furnaces at higher intensities than at present without suffering the present frequent irregularities when working at high intensities.

Increase in production rate.
Reduction in charcoal rate.

Obviously the blast furnace must be specially constructed to withstand increased blast and top gas pressures.

No Brazilian charcoal blast furnace has ever been operated on high top pressure.

6. **TABLE XXV** **OPERATIONAL DATA OF BRAZILIAN CHARCOAL BLAST FURNACES.**

Characteristics of blast furnaces:	Specific Production (tons/24 hr /m3 working volume)	Charcoal rate (cubic m/t)	Equivalent rate of fixed carbon (kg/t)	Power consumpt. (kWh/t)	Water consumpt. (cubic m/t)	Blast temperature °C	Blast pressure (meters of water gauge)
"A" Small to medium blast furnace plants. 80 to 200 t/day/furnace	Hematite iron ore: 1600 kg/t, good burden preparation, metallic recuperators, dry gas cleaning						
Hot metal for steel making (low Si)	0.8 - 1	3.5 - 3.6	600/630 kg	50kWh	5 - 10 recirculation	450/500	3.5 - 5 meters
Foundry pig iron Si: 1.6-2.2 %	0.7 - 0.9	4.2 - 4.5	690/740 kg			500/550	
"B" Medium sized blast furnace plants 150-200 t/day/furnace	Burden: Hematite iron ore: 1600 kg/t (for foundry pig iron partial sinter burden) Good burden preparation, 2 stoves, wet gas cleaning						
Hot metal for steel making (Low Si)	1.2 - 1.5	2.7 - 3.2	470/550 kg	60-70 kWh	15 - 25 no recirculation	600/700	4 - 6 meter
3 stoves: Foundry pig iron (1.6 - 1.8 Si)	0.8 - 1.0	3.4 - 3.7	590/640			700/800	
"C" Large blast furnace plants 400 - 800 t/day/furnace	Burden: Hematite iron ore (50 %) and selffluxing sinter (50 %), very good burden preparation, oxygen enrichment of blast: 23 + 25 %, injection of oil: 40 kg/t						
Hot metal for steel making (low Si)	1.8 - 2.2	2.5 - 2.6	430/450 (oil 34 kg)	80 kWh	50 - 60	800/900	6 - 7 meters

Observation: 1 cubic meter charcoal = 173 kg of fixed carbon
1 kg fuel oil = 0.85 kg fixed carbon

7. SUPERVISION AND MANNING REQUIREMENTS FOR BLAST FURNACES

The existing Brasilian charcoal blast furnace plants are very varied in the following respects:

(a) Furnace size and output.

(b) Degree of mechanisation and modernisation of equipment and operation.

(c) Manufacturing programme - whether hot metal for steelmaking, pig iron for sale or foundry use, hot metal for pipe casting or a combination of these programmes.

(d) The ability of the management.

In consequence the numbers and quality of supervisory staff and labour force varies from company to company and from plant to plant. To estimate manning requirements correctly different ranges of plant size are considered separately.

(i) Small to medium plants 50,000 to 150,000 t/yr - of current design and operation producing pig iron for foundries.

(ii) Large plants 400,000 - 600,000 t/yr producing exclusively hot metal for steelmaking.

It may be concluded that the large and modern plants with a high labour productivity require personnel which must be technically well educated, specialised and trained and therefore well remunerated.

Small blast furnace plants of simple design and operation can use less skilled personnel.

High technical development of personnel is achieved gradually in the course of years.

Table: Supervision and Labour for Plants "A" Operating on Three - Eight Hour Shifts Producing Pig Iron in Casting Machines

XXVI

Section	Function	Number of Blast Furnaces and Yrly Prod.		
		1 x 150 t/d 50,000	2 x 150 t/d 100,000	3 x 150 t/d 150,000
Plant Supervision	Superintendant.	1	1	1
	Prod. Manager	1	1	1
Charcoal Discharging, Storing and Screening	Operators	4	4	4
	Crew (or labour)	14	21	28
	Total	18	25	32
Charging and Operating the Blast Furnaces	Foremen	4	4	4
	Scale operators	4	7	12
	Hoist drivers	8	15	24
	Furnace operators	14	21	42
	Assist. operators	14	28	42
	Stove minders	4	4	8
	Total	48	79	132
Blower house and mechanical and electrical maintenance	Foremen	3	3	3
	Blower drivers	3	3	3
	Repair men	7	17	27
	Total	13	23	33
Repair of refractory linings	Foremen	1	1	1
	Masons	5	10	15
	Total	6	11	16
Laboratory	Supervision	1	1	1
	Chemists	2	4	6
	Total	3	5	7
Handling raw materials in plant transport, pig iron shipping	Supervision	1	1	1
	Crew (labour)	14	28	42
	Total	15	29	43
Office administration, costs, salaries, shipping, daily production, etc.	Office head	1	1	1
	Clerks	6	12	22
	Total	7	13	23
	PLANT TOTAL	110	185	296

Productivity - t/man/year = 500 tons

Productivity - man hours/t = 4.8 man hours

Figures to be increased 10 % for vacations, sickness and accidents.

The work force can be reduced approximately 10% if the plant makes hot metal for steelmaking.

Table: XXVII Supervision and Labour for Plants "B" Operating on Three - Eight Hour Shifts Producing Hot Metal for Their Own Melting Shops

Section	Function	Number of Blast Furnaces and Yearly Production: 3 x 400 t/d 400,000	4 x 500 t/d 600,000 to 700,000
Plant Supervision	Superintendant	1	1
	Prod. Manager	1	1
Charcoal discharging, storing and screening (all operations mechaniz.)	Supervision	1	1
	Foremen	3	3
	Operators	46	61
	Assist. operators	14	18
	Total	64	83
Charging and operating the blast furnaces (semi-automatic)	Superintendant	1	1
	Supervision	7	7
	Scale and hoist ops.	12	18
	Furnace operators	32	42
	Assist. operators	32	44
	Stove minders (3 st. per furnace)	8	12
	Total	92	124
Blower house, boilers, fuel injection mechanical and electrical repairs.	Superintendant	1	1
	Supervision	7	7
	Oil injection	4	4
	Blower driver	7	7
	Boiler operators	4	4
	Maintenance crew	35	55
	Total	58	78
Repair of refractory linings	Supervision	1	1
	Foremen	4	4
	Masons	15	20
	Total	20	25
Metallurgical and chemical laboratory	Chief metallurgist	1	1
	Metallurgists	6	6
	Chemists	6	6
	Assistants	3	3
	Total	16	16
Handling raw materials, hot metal and in plant transport	Supervision	1	1
	Assist. supervision	1	1
	Operators	12	16
	Total	14	18
Office administ. costs, salaries, shipping and transport, daily production	Head of office	1	1
	Clerks	5	5
	Total	6	6
	PLANT TOTAL	270	351

Productivity:	t/man/year	1,300 t	1,600 t
Productivity:	man hours/t	1.8	1.55

Figures to be increased 10 % for vacations, sickness and accidents.

8. CHARCOAL BLAST FURNACE PLANT DESIGN

(a) Blast furnace lines

As a consequence of the physical characteristics of charcoal, the height of charcoal furnaces is kept low compared with coke blast furnaces.

Figure 14 shows design changes of the principal Brasilian charcoal blast furnaces during the last 40 years. It can be seen that the working heights have been maintained practically constant and are now between 12 and 15 m, with exception of the Acesita furnace built in 1949 which had 16 m working height. This furnace had originally been designed to use charcoal and/or coke. Todays lines are the result of a gradual evolution process which has been going on for many years derived from furnace campaign experience and a continuous endeavour for improvement.

The hearth diameters have constantly increased from approx. 2.50 m to 6 m for the latest for the Belgo Mineira furnace and 6.50 m for the Acesita blast furnace now under construction.

Angles of lines:
Bosh angle: 80 to 84°
Stack angle: 84 to 86°

The lines of the three largest Belgo Mineira blast furnaces with a hearth diameter of 4,554 mm resulted from changes made in 1956 at three smaller existing blast furnaces. (See Fig. 14) These furnaces have a 90° bosh angle and no separate bosh and belt lines, following the Swedish design of a similar blast furnace. This special design was the result of a compromise between the desire to increase the furnace volume and output and the impossibility to increase the height of the furnace due to existing local hoist conditions. Although these furnaces work satisfactorily at high outputs and intensity of operation, their unique bosh and belt design has not been adopted in the new Belgo Mineira furnace of six m hearth diameter.

Figure 14
Lines of Typical Brazilian Charcoal Blast Furnaces Period 1935 - 1977

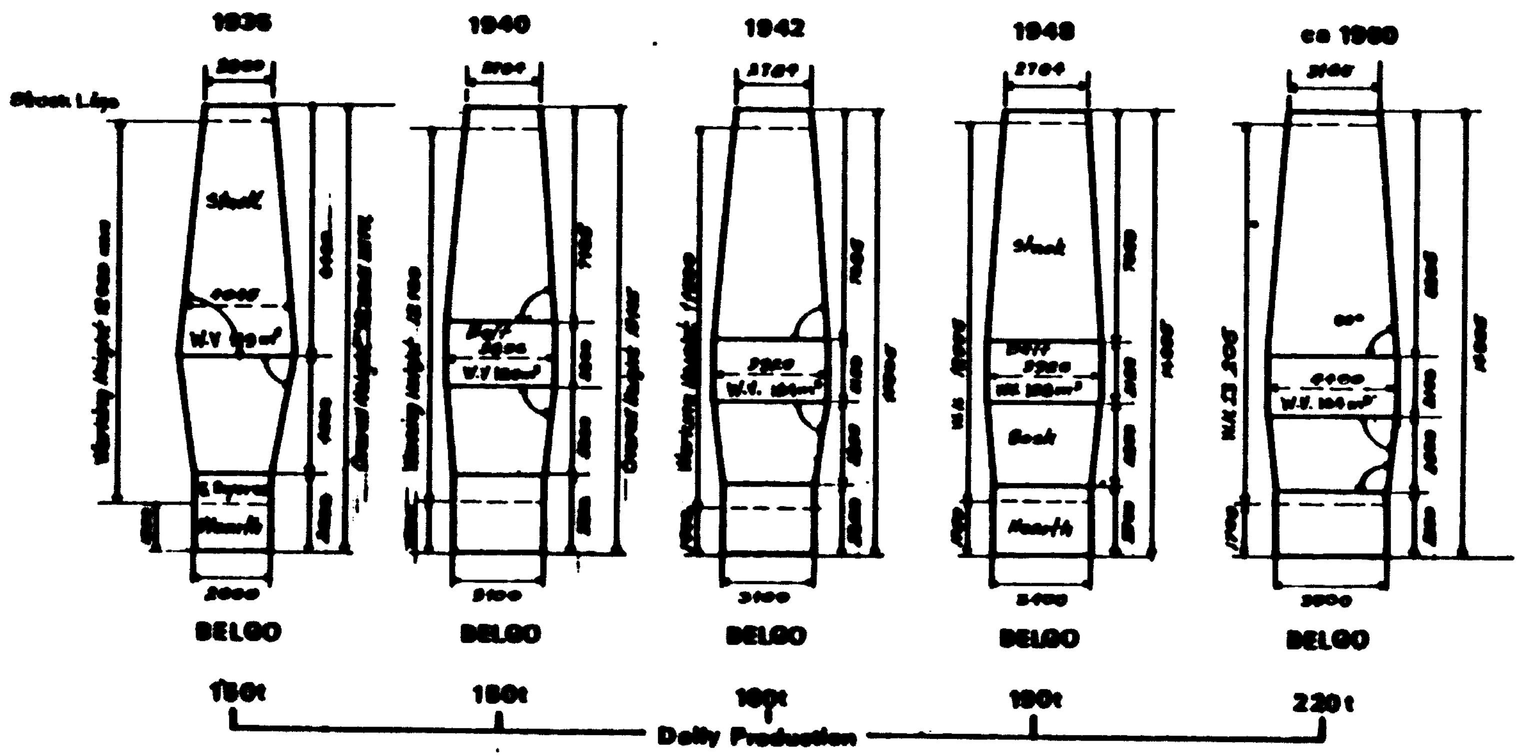
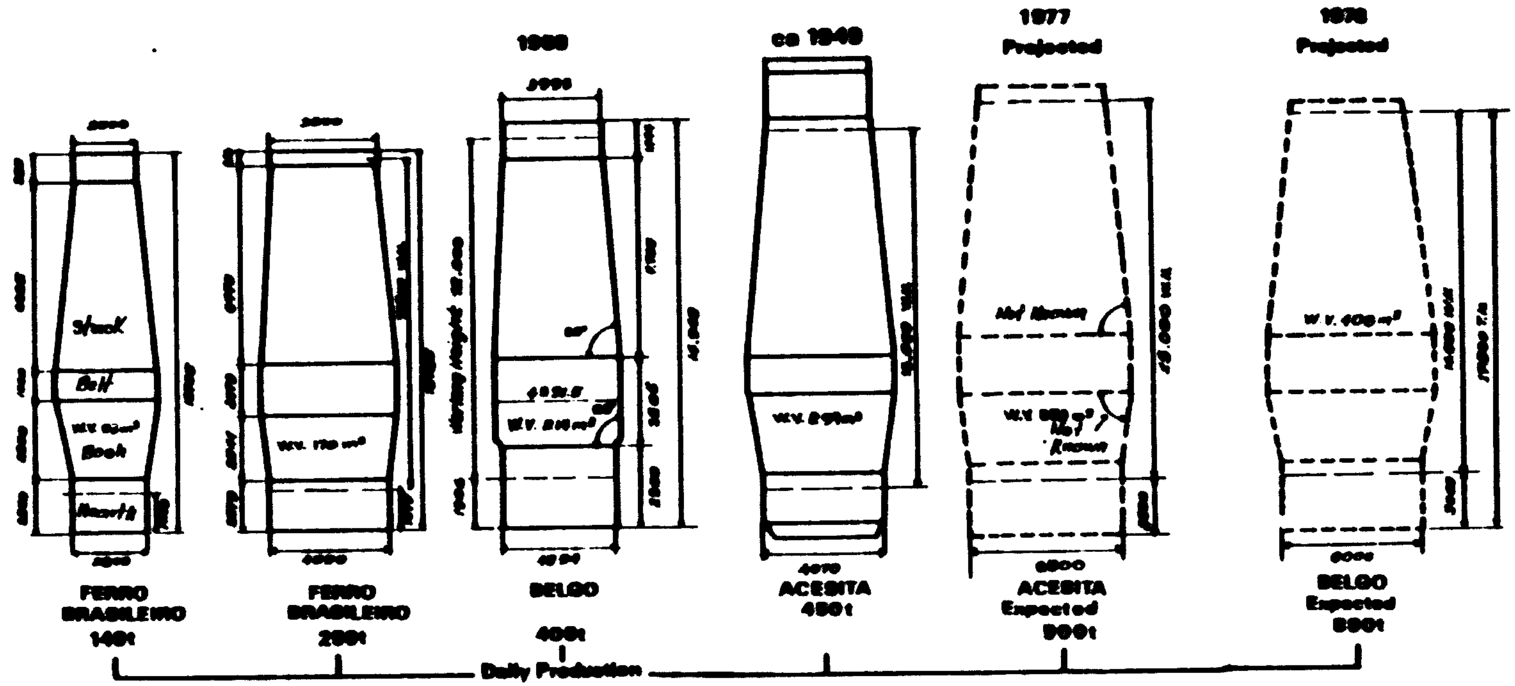


Figure 14 (continued)



(b) Tuyeres

Tuyeres are made of copper casting. Many plants cast their own tuyeres.

The welded tuyeres made of copper sheet and a forged copper nose are not used in Brazilian charcoal furnace practice.

Number and tuyere diameters: and nozzle diameters: generally used are:

Small furnaces, hearth diameter	2.50m - 3m	: 4 to 6 tuyeres,	90 mm diam.	
Medium furnaces, hearth diameter	3.50m - 4m	: 8 tuyeres,	90 mm - 110 diam.	
Large furnaces, hearth diameter	4.50m - 5m	:12 "	id	id
New furnaces, hearth diameter	6m	16 "	not disclosed	

The trend in recent years has been toward increasing the number of tuyeres to obtain a more regular blast distribution over the whole furnace cross section and the results have been good.

A good measure consists in inclining the tuyere nozzle 10° toward the hearth bottom.

(c) Blast furnace top

A good top construction must serve the following functions:

(i) Provide perfectly uniform distribution of the stock entering the furnace stock

(ii) Prevent the escape of large quantities of gas

(iii) Reduce to a minumum the amount of dust and coarse particles carried out with the gas

(iv) Offer a tight seal against gas leaks

The following types of tops are used on Brazilian charcoal blast furnaces.

a. Single bell tops. Mostly to be found on smaller furnaces, but there are exceptions. The Monlevade furnaces have single bell tops because, after the transformation of former smaller furnaces in the present large blast furnaces, it was not possible, due to local conditions, to increase the height in order to add a second bell. The principal disadvantage of the single bell design is the escape of blast furnace gas at each bell charging. The charge buckets, however, have covers.

b. Double bell top. Mostly used on medium to large blast furnaces. Satisfactory distribution of burden. Tight closing of top. Very little gas escape.

c. Belless top. One of the projected large charcoal blast furnaces will be built with this top system of Paul Wurth design which permits continuous charging of the blast furnace through a rotating and falling angle adjustable chute which guarantees an excellent distribution of the burden and permits high top pressure with very little gas leakage.

(d) Charging devices:

(i) Manual and semi-manual bucket charging over horizontal charging bridge is still used on a few of the smallest blast furnaces. These are built along a slope and the coal and ore stock houses are located at blast furnace top level.

(ii) Inclined bucket hoist is very popular - see figure 15

(iii) Vertical bucket hoist at Monlevade blast furnaces.

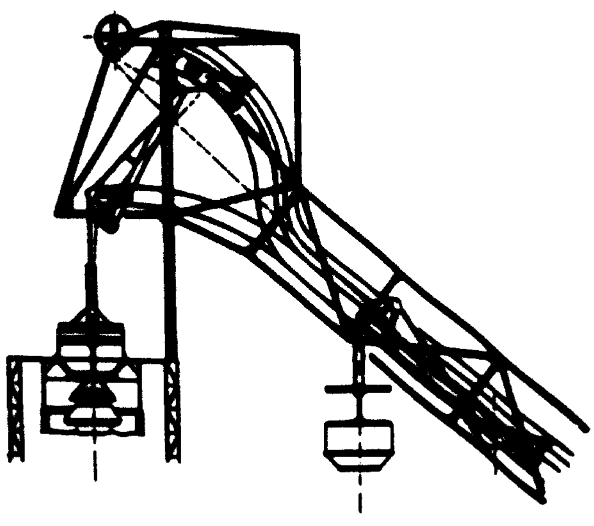


Fig. 15 Inclined bucket hoist. Staehler-Demag Design.

With bucket hoists, both inclined and vertical, the bucket is suspended from a carriage and drops the charge smoothly into the space above the blast furnace bell, or bells, through a bottom opening provided with a small bell. The bucket is placed on a revolving cone while it is being filled with charge. The practice gives a radially uniform charge distribution in the bucket and, consequently, into the furnace stack.

Inclined hoists are preferable to vertical ones as they allow shorter sequence of charging; one movement against two,but they require more space for the charging bridge.

(iv) Inclined skip hoist. The two largest Brazilian charcoal blast furnaces, at Acesita and Mannesmann, use skip hoists which are open ended charging steel cars which tip the charge into the hopper above the bell. These furnaces had originally been designed to use coke or charcoal (Acesita) or only coke (Mannesmann) and their charging mechanism had been adopted from coke blast furnace design. The open ended skip, through its tilting action, is more harmful to charcoal size degradation than the smooth and gradual action of the bottom dropping bucket.

The great advantage of the skip charging is its speed and it is therefore being considered for large charcoal blast furnaces, notwithstanding the harmful effect on charcoal size degradation.

(v) Conveyor belts. Some of the newer 200 t/day Brazilian charcoal blast furnaces use this type of charging in combination with a rotating stock distribution hopper which gives good burden distribution inside the furnace. Belt conveyors are continuous and fast but sufficient space must be allowed to develop the inclined path of the conveyor to the blast furnace top.

(e) <u>Blast Furnace Structure</u>:

Brazilian charcoal blast furnaces follow one of three designs; the classic American design, the classic European design or variations of these two.

(i) The American design, as exampled by Acesita 4.70 m hearth diameter furnace, has no separate outside steel structure.

Several steel columns, covered with caps, support the furnace mantle on which rests the load of the blast furnace stack from the bosh upwards, inclusive the furnace shell, the lining, the top appliances and the charging bridge, the vertical gas uptake pipes, the steel platforms at the different furnace levels, with their stairs.

Blast furnace hearth and bosh are independent from this structure and their lining can be removed without disturbing the inwall brickwork. Advantage of this design: simplicity and savings of steel work. Disadvantages: the supporting steel columns are located between the tuyeres, very close to the blast furnace, so that operation and maintenance work is somewhat hindered.

(ii) The European design, as exampled by two Belgo-Mineira furnaces at Sabara, uses a self-supporting structure erected around the furnace. This structure is independent from the furnace shell and its foundations and is supported by four columns made of steel structure. The structure carries the platforms and stairs at the different levels, the furnace top appliances, the charging bridge, inclined or horizontal, and the gas uptake pipes. The blast furnace stack rests on a steel mantle suspended by consoles attached to the four mentioned columns.

As in the American design hearth and bosh of the furnace are independent from this structure and their lining can be removed without disturbing the inwall brickwork.

Advantages are that the four steel structure columns are located at a good distance from the hearth and tuyere areas and permit easy access for operation and maintenance.

Disadvantage is the heavy and expensive steel structure around the furnace.

(iii) Variation to the American design, as exampled by 200 t/day Cimetal furnaces, has no supporting columns for the mantle. The furnace shell supports the top gear, the inclined hoisting bridge, the uptake gas pipes, the platforms and their stairs.

The circular refractory lined pipe for the hot blast, called the "bustle pipe" is supported by several independent steel consoles fixed to steel columns encircling the hearth jacket plate. Advantage over the American classic design is the absence of columns.

(iv) Variation to the European design, as exampled by Belgo-Mineira Monlevade furnaces of 400 t/day, maintains the use of independent steel structure. The blast furnace shell is in one piece and the whole furnace is self-supporting and no mantle is needed to support the stack. Advantage over the classic European design is more simplicity.

(f) Blast furnace shell:

The shell of charcoal blast furnaces is an all welded self-supporting structure made of butt welded plates to present continuous, smooth, outside and inside surfaces.

Thickness of plates of stack shell:

Small furnaces:	12 mm
Medium furnaces:	12 mm to 16 mm
Large furnaces:	19 mm (Monlevade).

The shell encircling the hearth, called hearth jacketplate, must withstand the busting forces from inside the furnace and must therefore be made of thicker plate, particularly in the columnless or totally self-supporting furnaces.

Examples of plate thickness in hearth jacket:

Furnaces with supporting columns:	19 mm
Large self-supporting furnaces, Belgo Minsira, Monlevade (design 4)	32 mm

Thickness of tuyere jacket in large furnaces: Monlevade 38 mm.

The hearth jacket may be welded to the stack shell or may be independent from it, following one or the other of the designs 1, 2, 3 or 4 of the steel structure.

(g) Blast furnace lining:

The Brasilian charcoal blast furnaces use exclusively high duty firebricks which are manufactured in the country. Carbon bricks are not used as they are not yet manufactured in Brasil.

Table XXVIII

Specifications of firebricks

Characteristics	For hearth and bosh. Super duty. High Al_2O_3	For stack in wall Low Al_2O_3
Al_2O_3	> 40%	> 35%
SiO_2	53%	52%
Fe_2O_3	< 1.6%	< 2.0%
Alkalis	< 1%	< 1%
Refractorness under load	1550°C	1420°C
Cold crushing strength	700 kgs/cm^2	500 kg/cm^2
Apparent density	2.3 g/cm^3	2.24 g/cm^3
Apparent porosity	12.5%	15%
Permanent dimensional change after re-burning at 1600°C	0.3%	- 0.4%

For hearth and bosh the bricks must resist high temperature and the action of fluxes; in the stack in wall the bricks must resist abrasion at comparatively low temperatures. They must also resist impact and abrasion of the charges as they are dropped into the furnace. In this area some Brazilian furnaces have used special cast iron rings with high surface hardness to protect the refractory lining.

For simplification and standardisation some plants prefer to use super duty high alumina bricks for the whole furnace lining. The price difference between the two qualities is small.

Firebricks are inspected carefully before being put in place in the furnace and all inequalities of the bricks are eliminated by machine grinding them. Some plants prefer to grind all the bricks independently of the individual variations. The bricks are laid in a thin slurry of refractory mortar which compensates for irregularities. A minimum of slurry must be used and all excess slurry must be squeezed out.

Thickness of slurry joint	1 mm	
Composition of refractory slurry	Al_2O_3	70%
	SiO_2	24%
	Fe_2O_3	< 2.5%
	Alkalis	< 1%

Between blast furnace shell and the refractory lining a fireclay refractory concrete is sometimes cast but it is preferrable to use thin refractory bricks or broken pieces of bricks. This avoids the presence of large amounts of moisture. An excellent practice consists in preassembling at a separate place the bricks for the complete bottom and hearth lining. This operation permits the bricks to be selected and to do the necessary grinding with much care and without hurry. All the bricks are marked before disassembling them. This practice has proved very useful resulting in a savings of erection time, an excellent quality of the executed work and consequently a longer lining life. The training, preparation and organisation of the blast furnace lining labour force is very important for the good and fast execution of the refractory work.

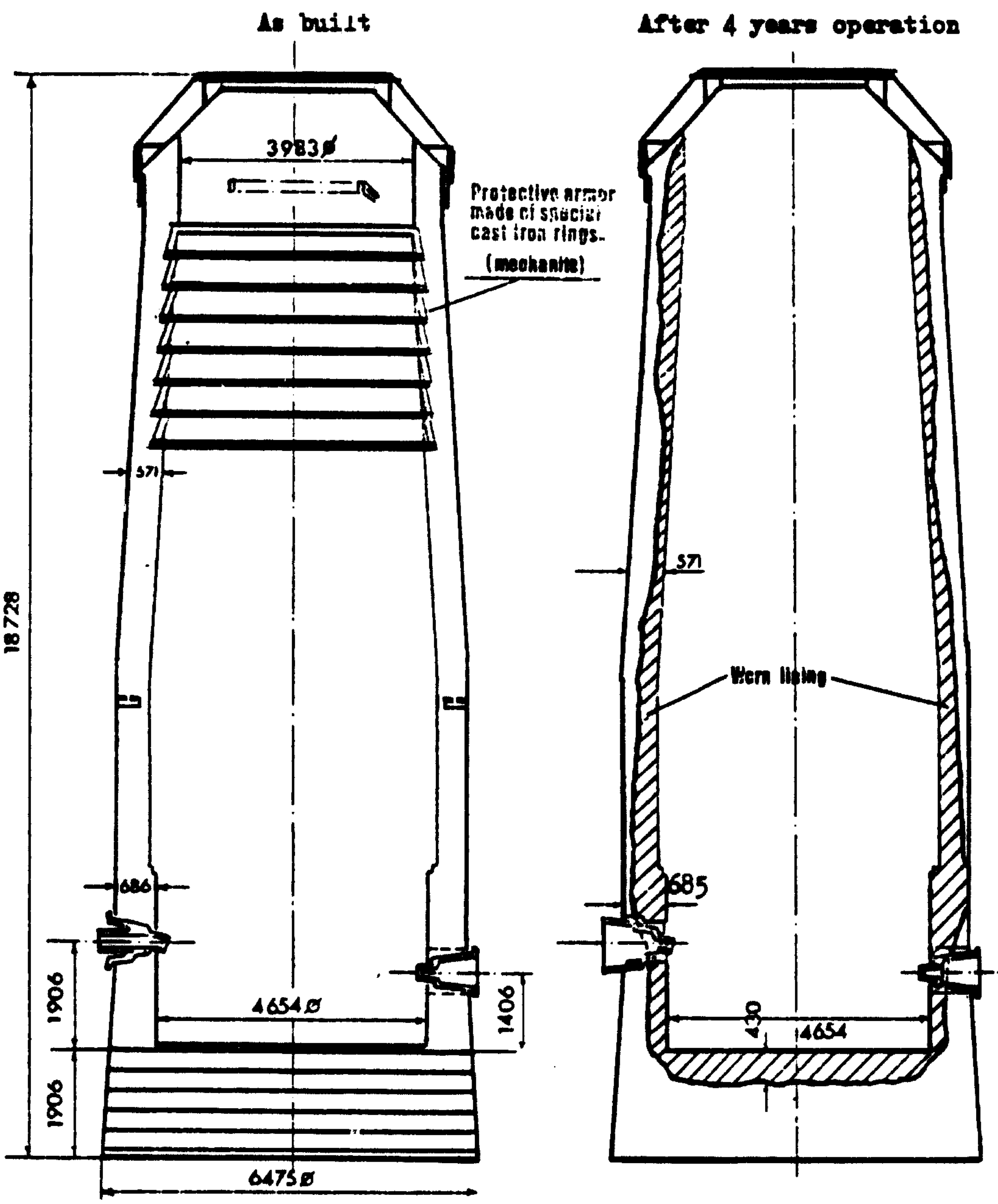
By careful preparation of the relining it was possible to reduce bricking time of a large Brazilian blast furnace from 40 days to 10 days.

Lining life:

Figure 16 below shows the refractory lining of a 400 t/day blast furnace at Belgo Mineira, Monlevade, as built and after four years of operation.

Figure 16

Blast Furnace Lining Wear.



Charcoal ash has a very high alkali content - 10 to 15% (soda and potash). It is a well known fact that alkalis, even in small quantities, flux the furnace lining and therefore have a pronounced harmful effect on the refractory properties. It is for this reason that the manufacturers' specifications as to maximum alkalis content in high duty firebricks are very strict.

In the middle and lower parts of the stack the reaction between the SiO_2 of the firebricks and the alkalis of the charcoal leads to an eutectoid composition with a low melting point. As a result of the softening of the lining, the blast furnace burden tends to adhere to the encircling wall impeding the smooth descent of the stock and damaging the lining.

The alkalis also partly volatilise, escaping with the gases and condensing to form troublesome scaffolds on the furnace lining. These two effects, combined, are responsible for the short refractory life of charcoal blast furnace linings in the middle stack area.

The life of the blast furnace lining, called campaign life, depends in a large measure upon:

(i) The cooling conditions of the furnace.
Experience has shown that intensively cooled charcoal blast furnaces have a longer life of lining than furnaces with a less intensive cooling system.

(ii) The regularity of the furnace operation.
A "chilled" hearth must be avoided which means that due to operational trouble, the furnace becomes steadily colder.

(iii) The quality of the bricks and the care with which the lining has been executed.

Campaign life of blast furnaces producing hot metal for steel making varies between three to six years depending on size, cooling system and conditions of operation.

The cost of lining is an important item in direct iron making costs as shown under the following table:

Table XXIX Cost of Blast Furnace Linings

Daily capacity of blast furnace	150 Tons	400 Tons
Type of iron produced	Low - Si	Low - Si
Hearth diameter	2.80 m	4.60 m
Working height	12 m.	14 m
Total weight of lining	250 tons	470 tons
Cost of lining (1977)	US $ 50,000	US $90,000
Cost per kg.	US $ 0.20	US $ 0. 20
Life of lining	3 years	3.5 years
Production of pig iron during lining life	150,000 t.	450,000 t.
Consumption of refractory/t pig iron	1.6 kg	1 kg.
Cost of refractory/t pig iron	US $ 0.32	US $ 0.20.

(h) Cooling water:

Charcoal blast furnaces require less cooling water than coke blast furnaces because they are smaller and operate at lower temperatures.

In most cases furnace cooling is done by spray cooling of the shell in the lower stack, bosh areas and around the hearth. A trough is fixed to the blast furnace shell encircling the bosh and constantly supplied with streams of water. The trough ensures a close contact between the cooling water and the outside shell of the bosh and provides a visible means of determining that water is circulating through the cooling system. Usually no inwall cooling boxes are used, but there are existing at least two exceptions. These two large furnaces had originally been designed for coke and/or charcoal. The practical results of the inwall cooling boxes on these two furnaces are reported to be satisfactorily and their refractory linings last longer than on furnaces without cooling boxes.

When comparing specific water consumptions of charcoal blast furnaces, a difference must be observed between the following several types of furnaces.

(i) Those using metallic recuperators with a dry gas cleaning system. Metallic recuperators have no water cooled valves and the dry gas cleaning does not require water.
Specific water consumption: 5 to 10 cubic m/t of pig iron (with recirculation)
Hourly water consumption for a 200 t/day blast furnace:

$$\frac{200}{24} \times 5 \text{ to } 10 = 40 \text{ to } 80 \text{ m}^3/\text{hr}.$$

(ii) Medium sized, 150 to 200 t/day blast furnaces, using two stoves, wet gas cleaning, spray cooling and operating at a moderate intensity of production:

Specific water consumption 15 to 25 m^3/t of pig iron

Hourly water consumption for a 2oo t/day furnace:

$$\frac{200}{24}x(15-25) = 125 \text{ to } 200 \text{ m}^3/\text{hr}.$$

(iii) Blast furnaces using three stoves, wet gas cleaning with disintegrators and operating at high intensity of production. Spray and inwall cooling boxes or only spray cooling.

Specific water consumption 50 to 60 m^3/t of pig iron.

Hourly water consumption of a 400 t/day furnace:

$$\frac{400}{24} x(50 \text{ to } 60) = 800 \text{ to } 1000 \text{ m}^3/\text{hour}.$$

(USA coke blast furnaces require 100 m^3/t of pig iron).

It is apparent from these figures that the larger and more elaborate the furnaces are, the greater the necessary water quantities. Recirculation practice, combined with cooling of the water, must therefore be considered for medium to large modern blast furnace plants to reduce the great water consumption and consequently the cost of cooling.

Water recirculation, combined with cooling, can reduce the indicated figures by 80%, the necessary fresh water make-up being 20% of the figures. This practice is especially important in cases of water scarcity and when the water requires some kind of treatment, for example filtering in order to remove suspended matter, or hardness reduction (softening) to remove a certain portion of calcium and magnesium carbonate.

Good water quality, chemical and physical, has a direct influence on the life span of all internally water cooled blast furnace appliances such as: tuyeres and their holders, inwall cooling boxes, slag notches, stove valves. These cooling members are very expensive.

Water pressure: 2 to 2.5 atmospheres = 20 to 25 meters water column.

Sources of supply: wells, brooks and rivers.

Water from deep ground wells is generally free from suspended matter. In calcareous regions it is always hard and must be softened through a chemical treatment. This is the case for the region of Sete Lagoas, Itauna, Divinopolis, North West from Belo Horizonte, where many small and medium sized blast furnace plants are situated.

Water from brooks and rivers is always soiled during the rainy season by suspended matter which must be removed by settling followed by filtering.

Large steel or concrete water reservoirs must be provided. Wherever possible they should be located at a sufficient height that, in case of an accidental failure of the electrical pumps, the blast furnace cooling system can be supplied by gravity during a certain time, for instance one hour, allowing the blast furnace operator to take the necessary measures for the protection of the internally blast furnace cooling plates. Diesel or gasoline powered stand-by pumps may also be used for the same purpose.

(i) <u>Hot blast</u>

The blast is preheated by metallic recuperators or hot blast stoves.

(i) Metallic recuperators.

Two types of metallic recuperators are commonly used: Glendons and Liessens.

<u>Glendons</u>:

These recuperators consist of a serpentine, normally made in cast iron sections, called "bottles", surrounded by a refractory chamber in which blast furnace gas is burned, thus heating the air which moves through the serpentine. The temperature in the combustion chamber must not exceed 900°C which is the maximum temperature to which the cast iron serpentines may be exposed without suffering damage. The resulting maximum blast temperature is 600°C.

The equipment works continuously avoiding the periodic reversals and the expensive water cooled hot air valves necessary in stoves.

The gas used in the Glendon recuperators is submitted to a primary dry cleaning through the effect of expansion in a simple dust catcher. The cast iron pipes become very dirty as a result of gas dust deposit and must be cleaned at six-monthly intervals. This takes four to six days. The loss of blast pressure is greater than in stoves and requires more work from the blowers. The loss of pressure of well dimensioned Glendon heaters is only 10 %.

The thermal efficiency of the metallic heaters is low, 30%, against 80% for the stoves.

The principal advantage of these blast furnace heaters consists in the low investment cost and for that reason they are generally used in small and middle sized charcoal blast furnace plants producing pig iron.

Example: 150 t/day blast furnace.

Cost of 4 Glendon recuperators with 96 "bottles" each	US $250,000
Cost of 2 stoves	US $750,000
Cost of 3 stoves	US $1,000,000

The higher cost for the more elaborate gas cleaning system must also be considered.

Liessens

These are metallic recuperators of a more advanced design. One company, Ferro Brasileiro, used these blast heaters during many years but has changed them for stoves, in order to increase the blast temperature.

(ii) Hot blast stoves (usually called Cowpers)

Normally three stoves are used for each blast furnace. Another arrangement consists in having five stoves for two blast furnaces. The normal operational cycle is for two stoves to be heated up and one stove to be on blast. Stoves preheat the blast at higher temperatures than the before mentioned metallic recuperators, the result of the higher temperature being:

a. A reduction of charcoal rate.

According to Stahl und Eisen 83 (1963), the fuel savings will be between 5% and 3% for every increase of 100°C of blast temperature between 500°C and 1,000°C. The higher the blast temperature, the less pronounced the fuel savings.

b. Increase of blast furnace output.

According to same source: A 7 to 5% increase of output for every 100°C increase in blast temperature between 500°C and 1,000°C. The higher the temperature the less pronounced the increase of the output.

c. Possibility of injecting additional solid, liquid or gaseous fuels into the furnace which will reduce still more the charcoal rate. For these advantageous reasons all medium to large Brasilian charcoal iron and steel plants have adopted stoves for the preheating of the blast. These stoves are all of the side combustion chamber type.

Due to the high investment costs of stoves, and also because some years ago it was a general opinion that charcoal blast furnaces should not operate at high blast temperatures, most plants started blast furnace operation with two stoves and later added a third one. The present trend is toward high blast temperatures. A detailed description of the construction and operation of these furnace auxiliaries in the present paper is unnecessary as charcoal and coke blast furnaces stoves have the same characteristics. The specialized technical literature contains all necessary information on this subject.

Usual blast temperatures in Brasilian charcoal furnace stoves are:

Two stoves	550°C - 650°C.
Three stoves	700°C to 900°C, exceptionally 950°C.
Maximum dome temperature	1,100°C

It is essential that the blast furnace gas used in stove heating be cleaned after the dust catcher in two stages, usually by wet washing, to reduce to a minimum the content of flue dust. It is well known that charcoal blast furnace flue dust severely attacks the fireclay bricks of the checkerwork, destroying them, almost certainly by the fluxing effect of the alkalis in the charcoal ash.

Required degree of cleanness of stove heating gas: Max 0.10 gm dust/nm^3

Stoves require large amounts of high and super duty refractories.

Example: 150 t/day blast furnace with two stoves.

Heating surface of each stove: 4,700 sq. m.

Height of refractory work: 14 m

Total weight of refractory bricks of two stoves: 840 tons

Cost of bricks, inclusive erection of masonry: US $350,000.

The brick lining of a stove usually lasts 15 years.

(j) Gas cleaning plants

Small and medium sized pig iron producing plants with Glendon blast heaters, use primary stage dry cleaning of the gas in dust catchers and/or one or two centrifugal cleaners, cyclones, installed in series. All these plants have a gas excess which they burn in torches.

The iron and steel plants with stoves use primary, dry and wet, and secondary wet stage gas cleaning. The following table shows the result of a typical gas cleaning installation (Belgo Mineira).

Table XXX Dust concentrations in blast furnace gas cleaning installations

Stage of cleaning	Dust concentration mg/nm^3	
	Inlet	Outlet
Primary stage dry dust catcher	26.0	6.0
Primary wet washer : stationary spray tower	6.0	0.5
Secondary wet washer: Theisen disintegrator *	0.5	0.3
Moisture eliminator	0.3	0.025

* Old fashioned technique but still used in Brasil for simplicity of operation and maintainance.

The integrated steel plants and blast furnace plants having own foundries generally make passably good use of their blast furnace gas, but some plants lose a great quantity.

Iron and steel plants should make a maximum use of their blast furnace gas. Stoves or metallic recuperators use about 25 % of the gas produced.

Other uses are: -

Drying of hot metal runners and sand casting beds.

Drying and preheating of hot metal ladles, both for hot metal and for liquid steel.

Heating of hot metal mixers.

Rolling mill soaking pits and reheating furnaces.

Drying and preheating of open hearth furnaces after repairs.

Foundries: Drying of molds, heating of drying furnaces for cores.
Heat treatment furnaces: For wire, sheet, strip.
Restricted uses: Boilers.

Formerly, the gas was also used in internal combustion engines coupled to generators of electric power and for direct operation of air blowers for the furnaces. Blast furnace gas was also formerly used for heating open hearth steel furnaces.

Two plants, Mannesmann and Acesita, have blast furnace gas collection and storage vessels (gasometers) of approximately 30,000 cubic m. volume which have proved very useful for storing large amounts of gas and equalising its pressure at approximately 300 mm water column pressure. This practice is very recommendable though little used.

(k) Air blowers:

The blowing of modern charcoal blast furnaces is mostly by electric powered turbo blowers. The blast pressure required depends on the furnace working height and the permeability of the burden. Generally spoken charcoal blast furnace require low pressure compared with coke blast furnaces.

Usual air blast pressures at exit of blowers are:

Small to medium blast furnaces (50 - 100 t/day):	3 to 5 meters w.g.
Medium blast furnaces (100 to 200 t/day):	5 to 7 " "
Large blast furnaces (4oo to 800 t/day):	6 to 9 " "

Air rates are also lower than for coke blast furnaces. Air rate for charcoal blown hot metal: 1,400 to 1,600 nm^3/t of pig iron.
Coke blast furnaces require 1,500 to 1,800 nm^3/t of pig iron.
It is necessary to add 10% to each figure to cover losses.

Table XXXI Blowers installed on charcoal blast furnaces

Capacity of blast furnace	Type of blower	Volume Nm^3/hr	Pressure m.w.g.	Motor K.W.	Remarks
80 t/day	Radial	6000	5x1.1	5x45	5 Series blowers
200 t/day	Radial	14,000	5x1.4	5x112	5 " "
250 t/day	Turbo-blower	21,000	5	320	
400 t/day	"	30,000	10	1100	

(l) Pig casting machines

Sand casting of the iron in most plants gradually has been replaced by machine casting. When machine casting, the molten iron is usually first poured into a ladle which may be heated and from this tilted into the pig machine.

Two types of pig machines are used in Brasil:

(i) The standard endless chain type machine. Its description here is unnecessary as all the interesting details will be found in the technical literature.

(ii) The circular casting machine. This machine is a simple and very efficient device. The casting wheel, already used in the beginning of the century, consists of a circular structure made of two concentric rings forming a horizontal plane and joined by radial members to a centre of rotation. These rings carry the molds supported by wheels coupled on fixed and independent axles. A simple transmission makes the machine rotate as the molds fill with the liquid iron. An operator tilts the molds which rotate about their longitudinal axis. This tilting action is effected by means of an appropriate cam which causes the disengagement of the pigs which fall into a pit and are removed from there by a truck. The empty molds are sprayed with a lime or graphite wash to prevent sticking of the iron to the molds.

The travelling and casting speed of the machine is synchronised with the metal flow from the ladle by the machine operator so that a full sized pig is formed in each mold.

(m) Continuous blast furnace tapping

A Brazilian company, Sidsrurgica Itatiaia, city of Itauna, Minas Gerais, has developed and patented a continuous blast furnace tapping method which has been adopted by 30 small and medium size charcoal blast furnaces and is reported to work satisfactorily.

A fixed refractory lined rectangular vessel is added to the outside of the blast furnace hearth. Molten iron flows continuously from the hearth of the blast furnace through a channel connected with the hearth of the rectangular vessel and from this to the pig machine or iron heated ladle or mixer. The latter can be mounted on a special truck for transport of liquid iron to the nearby steel plant. One plant receives by this method 12 tons of liquid iron every three hours.

It is reported that this continuous tapping method offers many operational advantages for small and medium sized furnaces.

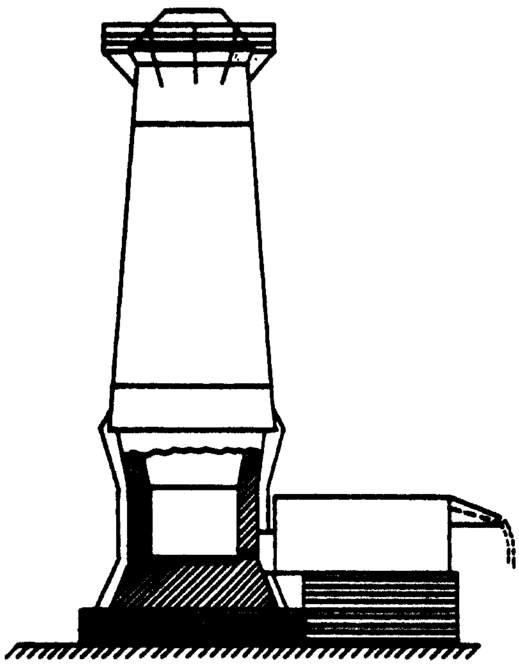


Figure 17. Continous Blast Furnace Tapping.

(i) Tap hole clay gun

Closing the hot metal hole is done on all charcoal blast furnaces by means of a pneumatic clay gun of the swinging type mounted on a pedestal in the cast house or on one of the furnace columns.

(ii) Disposal of iron

Open refractory lined ladles are mostly used; capacities range from 10 to 60 tons depending on blast furnace size.

The larger iron and steel companies use ladles mounted on a rail carriage which transports the hot metal to the steel plant.

The pig iron producing plants have rarely a railway transportation system and use fixed ladles which are moved to the pig machine by overhead hoists which do also the tipping of the ladles over the casting machines. These pouring ladles are sometimes heated, which is an advantage. A few plants have started truck transportation of the hot metal to steel plants. One steel plant uses cigar-shaped (torpedo) hot metal transfer cars to its own steel shop. This ladle also functions as a metal mixer and the regular fixed mixer is eliminated.

(n) Channel type induction heated furnaces for iron

Some charcoal blast furnace plants with iron foundries use channel type induction heated furnaces (Ajax) which receive the molten iron from the blast furnaces. These furnaces increase and maintain the hot metal temperature at the desired level for casting and also make the necessary adjustments of chemical composition by additives.

This is particularly important for silicon content because if the blast furnace does not have to produce high silicon iron it can operate at a lower coke rate.

Power consumption of the electric heating: 200 to 250 kWh/t. The results of these furnaces are excellent. Some American steel experts are presently developing a new application of this method for hot metal use in basic oxygen steelmaking through an increase of the hot metal temperature by up to 260°C which would allow to melt higher proportions of scrap, cold metal or sponge iron. No results are yet reported. This method might prove especially useful for charcoal blown hot metal because of its lower temperature.

Similar results are obtained by preheating scrap (Mannesmann).

(o) Slag disposal

Blast furnace slag usually flows into cinder ladles which are unlined cast iron pots mounted on railway cars which take the cinder pots to the slag dumping pits.

Where no railway transportation system is available, the flow of molten slag may be directed into a specially prepared dump from which it is removed after cooling. The molten slag may also be directed into fixed cinder pots which are later removed by trucks. Sometimes, the molten slag is granulated by striking it with a jet of water as it falls from the lip of the runner into a water basin. The granulated slag must be removed from the basin by a grab bucket. The granulated slag is a good ingredient of the self-fluxing sinter mix as it lends the sinter an excellent porosity and takes the place of an equal amount of necessary additon of sand and limestone. Addition is limited to about 2% of the wet sinter mix.

Charcoal blast furnace slag may be transformed into an excellent lightweight insulating material by blowing high pressure air into the stream of molten slag at its exit from the slag notoh. However, this operation is very disagreeable for the operators due to the flaks of insulating light material which blow around like snow.

Other possible applications of oharcoal blast furnace acid slag are: As a substitute for stone in the building of highways, roads, railways, in cement making, used in granulated form, up to 10 % of the clinker, and in the manufacture of special bricks.

Brazilian charcoal blast furnace plants do not usually make slag disposal a profitable operation because the quantities of slag are small and for that reason, interest in slag disposal is limited. However, most plants recover metallic iron from the slag after dumping.

(p) Instrumentation and control

The blast furnace operator is aided and guided in establishing and maintaining the best possible balance between the many variable factors affecting furnace operation by some automatic devices which indicate or record conditions at various points in the furnace system. The principal recording and indicating instruments are located on a panel in a control room.

In blast furnace plants with metallic recuperators the usual instruments are:

(i) Blast volume, pressure and temperature indicators and recorders. Measured in bustle pipe.

(ii) Metallic recuperator combustion temperature indicator and recorder - measured inside combustion chamber. Range 0 - 1,000°C

(iii) Blast furnace top temperature (0 - 800°C) and pressure indicators and recorders.

(iv) Manually operated visual stockline indicator.

(v) Stock line recorder.

(vi) Blast furnace top gas analyser and recorder.

In blast furnace plants with secondary gas cleaning and stoves for blast heating the usual instruments are:

(i) Blast volume, pressure and temperature indicators and recorders - measured in bustle pipe.

(ii) Gas pressure indicator and recorder after secondary cleaning.

(iii) Combustion and air temperature recorder and indicator in each stove - separately in dome and stack.

(iv) Blast furnace gas volume recorder and indicator for each stove.

(v) Stock line recorder and indicator.

(vi) Blast furnaces gas analyser and recorder.

(vii) Analyser of combustion gases at stove and exit to stack.

(viii) Oxygen content analyser of combustion gases at stove exit to stack.

(ix) Cooling water pressure indicator.

In blast furnace plants with oil injection and oxygen enrichment of blast additional instruments are:

(i) Oil pressure, temperature and volume indicators.

(ii) Oxygen content analyser of enriched blast.

(iii) Automatic oxygen volume controller and recorder.

9. SPECIAL QUALITY FEATURES OF IRON AND STEEL PRODUCTS MADE FROM CHARCOAL BLOWN IRON

The good qualities of charcoal blown pig iron, particularly Brazilian charcoal pig iron are due to the following factors:

(a) The absenoe of sulphur in the charcoal.

(b) The low temperature in the blast furnace and of the molten iron.

Brazilian charcoal pig iron has the further advantage that it is made from hematite, low phosphorus, iron ores of high purity which are practically free from harmful ingredients. The Brazilian standards for coke and charcoal blown pig irons are given in the following table:

Table XXXII Brazilian Standards for Coke and Charcoal blown pig iron.

Brazilian Standard	Phosphorus		Sulphur	
	Class I	Class II	Class I	Class II
Coke blown pig iron	0.15 max	0.16 to 0.30	0.025 max	0.026 to 0.050
Charcoal blown pig iron	0.070 max	0.070 to 0.100	0.010 max	0.011 to 0.020

In most Brazilian plants no bought scrap is used, which is frequently contaminated with tramp elements, "home" scrap is used.

Charcoal blown pig iron has a fine graphite grain structure which does not deteriorate after remelting, in contrast to coke blown pig iron. The mechanical qualities of charcoal pig iron are also superior to those of coke pig iron. Due to the lower blast furnace termperature, the contents of oxygen, hydrogen, nitrogen, as well as tramp elements are much lower than in coke pig iron.

All these qualities make charcoal pig iron an excellent natural raw material for foundry iron, principally for nodular cast iron. One recent example of this excellent quality are the German and Swedish nodular iron rolls made from charcoal iron.

The superior quality of charcoal foundry iron over coke blown iron has been specifically proven in the following applications:

(a) Ingot moulds.

The consumption per ton of crude steel is at least 2 kg less than for moulds made from coke blown iron.

(b) Internal combustion engines.

The Brazilian automobile manufacturers, who use exclusively charcoal blown iron in their foundries, have all attested the superior quality of the charcoal iron.

The inherent qualities of the charcoal pig iron also make it an excellent raw material for steel manufacturing, particularly for the carbon and special quality grades. The high purity of charcoal blown steel gives it good hot and especially cold, plasticity. The elongation value of charcoal blown steel is at least 2 % better than that of coke blown steel having the same yield strength. This quality has proven very useful in the manufacture and the performance of two products:

- Rim sections for automobile and truck wheels requiring a high fatigue resistance.
- Chassis sections for automobile and trucks requiring the same characteristics.

The outstanding qualities of charcoal blown steel have proven especially useful in the manufacture of steel wires, principally the very fine high carbon ones permitting high drawing speeds at reductions, from the rod diameter, of up to 94% without breakage of the wires. It is a well known factor that the manufacture of wires with the high plastic deformation of the original section is frequently accompanied by quality problems and it is in this respect that charcoal blown steel has proven very useful.

Brazilian and foreign manufacturers of steel ropes, special springs, bead and cord wires for tires, who use wire rod made from charcoal blown steel as raw material, have all expressed their favourable opinion as to the superior quality of the raw steel and the finished products.

Although good steels can and are generally made from coke blown iron, the use of charcoal hot metal makes the steel manufacturing process easier and cheaper, avoiding some of the usually expensive and difficult treatments which are required in coke based steel practice. It would certainly be useful and profitable for the Brazilian charcoal based iron and steel industry to establish with more precision, through metallurgical research and development work, the influence of the characteristics of charcoal blown iron on the oustanding quality of many foundry and steel products derived from that material.

SECTION 4.

EXPERIENCE IN OTHER COUNTRIES, ALTERNATIVE CHARCOAL TECHNOLOGIES AND DETAILS OF BRAZILIAN CHARCOAL BASED WORKS AND ENGINEERING FACILITIES ETC.

1. CHARCOAL BASED IRON AND STEEL INDUSTRIES IN OTHER COUNTRIES.

(a) SWEDEN. (Bibliography references 3, 20, 21, 28, 29, 30, 31)

Sweden was the dominant iron producer in Europe from the latter part of the XVII Century to the end of the XVIII Century. The only type of fuel which could be used in ironmaking was charcoal which was produced in large quantities from wood out of vast forests. Until the end of the last War pig iron production in charcoal blast furnaces was the most important method of iron ore reduction. In 1917 the Swedish charcoal pig iron production reached its peak which was nearly re-attained in 1944. The last charcoal blast furnace was closed down in 1966.

Table XXXIII Swedish Charcoal based iron production.

Year	Blast furnaces		Electric furnaces		Total production tons
	Number in operation	Yearly output tons	Number in operation	Yearly output tons	
1750	about 400	61,000	-	-	61,000
1843	208	119,000	-	-	119,000
1900	133	504,000	-	-	504,000
1910	103	541,000	1	1,000	542,000
1917	109	661,000	8	58,000	719,000
1920	82	379,000	12	67,000	440,000
1930	47	274,000	4	34,000	308,000
1940	37	354,000	5	48,000	402,000
1944	approx.	650,000	5	40,000	690,000
1950	24	173,000	5	38,000	211,000
1960	3	23,000	2	33,000	56,000
1966	1	10,000	-	-	10,000
1967	-	-	-	-	-

Swedish charcoal is an excellent reducing agent as it contains only small amounts of sulphur, phosphorus and ash. Its reactivity is much higher than that of metallurgical coke.

The charcoal pig iron which generally contained less than 0.015 % S and 0.025 P, was an ideal raw material for the making of high quality steels.

The charcoal blast furnaces were small production units. In 1947 the average hearth diameter was 2.3 m, total height 16.7 m with a working volume of 81 cubic m. The average production was 40 t/day per furnace. The largest charcoal blast furnace ever to to be built in Sweden was the furnace Nr. 1 at SKF, Hofors, closed down in 1953, whereupon the works changed over to use refined coke pig iron and sponge iron for the production of acid open hearth steel.

Table XXXIV <u>Operational data on No.1 blast furnace at Hofors</u>

Total blast furnace volume, m^3	112
Pig iron-% of burden (100 % sinter)	63.9
Blast temperature (directly heated metallic recuperator)	620° C
Consumption of dried charcoal m^3/t	4.4
Daily output, tons	115
Total production 1947, tons	32,245

Great progress was made between 1910 and 1940 in reducing the charcoal consumption as may be seen in the following table.

Table XXXV <u>Charcoal consumption in Swedish blast furnaces</u>

Year	Pig iron production tons/year	Charcoal m^3/ton of pig iron	Charcoal production	
			% from Stack Forest piles	% from Furnaces
1910	541,000	6.3	91.8	8.2
1917	661,000	5.7	95.3	4.7
1920	379,000	5.6	90.0	10.0
1930	374,000	5.3	84.8	15.2
1940	354,000	5.2	80.2	19.8
1944	650,000 (approx.)			
1950	173,000	5.3		
1960	23,000	5.3		
1967	-	-	-	-

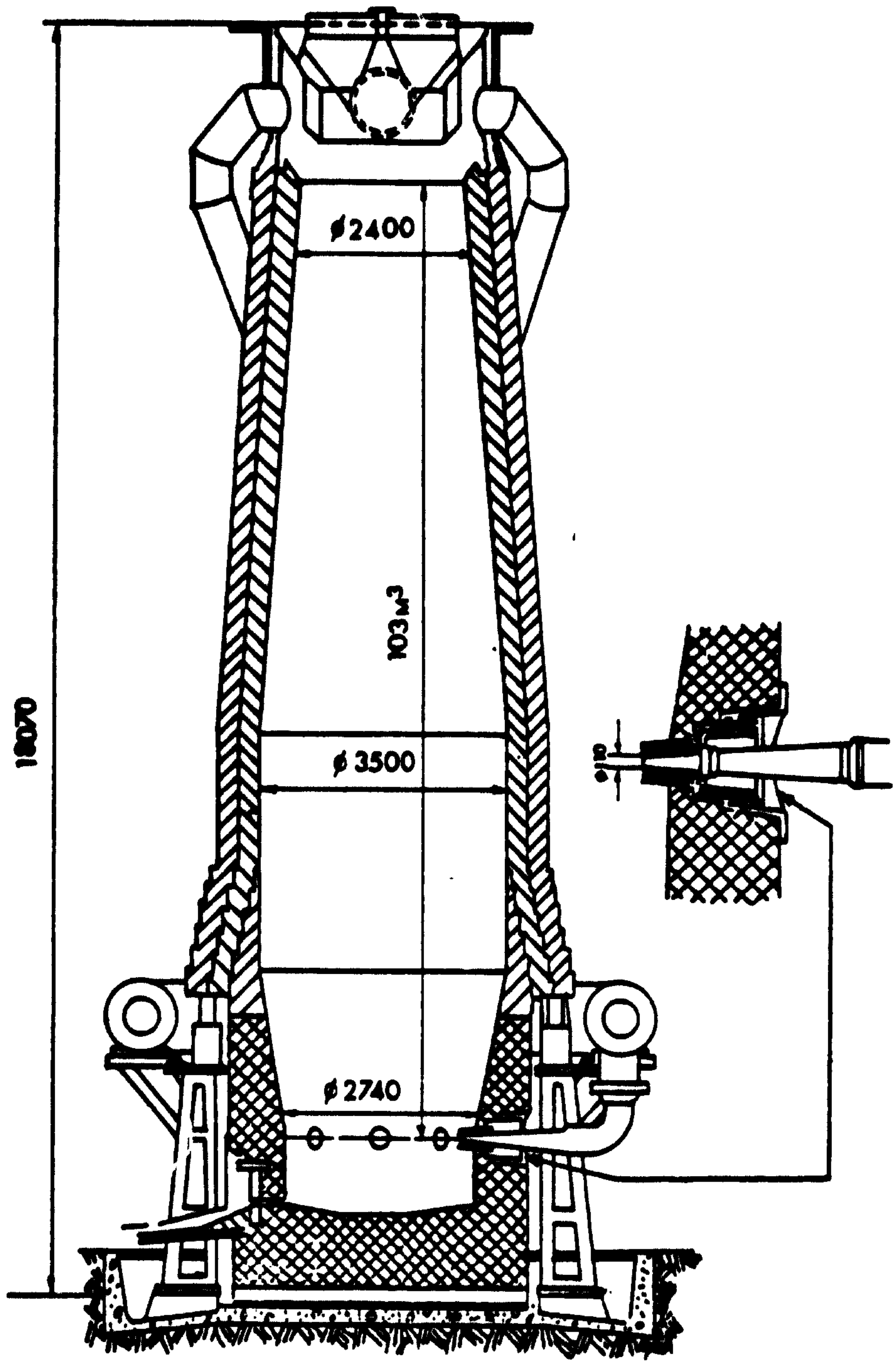


Figure 18. No.1 Blast furnace SKF Hofors.
The largest furnace ever built in Sweden; shut down 1953.

For comparison of charcoal consumption with Brasilian practice it should be remembered that Swedish charcoal has a lower bulk density.
The first sintering plant, using the Greenawalt system, was built in 1915. Sweden became a pioneer in the use of sinter in the blast furnace burden. Since 1930 all lump ore was replaced by sinter at Hofors with the result that the charcoal consumption fell considerably. In addition to the saving of fuel, the use of sinter also had the important advantage of leading to increased production. For many years it was common practice to use burdens consisting mainly of sinter. Concentration of iron ores introduced richer burdens and led to considerably reduced slag volumes, about 250 kg per ton of pig iron and even less in certain cases.
Among other methods adopted to reduce charcoal consumption was the addition of the necessary limestone or, even better, lime, to the mixture for sintering and the use of increased blast temperature. The charcoal consumption per ton of pig iron, a figure of decisive importance to the economy of the process, amounted to 850 kg on an average in 1913. In 1947 the figure had been reduced to 630 kg.

(i) <u>Coke blast furnaces</u>

Coke was first used as a reducing agent in Swedish blast furnaces at the end of the XIXth century, at first mixed with charcoal and later alone. For a considerable time the quantity of coke pig iron produced was only moderate, but after the economic depression in the 1930's the production began to increase considerably. The years following the last War show a very marked rise from about 220,000 tons in 1946 to 750,000 tons in 1953.

The main reason for this was the increase of the price of wood due to the high demand of timber for woodpulp.
Also, as charcoal-making requires much manual labour and as labour costs have increased very much, the charcoal price has consequently also risen and became so expensive that the charcoal blast furnace

lost ground in competition with the coke blast furnace.
Most of the Swedish coke pig iron is consumed in the production of commercial steels. At some works, where the coke pig iron is used as raw material also for quality steels, the pig iron is desulphurised outside the blast furnace with finely ground powder of burnt lime.

(ii) Electric pig iron furnaces

The first method of producing pig iron electrically was developed in Sweden. In 1910 "Jernkontoret" built a pilot-plant furnace of the "Elektrometal" type and during the next ten years several furnaces of this type were erected at different works. The upper part of the furnace is similar to that of a blast furnace and the lower part consists of a wide melting chamber with four to eight electrodes on the circumference of the roof. Charcoal is used as principal reducing agent but, as the heat necessary for the process is supplied by electric energy, the charcoal consumption is much lower than of the charcoal blast furnace.

This type of furnace, which may be called the electric high shaft furnace, cannot work with coke alone as a reducing agent at least 60% charcoal must be used. Therefore, only a few units are now in use and no new ones have been installed. The units are small and produce, depending on furnace size, 50 to 70 tons of pig iron per day. The energy consumption is 2,000 kWh/ton.
The electric low shaft furnace of the Tysland Hole type, which was developed in Norway, is used in some works in Sweden. This furnace can use either charcoal or a mixture of coke and coke breeze as a reducing agent.
The largest units built in Sweden have a power input of 10,000 KW, produce 100 tons a day and 30,000 t a year, of pig iron. Coke consumption (for a 55% Fe ore) is 380 kg per t of pig iron.
Brasil has larger electric furnaces. One unit of 33,000 KVA and 200 t/day capacity is presently being projected.
The reason why the electric processes have not become more important is their high power consumption - 2,000 to 2,500 kWh/ton of pig iron, which means that they require access to very cheap power.

This situation has of course changed since 1973 and countries like Brasil show a new interest toward electric reduction furnaces. The following table shows Swedish fuel and power consumption figures, until 1954, for different methods of iron making.

Table XXXVI Swedish fuel and power consumption for iron-making

Process	Charcoal kg/ton iron	COKE (Blast furnace) kg/t iron	COKE (Breeze) kg/t iron	POWER kWh/t
Charcoal Blast Furnace	630	-	-	80
Coke Blast Furnace	-	650	-	110
Electric Pig Iron:				
High Shaft Furnace:	310	-	-	2000
Low Shaft Furnace:	-	200	200	2300

(iii) Charcoal Manufacture

Charcoal manufacturing was mostly integrated with a lumbering operation. Waste wood, branches and sawmill slabs were used. The oc uation of carbonisation of wood had reached in Sweden a high degree of perfection.

Carbonisation was by forest piles and charcoal carbonization furnaces. During the last war a total of 5,000 units of these two types were in operation, producing charcoal for iron and steel plants (30%) and for automobile gas generators (70%), as all motor vehicles in Sweden were converted to use gas generated from charcoal.
During the years 1939 to 1949, due to the fuel shortage, several large charcoal production plants with recovery of by-products were built for Swedish Government owned enterprises. The largest amount of the charcoal produced in these plants was used in automobile gas generators.

a. Preparation and transportation of the wood for forest charcoal piles

The slender round logs of coniferous trees and the thick branches of big trees are cut in pieces of 1,5 to 3 meters length. The length of the wood pieces depends on the type of wood. To obtain a tight packing of the wood inside the pile or the furnace, the very straight pieces of wood are cut into three meters lengths, the tortuous pieces into 1,5 meter lengths. One fifth to one quarter of the wood surface is barked to hasten the drying process. The wood is then piled and measured for the purpose of paying the labour which works mostly on contract per volume of wood. The trees are cut during spring and early summer and the woodpiles allowed to dry for approximately three months, when their moisture content will have attained a minimum of 20%. In Sweden, the relative humidity of air is lowest in early summer, with 66%, and highest in winter, with 90% humidity. Therefore the trees are cut in spring and early summer, the wood dried during summer and the carbonization is done in fall and winter. Years ago wood transportation was frequently done in winter time by sledges, which were frequently drawn by horses. Where watercourses are available, they supply simple and cheap transportation for floating of large quantities of wood pieces to or close to the charcoal furnaces, where the unloading from the water is done by cranes.

b. <u>Forest piles or earth kilns</u>

They represent the oldest and simplest method for manufacturing charcoal. They were located in the forests to reduce the transportation costs of the wood as the charcoal made of coniferous wood and by the Swedish method has a bulk density of only 130 to 150 kg/m^3 and the ratio $\frac{\text{weight of wood}}{\text{weight of charcoal}}$ = approximately 7:1

Charcoal made from tropical woods and Brazilian charcoal practice on the other hand, has lower carbon and higher volatile matter, with bulk density around 250 kg/m^3 and a weight ratio of wood to charcoal of between 4:1 and 5:1.

The forest pile was, until 1950, very popular in Sweden for blast furnace charcoal manufacturing and a high degree of perfection had been obtained, both in its construction and its operation.

The most important improvement in the forest kiln was the bottom flue and the outside stack.

In 1940, 80% of all Swedish charcoal was produced in forest piles and the remainder by other methods by 1944 the forest piles produced only 40% of the total charcoal. This inversion of trend was caused by the War and its effects on the fuel economy of the country which required the by - producte of wood distillation.
The modern type Swedish circular forest pile, as described by Bergstrom, is shown in Figure 19.

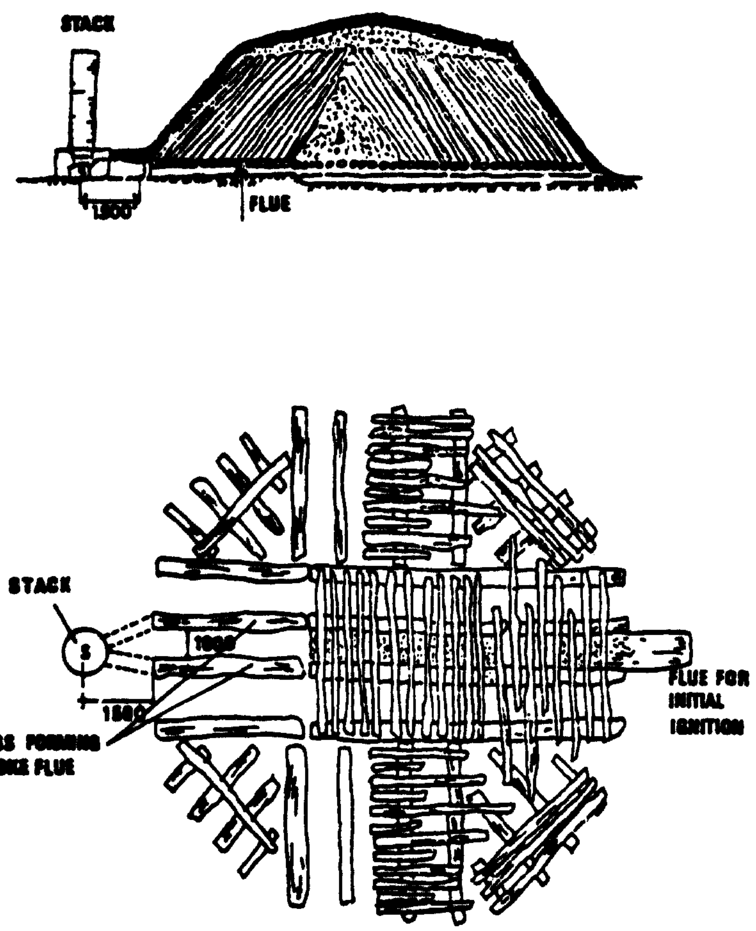


Figure 19. Modern Swedish circular forest pile

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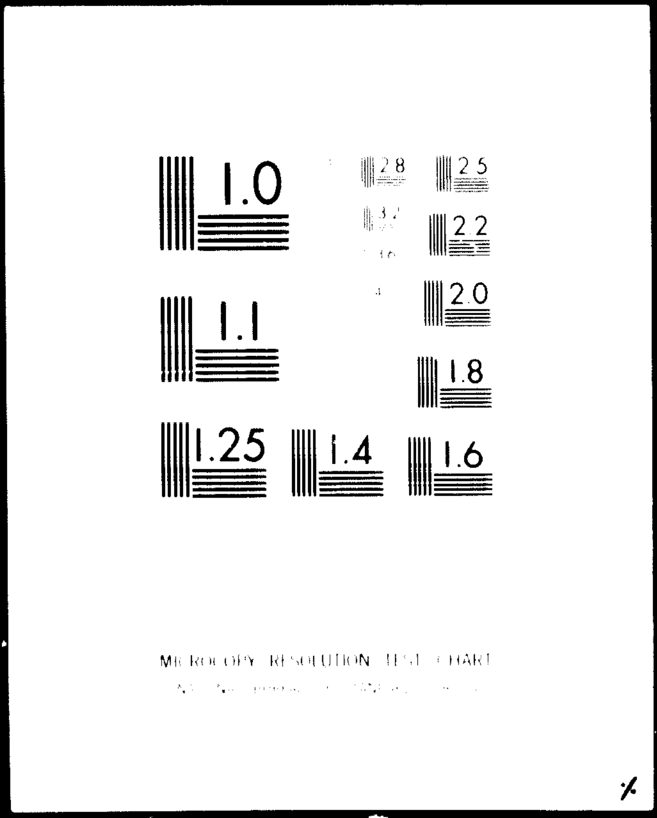

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It is built in the following manner:
The bottom of the base is covered with wood logs forming a grate on which the wood is piled vertically. The grate forms a free space between the bottom and the woodcharge through which passes the air necessary for the carbonization process.
The pile has an outside stack, made of steel drums, which is connected to the pile through a flue cut into the ground and running under the pile and covered with round logs. The pile has a certain number of air vents located around the circular base.
The carbonization process is started by introducing a torch into the flue. This type of pile is reported to be easy to operate, to produce good charcoal quality with a yield of 55% charcoal to wood volume. This is excellent. The pile's volume varies from 100 to 250 m^3 of wood. The whole cycle takes 24 days; four days for charging, six days for carbonization, 10 days for cooling and four days for discharge.
Due to the high carbonization temperature, approximately 550°C, and the slow process, the charcoal produced in Swedish earth kilns has a high proportion of fixed carbon, low volatile matter and consequently a low bulk density, 130 to 160 kg/m^3 for charcoal made from coniferous trees. It has a very low tendency to self ignition, in contrast to charcoal made in furnaces. However, the use of earth kilns should not be considered any more for the following reasons:
The kiln must be completely rebuilt after each cycle. The production cycle of 24 days is too long. The kiln operation, although basically simple, requires considerable skill, experience and even a certain degree of artistry. Wherever rusticity of construction and operation, flexibility and mobility are desired, the simple brick built, beehive kilns give good results, good yields with much operational simplicity, case and speed of operation.

c. Carbonization Furnaces with or without recovery of by-products

During World War II the charcoal manufacture in furnaces increased considerably for the reasons given before.

In Sweden three types of carbonization furnaces or ovens exist:

i. - Retorts which use the reheated recirculated gases, produced during the distillation process and which are totally or partially forced by fans through the wood being carbonised.

These installations are very expensive and their operation is only economical in large installations. Continuous and non-continuous carbonisation retorts of this type exist.

One process largely used during the last War with recovery of the distillation by-products, was the INKAPERSTORP carbonisation process. Carbonisation takes place in vertical retorts at temperatures of 500 - 600°C. The hot gas enters at the top of the retorts, leaves at the bottom at a reduced temperature and passes through a system of scrubbers and condensers where tar is removed and other by products are recovered.

During the War years, from 1939 - 1943, several INKA process charcoal plants were operated by Swedish Government enterprises. The largest one was the plant at Pitea which produced 120,000 m^3 of charcoal per year and was (maybe still is) the largest carbonisation plant in Sweden and probably in Europe.

The necessity for these large plants was dictated by the scarcity of oil and gasoline for motor vehicles which were converted to use gas generated from charcoal. A considerable part of this charcoal was supplied by the above mentioned plants.

One small INKA plant was erected at a blast furnace. It had three retorts in which crosscut wood, split and dried round wood was heated to carbonising temperatures with circulating gas mixed with the flue gas from an oven heated with blast furnace gas. This plant operated only two years. The reasons for this short period are not known.

The continuous carbonisation retorts are most suitable for use with waste wood of small dimensions and the charcoal produced is suitable for a variety of purposes. The temperature in the carbonising zone is higher than in the semi-continuous retorts and consequently the charcoal is very low in volatile matter. The continuous carbonization retorts are claimed to be cheaper in first cost, have lower operating costs and save labor.

ii. - Furnaces which use for the carbonization process the heat generated by the partial combustion of the wood being carbonized.

These furnaces are of simple design easy to operate, and therefore cheap; many of them were built in Sweden during the last war.
The most important installations consist of horizontal tunnels with rails, which hold four to five wheel carriages of 10 m^3 volume each, which pass successively through a drying chamber, a carbonization chamber and finally through a cooling chamber.

iii. - Furnaces using an outside source of heat for the wood drying and carbonising process.

Some of these furnaces use the heat produced by the combustion of wood or charcoal fines, in a separate combustion chamber, for wood drying and the carbonisation process, increasing thus the yield wood to charcoal. A very simple and efficient design is the SCHWARTZ furnace which burns small wood in an outside cumbustion chamber. A detailed description of this furnace and its operation is given in the section about Argentina.

d. Kilns

These are direct heated, which means that they use for the carbonisation process the heat generated by the partial combustion of the wood being carbonised. They are built of bricks, with a lime mortar, and mostly are circular with a dome shaped ceiling.
They are very large, have a diameter of six to nine meters and an overall height varying from four to seven meters and a wall thickness of 0.30 m. Their capacity of wood ranges from 200 to 350 m^3.
As they are very large, they allow mechanisation of the operations of wood charging and coal unloading.

They have once been very popular in the USA, where some furnaces of this type were built as late as 1959. The mechanical charging of the wood is done through a central opening in the dome or through a large side door which is also used for coal discharge. In general, such kilns are built, in batteries of three to five, along the base of a hill or bank, so that they can be conveniently charged through the top. Wood charged in carriages run along and at the height of the kiln ceiling and can feed two rows of kilns. A complete cycle takes approx. 25 days: four days for charging, seven days for heating and carbonization, 12 days for cooling and four days for discharge. Due to the long cycle, production of these large kilns is very low. A battery of five kilns produces about 900 m^3 charcoal/month. Each kiln costs about US$10,000 and this factor, combined with their low productivity, makes them uneconomic so they cannot be recommended.

(iv) Protection, transportation and measurement of charcoal

Swedish charcoal with 20% or more moisture was not charged into the blast furnaces because it was found to decrease iron output 20% and increase charcoal consumption by a similar amount. Wet charcoal was dried on special metallic conveyors at temperatures of 100°C to 120°C. Special care was taken against risks of fire.
After careful drying charcoal recovers its original mechanical strength. To protect charcoal from rain and snow, it was stored in wooden buildings covered with tar-paper.
It was important that the different kinds of coal were stored separately. This on account of fire as far as the charcoal produced in furnaces was concerned. In the coal houses the charcoal was screened and the coal fines were taken to the sintering plant. Different kinds of charcoal were mixed in given proportions.

When truck transport was used, because of fire danger, the insurance companies did not allow the trucks to enter the charcoal houses of the steel companies and the charcoal was therefore unloaded outside the depots, onto belt conveyors.

For railway transportation, special care was taken to avoid flying embers from the wood fired locomotives which could ignite the charcoal. The cars were covered with well tied tarpaulins. It has been reported that even sparks from electric locomotives have ignited charcoal.

For railway transport, the tariff was fixed on the charcoal volume when leaving the railway station because, during transportation, a reduction of volume of 2 to 5% takes place due to the settling of the coal.

Official charcoal measurement after production, measured in a 2 m^3 ....1.00 m^3

Volume measured in the charcoal shelter, situated in the forest ....0.94 m^3

Volume measured when leaving the shelter:....................1.03 m^3

" " at railway car loading station: ....0.96 m^3

" " at " " steel plant arrival station.....0.93 m^3

(In Brazil the tariff is calculated on a fixed specific weight of 300 kg/m^3).

(v) Training of people for charcoal manufacture

"Jernkontoret" used to hold yearly three technical courses for the future operators of kilns and furnaces. The courses give theoretical and practical knowledges and had the duration of 12 months. The following disciplines were taught:

Cutting of the trees and their treatment after having been felled, measurement, transport, preparation of the kiln, carbonisation, discharging of kiln, storing and transport of charcoal, salaries, accountancy of charcoal operation, knowledge of forestry. After completion of the course, the students used to continue their studies at the Academy of Forestry and in the School of Forest Inspectors. The "Jernkontoret" course was reserved for Swedish citizens and was free, with exception of living expenses.

(vi) Some factors influencing charcoal quality.

Although Swedish tree species used for charcoal are quite different from those of warm or tropical regions, some of the factors which have an influence on the quality of charcoal are common to all regions of the Earth.

a. Humidity. It should not exceed 20% for blast furnace charcoal and 12% for gas producer charcoal. The latter must be free from tar.

b. Bulk density of dry charcoal. It is a very important factor for the correct estimation of charcoal quality. The bulk density of dry charcoal depends on:

i. The density of the wood.

General speaking, dense wood will yield dense charcoal and light wood light charcoal. The density of wood depends, beside the tree species, on the conditions under which the trees have grown.

The same tree species can produce charcoal of bulk densities varying upto 40%, depending on the age of the trees and their conditions of growth, whether slow or fast. Trees which have grown slowly give charcoal with a higher bulk density than that of fast growing trees. Swedish example for the same species of trees:

Bulk density kg/m^3

	Wood	Charcoal
Slowly grown	460	320
Fast "	350	230

For artificially planted forests it is very important to determine the optimum age at which the trees should be harvested to combine a fair yield of wood per hectare and a good charcoal quality. Depending on the species of trees and the regions, only experience can determine that age.

Rotten wood will give charcoal of bulk density half that of healthy wood and with a low mechanical strength.

Charcoal produced from the bark of the wood has only 2/3 of the bulk density of that made with the trunk of the tree. It also produces more ash and more charcoal fines.

ii. The charcoal size: Example:

Coarse charcoal, average size 9 to 15 cm ....121 kg/m^3

Fine charcoal, average size 2 to 4 cm ....152 kg/m^3

As mentioned before, charcoal made of coniferous woods and by the Swedish practice, is much lighter than charcoal made from tropical hardwoods and by Brasilian practice.

- How the kiln or furnace is operated: High or low temperature, fast or slow, good or bad supervision.

Table XXXVII Swedish Charcoal analyses

Analysis	Pine and spruce wood	
	Charcoal from Forest Piles	Charcoal from Furnaces
C	89.0-92.5 %	79.0-88.0 %
H_2	3.2 - 2.3 %	5.1- 3.2 %
O_2	6.6- 4.5 %	15.0- 7.0 %
Ash	0.7- 1.2 %	0.7- 1.2 %
P	0.02-0.03 %	0.02-0.03 %
Calorific Value Bulk Density	8,000 Kcal/kg about 150 kg/m^3	7,900 Kcal/kg about 120 kg/m^3

Forest pile charcoal is produced at higher temperatures than furnace charcoal. It was always preferred by the blast furnace operators. The risk of self-ignition is considerably greater with furnace charcoal. It must be underlined here that there exists a difference between Swedish and Brasilian charcoal as to quality, both chemical and physical. The Swedish charcoal has a higher fixed Carbon content, lower volatile matter, lower bulk density, lower tendency to self-ignition than charcoal made in Brasilian practice. However, the average Brasilian charcoal has a good mechanical strength and has given good results from all points of view, in large blast furnaces, upto 700 t/day and, in the near future, 900 to 1,000 t/day.

c. Phosphorus content

The rule is: The lower the better. Leaf trees have 4 times more phosphorus than coniferous woods. The bark and the small branches contain more than the tree-trunk. Phosphorus content also varies with the soil composition.

(vii) Conclusions from Swedish experience

Although the last Swedish charcoal blast furnace was closed down in 1966, and for that reason the manufacture of charcoal pig iron in Sweden must be considered as history, their experience still contains much valuable information for countries or regione wishing to introduce charcoal based iron and steel making technology.

Specific pointe to be considered are:

Forestry: Careful harvesting of the foreste.
Mandatory replacement of felled forest areas.
Substantial use, for charcoal, of eecondary wood, like waste wood, branches, slender trees.
Preparation of the wood, barking, drying, cutting.

Charcoal manufacture: Careful preparation of the piles.
Good stacking of the wood.
Careful operation.

Charcoal transportation and etoring: Protection against water.
" against fire risks.
Screening before etoring to eeparate the finee.

Charcoal quality: Special attention as to composition. High fixed carbon. Laboratory methods for testing the chemical properties

Work force: Theoretical and practical training in all operations.

Blast furnace operation: Good burden preparation.
Intensive use of eintered iron ores.

Wood and charcoal as industrial fuels: Experience during the last War and possibility to use that experience in countries with large forest reserves.

(b) AUSTRALIA (Bibliography references 20, 34)

(i) Introduction

Australia has one small charcoal based iron and steel plant the Wundowie Iron and Steel Co. Western Australia producing 60,000 t/yr of pig iron.

(ii) Charcoal Manufacture

The Wundowie plant is characterized by the unique fact that the charcoal is manufactured right at the iron plant site and not, as usual, in the forests.

(iii) Forest Operation

The wood used for carbonisation comes from natural eucalyptus forests which are located in the vicinity of the plant. Much of the land is privately owned and has been cleared for farming purposes under arrangements with the owners which resulted in the wood being reserved to the iron plant. The owner was compensated by having his bulldozing carried out at half cost.

Over the past 100 years, the sawmilling and allied industries have been steadily cutting these forests, removing the best logs and leaving the worst. These trees which are not good for sawmilling have tended to remain standing in the forest because their removal is costly and uneconomic.

The form of the natural old eucalyptus tree, with its spreading crown, necessarily produces large quantities of branchwood even in good type forests. Adding to this the poor type trees, the dead and useless species, it is evident that up to 70% of the wood produced by a natural old eucalyptus forest is only waste wood.

Eucalyptus waste wood will last for many years when lying on the ground and there is a great need for industries to use the vast amounts of waste wood and remove the forest debris which, otherwise, can only be destroyed by periodic bush fires.

A good forest operation results in a forest floor clear of fallen and dead trees, traversed by tracks and roads.
The cost of wood is a very important factor as it takes approximately 3.5 to 4 t of wood with 25% moisture to produce one ton of charcoal. Under the conditions in Wundowie wood represents 75% of the total cost of the charcoal and is therefore given a great deal of attention. An important consideration is the gathering and hauling operation in the forest. Care is taken to see that properly made tracks and roads are constructed so that the heaviest permissible loads are drawn from the forests. The loading operation is fully mechanical using tractor type logging equipment and the operation is planned so that winter (Australia) cutting is confined to the high and dry areas.

(iv) Wood preparation

Wood preparation is arranged to suit the particular situation at Wundowie where two different types of carbonizing plant are used each requiring a feed stock of a different size of wood.
The Wundowie plant has developed a unique mill operation for this purpose. Dry logs, up to two m in diameter and up to 6.5 m long are cut across the grain into "cheeses" 250 mm thick. The "cheeses" are then passed under a splitting machine which reduces them to slabs about 100 mm thick. The mill has a capacity of 100 t per eight hour shift.

(v) Wood drying

Freshly felled eucalyptus trees contain from 40 to 60% free moisture. Drying experiments with wood cut into 25 cm blocks gave the following free moisture content:

1 week	6 months	12 months	18 months
54.4%	31.6%	21.6%	15.9%

The initial free moisture content of the wood charged to the carbonisation units has a great influence on fuel consumption and carbonisation time.

The process of drying wood is slow. Short cuts of wood across the grain dry at a faster rate but shorter cuts mean more frequent saw cuts, requiring more milling time and increasing sawdust losses. Consequently a compromise has to be reached.
It is important to airdry the wood as far as possible in the forest before gathering and hauling. This avoids the cost of transporting large quantities of moisture and the expenditure of much heat for subsequent drying in the carbonization units.

(vi) Charcoal manufacturing plant.

The Wundowie plant uses two different charcoal carbonizing methods.
a. Batch type of retorts, derived from the Pennsylvania type retorts, popular in the USA until the late 1950's.
Air dried wood cut in 1.20 m lengths is piled into lattice type steel containers mounted on buggies. Four buggies, each containing 4.5 t of airdried wood are connected together and are pushed into a retort 16 m long. The retort is a closed steel vessel three m high by two m wide with flat sides and bottom and an arched roof. It is hung in a brickwork setting. It has two off-takes leading to condensers and it is heated externally by flue gas from five combustion chambers located under the retort length. After the buggies having been pushed into the retort, it is closed and firing commences, using blast furnace gas or non condensable wood gas. During the first few hours the heating is rapid, to reach the distillation temperature. When the exothermic reaction takes place, the external heat must be decreased. The whole operation takes between 12 to 24 h, depending on the moisture content and size of the wood charged. When the distillation is over all burners are turned off.
The buggies are withdrawn hot and transferred to an air-tight cooling chamber for two days with a quenching spray of water after the first day. The charge shrinks considerably during the distillation. The charcoal consists of rather large pieces with very little dust.

Duration of total cycle, including cooling: ....three days

The plant consists of seven retorts of this type.

Daily production capacity: 40 t of charcoal

Yearly " " 12,000 t.

The system requires frequent repairs and replacements of the steel retort shells, so a further development of the horizontal retort has been made. The vessel is cylindrical and does not require a brickwork setting but is heated by hot gases blown around a circumferential steel annalus. The hot gas is recycled through an external reheating furnace which maintains temperatures at the desired level of 450°C. This retort has eliminated many of the disadvantages of the previous type, but still suffers from the limitation of temperatures to which mild steel can be subjected.

Yield in weight of charcoal: ....40% of the wood charged.

This yield is high and is due to the low carbonizing temperature, resulting a charcoal with high volatile matter similar to charcoal made in Brazilian practice.

b. Continuous circulating gas retorts using the Lambiotte or SIFIC Belgian process.

The disadvantages of carbonizing of wood by the external heating of a retort containing the wood were overcome by the SIFIC process. The principle of design and operation of these retorts is to utilize the hot gases as a medium for both drying and carbonizing the wood as well as for cooling the charcoal. The gases are circulated counter-current to the wood and heated by partial internal combustion. The wood is fed continuously and charcoal removed continuously. (See figure 20).Each retort consists of a vertical steel unlined cylinder approx. 30 m high and 3.3 m in diameter with a flap type valve at the top to admit the wood and specially designed valves at the bottom to permit periodic withdrawal of the charcoal. The steel used consists of mild steel at the bottom, creep resistant steel at the high temperature middle section and stainless steel in the upper section. The wood pieces, 20 to 25% moisture, diameter 8 to 20 cm and length of 30 cm are skip fed to the retort. The wood is dried by ascending gases in the top section, carbonized by recirculating rinsing gas in the middle section and the charcoal is cooled before withdrawal in the bottom section.

(The newer SIFIC installations use separate wood pre-driers heated by the hot gases produced in the carbonizing retort. The wood is dried to 10% moisture. This system is preferable).
The cooling gas is blast furnace gas which is admitted at the bottom of the retort and passes through it without change. The rinsing gas is the retort's own atmosphere which is recycled through a reheating external combustion chamber fired with gas drawn from the top of the retort. The gas which dries the wood is therefore a mixture of blast furnace gas, flue gas from the external combustion chamber and the products of wood distillation. The mixture leaves the retort at approximately 120° C and, after scrubbing for tar is piped to the boilers for use as fuel in steam production.
The calorific value of the mixture of gases is similar to blast furnace gas at about 980 kcal/kg. No other source of heat beside the gas produced is necessary with wood of 25% moisture. Duration of process, from entering the retort to the exit of the cooled charcoal, is approximately 12 hours.

The product quality is well controlled by the gas temperature and can be maintained at 90% fixed carbon at will. The withdrawal of the charcoal results in some size degradation caused by the valves but the material is otherwise of excellent quality for blast furnace use. Yield in weight of charcoal: 25 to 30% of the charged wood with 25% moisture. The SIFIC units are very expensive to install and require large saw-mills to cut large quantities of wood into small pieces. They are economical in labor and maintenance, are thermally very efficient and economical to operate. There is practically no interruption of the operation once the retorts are in order. If any repair or alteration is needed, it is only necessary to put the retorts on slow burning for a few hours or a few days.
The SIFIC process is especially appropriate in countries where wood and labour costs are high. This is the case for highly industrialized countries.

Daily production of two retorts at Wundowie	70 t/day
Yearly production	20,000 t.

CIRCULATING GAS RETORT
FOR CONTINUOUS CHARCOAL PRODUCTION

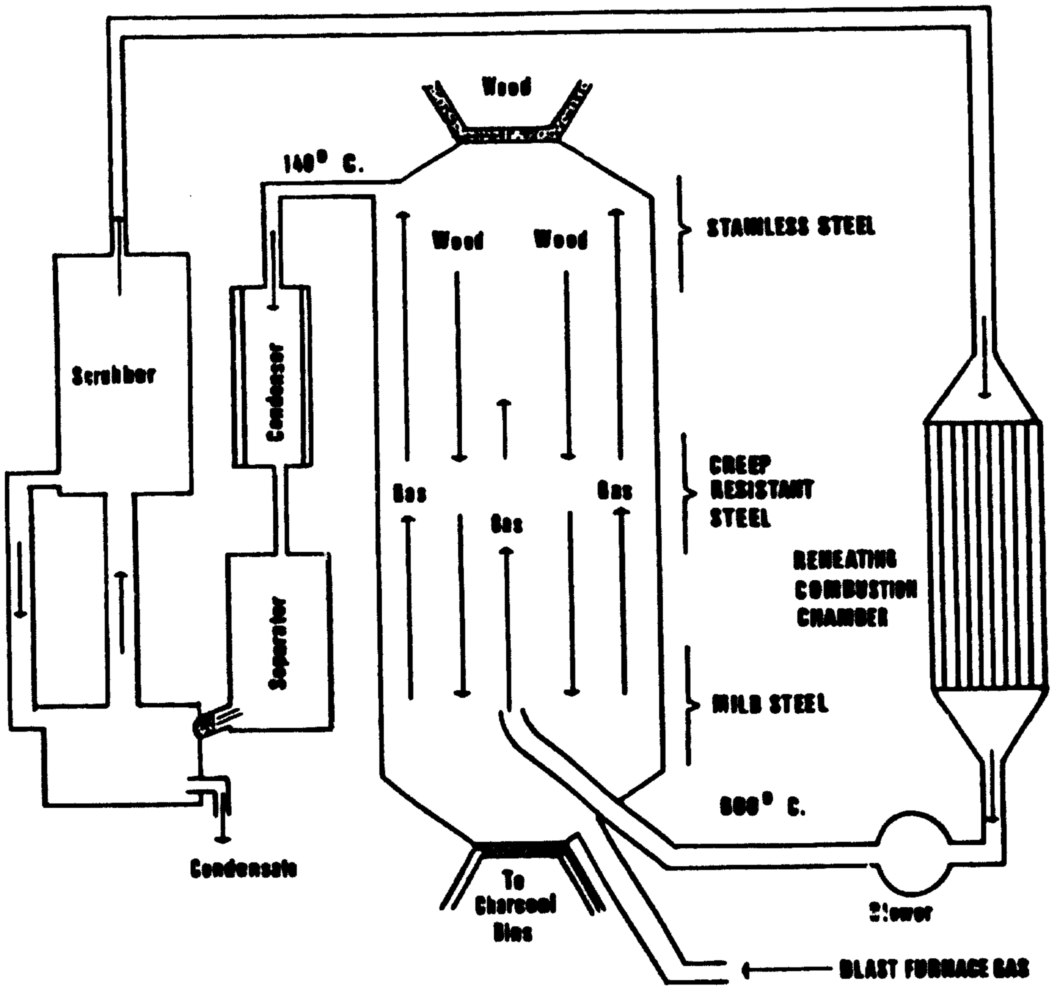


Figure 20. Diagram of circulating gas retort for continuous charcoal production, SIFIC process.

A pilot plant portable retort has been developed at Wundowie with a capacity of one ton per day.

It consists of a jacketed steel cylinder located above a firebox burning wood waste. The flue gas is directed over the whole outside surface and through a central chimney of the inner vessel holding the charge. Downpipes from the inner vessel direct the pyroligneous vapors into the firebox, thereby saving fuel and eliminating pollution.

Yield by weight of charcoal = 20 % of the charged wood. (This low yield is probably due to a high carbonizing temperature resulting a charcoal with high fixed carbon and low volatile matter).
Duration of complete cycle, including cooling: two days
Disadvantage of the system: The wood must be cut in small pieces and the operation is labour intensive.

(vii) Blast Furnace Plant

The Wundowie plant has two blast furnaces each 2.44 m hearth diameter with working volumes of 84 and 67 m^3.

Total output is 200 t/day and productivity is 1.32 t/m^3 of working volume or 20 t/m^2 of hearth area. Output is limited by available fuel. For comparison the Monlevade furnaces in Brazil have maximum productivity of 28 t/m^2.
Six tuyeres are used of 76 and 89 mm diameter. Blast furnace lining: ceramic bricks in throat, stack and bosh with carbon bricks in tuyere jacket and hearth walls.

Furnaces have double bells, charged by skip and distributed by McKee rotary hopper.
Gas cleaning is by primary dust catcher and Venturi scrubber.
Furnace cooling is by splash cooling of bosh, tuyere jacket and hearth. Stack cooling boxes were orginally installed but their cooling effect was too severe on such small furnaces so they are no longer used.

(viii) Furnace operation

The screened raw materials are stored in bunkers located above a scale car tunnel. Burden is mixed and not separated which means that all raw materials composing one charge are dumped together into the skip. Mixed, layer and spiral charging have been tried without noticeable difference in furnace operation. (Probable reason is the very small furnace diameter).

Iron ore mine is situated at 320 km by rail transport.

The ore is mixed hematite and limonite with average Fe content 61 %. Mn, P and tramp elements are low.

The charcoal has bulk density of 290 kg/m^3 fixed carbon of 70-80 % and 15-25 % volatile matter. All charcoal +4 mm is charged to the furnace. -4 mm fines are about 12 % of total charcoal.

The small size of charcoal is possible because of small furnace volume.

Screening at 12 mm has a favourable effect on the permeability of the furnace burden and on the charcoal rate per t of pig iron which decreases 10 %. However, this level of screening would reject about 23 % of the charcoal produced and may exceed the maximum possible to be injected through the tuyeres. Conclusions on this matter are reserved until trials have been carried out.

As the charcoal is produced at the iron and steel plant it suffers a minimum of transportation. This explains the very small amount of fines under four mm. In Brazilian practice -4 mm fines average 18-20 %.

(ix) Injection of charcoal fines through the tuyeres

The screenings under four mm are pulverised in a hammermill to minus two mm and are injected through the tuyeres of the furnaces. The pulverised fines are transported by air and separated out by cyclones into a pressure vessel at each furnace. It is discharged periodically into a second pressure vessel situated directly below it fitted at the bottom with venturi nozzles. Compressed air at about two atmospheres is used to pick up the fines and transport them by heavy walled rubber hose to lances inserted through the eyepieces of the tuyeres. Usually two lances per furnace are employed and these are periodically rotated from tuyere to tuyere. Charcoal consumption per ton pig iron, including fuel injected through tuyeres.

When screening at + 4 mm: ....700 kg = 2.4 cubic m.
" " at +12 mm: ....630 kg = 2.2 cubic m.

It is believed that the furnaces at Wundowie can be made much more productive by the use of sinter or pellets, higher blast temperatures and better sizing of the fuel.
An overall fuel ratio of less than two cubic m/t of pig iron may thus be possible. If this can be achieved, the operation will compare favourably with large coke fueled blast furnaces.
Research work is being done on the briquetting of charcoal fines. (One drawback is that charcoal fines, due to their high porosity, require large amounts of binder and that secondary carbonisation must be carried out before the necessary strength is developed for blast furnace use.)

(x) Secondary processing of the pig iron

The hot metal direct from the blast furnaces is transferred to high frequency induction furnaces for alloying and superheating. (See also similar trends in Brazil). All type of cast iron have been produced, including grey iron of all grades, ductile iron, ni-hard, high chrome alloys and chrome-molybdenum irons. Recently, steels have been made in a shaking ladle and held in the induction furnaces prior to casting.

(xi) Conclusions

The Australian operation at the Wundowie plant has unique conditions in the charcoal iron and steel industry. The aspects described are typical of conditions existing in highly developed countries like Australia with a strong emphasis on low labour and high capital intensity.
The following points are worth considering:

a. Forests

The forests which supply the wood consist of natural old eucalyptus trees. The forest and sawmill operations are highly organised and mechanised. Good use is made of waste wood for the charcoal manufacture. Great care is taken to properly airdry the wood to reduce the transportation costs of the wood to the distillation plant.

b. Charcoal manufacture

The charcoal is produced in a central carbonising plant located right at the iron plant. The equipment consist of two different systems of retorts which use the combustion gases produced during the distillation process, besides some available blast furnace gas. The thermal efficiency of the carbonising process and the yields charcoal to wood are high and air pollution by the pyroligneous vapors is avoided. All operations are mechanised. Charcoal quality is reported to be good. Maximum fixed carbon content is aimed at. The following serious drawbacks must be remembered.

i. Necessity to transport four ton of wood for each ton of produced charcoal.

ii. High capital intensity of the equipment.

iii. Unsufficient charcoal production for the blast furnace needs.

Cost figures are not revealed and therefore in this respect no comparison can be made with conditions and methods in other countries, principally Brasil.

c. Blast furnace plant

It consists of two small well designed and operated blast furnaces. Specific charcoal rates and furnace productivities are good and are being improved through advanced operational techniques. Of special interest is the technique of injection of charcoal fines into the furnaces through the tuyeres.

Secondary processing of the pig iron takes good advantage of the inherent good qualities of charcoal blown iron for the manufacture of quality foundry products.

(c) ARGENTINA (Bibliography references: 33, 34, 35, 36, 37)

(i) Introduction

Since 1944 Argentina has one integrated charcoal based iron and steel works "Altos Hornos Zapla" owned by the Government and operated by a department of the Defense Ministry. This was the first integrated plant in Argentina followed later by coke based plants.

The plant, situated 12 kms from San Salvador de Jujuy 1356 kms north of Buenos Aires, produces 275,000 t/yr of pig iron. It uses as principal fuel charcoal as well as some small amounts of petroleum coke and metallurgical coke.

(ii) Charcoal Manufacture

90 % of all the charcoal used is produced from "Quebracho" wood by independent manufacturers in the GRAN CHACO region situated south and southeast from Zapla and transported long distances to the plant.

The GRAN CHACO covers an area of 725,000 sq. km of three countries Argentina, Bolivia, Paraguay. Half of the region is situated in Argentina and most is covered by "Quebracho" bush forests. "Quebracho" is a tree of the ANACARDIACEAE family, genius SCHINOPSIS. It appears mostly in the form of bush. It is a hardwood and yields charcoal of high bulk density (about 350 kg/m^3) and high mechanical strength. The tannic bark of the wood is used in tanning. The charcoal is produced in forest piles and in kilns.

Beside the paramount supply from the GRAN CHACO area, the Zapla company has started to produce some of its own charcoal from eucalyptus forests planted in the works area. A forestry and charcoal production department is in charge of the activity which is being expanded. Its aim, beside forestry and charcoal production, is to determine through research and experiments, which methods and types of equipment are best suited for carbonisation. Two types of kiln are used.

a. Mostly beehive brick kilns similar to those developed in Brasil by Companhia Siderurgica Belgo Mineira. The difference is that the Zapla kilns use steel doors instead of brick doors. This arrangement facilitates the operations of wood charging and charcoal unloading. The steel doors last many years.

$$\text{Yield in volume} \left[\frac{\text{air dried eucalyptus wood}}{\text{charcoal}}\right] = 2.2$$

Fixed carbon in charcoal = 70 %

b. Experimental kilns with an independent outside wood fired hearth called Schwarts kiln. (See figure 21)
This type of kiln is still used, though little, by some charcoal manufacturers in Sweden and in Norway.
The kiln, built of ordinary clay bricks, is rectangular shaped, has vertical side walls and an arched roof. The side walls are reinforced by face standing U-beams and the arched roof is restained from movement by steel bars connecting the U-beams. The hearth, made of refractory bricks, is located under the kiln. It consists of the wood fueled fire chamber with a cast iron door and below it an ash tray with cast iron grate bars and an air port. There is a flue between hearth and central kiln floor opening. The hot gases produced by the wood combustion in the hearth penetrate into the kiln through the entrance "a" and leave it through the floor openings "b" located at the two kiln extremities and from these through the flues "c" to the outside chimney. The only air port is the hearth door and the kiln is therefore easy to operate. The only care which must be taken is to keep the fire in the hearth constantly burning until termination of the carbonisation process. If the fire goes out, the cold air entering through the door would set fire to the whole charge and burn it.
The two loading and unloading doors are made of four mm thick steel. The carbonisation process is best controlled by two pyrometers located each at the kiln extremities 20 cm above the floor. The carbonisation process reaches these points last; this is indicated by a constant temperature of 350°C.
When pyrometers are not available, the progress of the carbonisation process can be controlled by introducing steel bars through the openings "e": The hearth fire is then extinguished, the hearth and ash tray doors hermetically closed, and the kiln is left to cool.

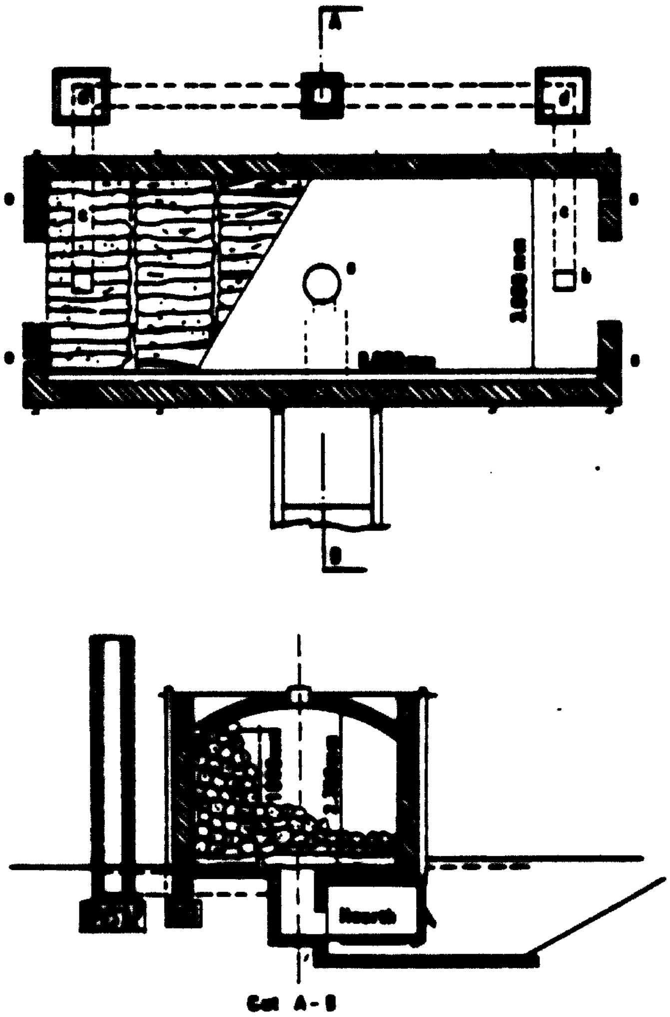


Figure 21
Schwartz Kiln for charcoal production.

It may happen that the distillation process at one extremity of the kiln is more advanced than at the other. When this happens the carbonisation can be controlled at one or the other point by regulating the gates located at "d-d". During cooling the same precautions must be observed as described in the operation of the Brasilian beehive kilns. Cycle for carbonisation of air dried wood with 20% moisture:

Carbonisation:	three days
Cooling:	four days
Loading and unloading:	one day
Total:	eight days

Wood consumption for hearth fire: four to seven steres, depending on moisture content

Table XXXVIII Schwarts kiln Yields from eucalyptus wood	Steres m³ charcoal min.	max.	average
Excluding fuel wood for hearth fire	1.33	1.80	1.60
Including " " " "	1.50	1.90	1.70

These latter yields are similar to those obtained recently by Belgo Mineira with its improved operation with central stack beehive kilns. The Schwarts kiln costs approximately twice the price of a brick beehive kiln of same capacity. This cost could be somewhat reduced by simplifying the equipment of the outside hearth and the two loading and unloading doors.

(iii) Conclusions

The Schwarts kiln presents some favourable points which are:

a. Use for hearth fire of low quality fuel wood, for instance branches, dry leaves, wood chips tree bark, unsuitable for charcoal manufacture.

b. Easy operation of the kiln and control of the carbonisation process through one air port.

c. Good and uniform charcoal quality.

d. Easy loading and unloading operations.

However, it must be examined whether these advantages outweigh the double cost of kiln compared with the circular Brazilian bee-hive kiln of similar wood capacity and charcoal production.

The Zapla company has kindly offered to supply the blue-prints of the Schwartz kiln on request by the interested persons.

(iv) Blast furnace plant

The plant has five blast furnaces of various sizes from 60 to 250 t/day capacity with hearth diameters of 2.6 to 5.6 m. Blast heating is by three cowper stoves/furnaces with blast temperature of 600-700°C.

1.34 t charcoal (1972) is used/ton pig iron. This high figure is due to the low iron content of the ore 40% - 48 % Fe. The total burden is 2,100 kg/ton iron and slag volume is 1,050 kg/ton.

Charcoal characteristics are 70% fixed carbon, 20-22% volatiles and bulk density 350 kg/m³. Hot metal composition is Si = 0.35-0.45%
(suitable for Thomas converter practice) Mn = 0.45 - 0.55%
P = 1.90 - 2.0%.

As previously stated small quantities of petroleum coke and metallurgical coke are also used in the furnaces; oil injection is also used in some furnaces.

TAMET, Talleres Metallurgicos San Martin, an iron and steel products manufacturing company located in Buenos Aires, is building a charcoal based iron and steel plant at Puerto Vilelas, on the Paraná River in the Chaco Province. Initial capacity of pig iron will be 50,000 t/year and the plant will gradually be expanded during the next ten years to 350,000 t/year and 90,000 t of sponge iron. Production will consist of pig iron, heavy iron castings and steel billets for rerolling. Charcoal will be produced in the plant vicinity which has large natural forest reserves and offers good conditions for reforestation. Iron ore will be shipped from mines situated near Corumbá, Mato Grosso, Brazil.

(d) PARAGUAY

The Government of Paraguay has decided to start in the near future a charcoal based iron and steel plant with the assistance of Brazilian capital, know how, engineering and equipment.

The company called "Aceros del Paraguay SA" (ACEPAR) will be controlled by Siderurgia Paraguaia (SIDEPAR) representing the Government ownership of 60%. Brazilian partnership of 40% consists of several companies.

The plant will be located at Villa Hayes on the river Paraguay a few kms north of Asunción. The site was chosen to be near company headquarters and the principal market and to permit water transport of all iron and manganese ores and 60% of the charcoal. Pig iron production is scheduled to be 100,000 t/yr with specific charcoal consumption of 740 kgs/ton corresponding to about 3 m^3 of charcoal with 70 % fixed carbon. The burden will be screened ores, hematite and manganese ore, from the Urucum mines, Corumbá, Mato Grosso, Brazil, 2,000 kms away. They will be transported by barges on the Paraguay river. Charcoal during the first eight years of plant operation will be made from natural forests in the vicinity of the plant.

After this period the wood will be supplied from artificial forests probably eucalyptus, at a rate of 60% of the charcoal needs. The other 40% will be supplied from natural forests by private charcoal manufacturers. Most of the charcoal will be transported by river barges. Two blast furnaces will be used; each 3.5 m hearth diameter, 148 m^3 working volume. Productivity will be 163t/day per furnace at 1.1 t/m^3 working volume.

Eight tuyeres will be used and three stoves per furnace will heat the blast to 700°C.

100,000 t/yr of hot metal and 18,000 t/yr of in plant scrap will be used in two BOF vessels of 12 t capacity producing 120,000 t/yr of crude steel.

Continuous cast billets will be used to make 100,000 t/yr of finished products in the form of reinforcing bars, wire rods, rounds, flats and angles.

2. POSSIBLE USES FOR CHARCOAL FINES

In the charcoal manufacturing process and in the numerous handlings to which charcoal is submitted from the kiln to the blast furnace between 10 and 25% by volume of fines less than six mm in size are produced. These fines represent a heavy loss and therefore all the important iron and steel companies are concerned with this serious problem.

The fines can be effectively used in the following ways:

(a) In the sintering process

Charcoal fines are an excellent fuel in the sintering of the Minas Gerais Hematite type fine iron ores called by "Jacutinga", with an average Fe-content of 65/69%. Inferior quality iron ores are also successfully sintered with charcoal fines. The wet sinter mixture needs 7 to 8 % charcoal fines by weight.

When 100% of sinter is used in the blast furnace burden, all the produced charcoal fines, roughly 20%, are consumed in the process and a complete equilibrium will be achieved between produced and consumed charcoal fines, plus the advantages of good sinter burden for blast furnace productivity and economy of charcoal rate.

Until recently all operating sinter plants using charcoal fines in Brazil were of the discontinuous Greenawalt pan type. The first continuous Lurgi design sinter plant of 1,000,000 t/yr capacity started successful operation at the Monlevade plant of Belgo Mineira in February 1978.

It consumes all the charcoal fines produced at Monlevade and allows a 90 - 100% sinter burden at the blast furnaces.

(b) Pulverized charcoal burning

Charcoal gives good results as fuel for pulverized fuel burners. The resulting flame has a high luminosity. Ferro Brasileiro uses it for boiler heating. Recently some cement plants are using charcoal fines for the heating of rotary cement kilns. The charcoal fines must be previously dried and screened to separate the majority of impurities and ashes. The charcoal is ground to approx. 100 mesh in a rotating ball mill. The powdered coal is blown through a special burner, alone or as an addition to another fuel, e.g. blast furnace gas.

During the last War some experiments were made in heating open hearth furnaces and rolling mill reheating furnaces with powdered charcoal fines, but the results were unsuccessful. Reasons: No previous drying and screening of the charcoal fines was done and, as a result, the content of impurities was too high. In the case of the reheating furnaces, the steel billets were covered in a short time with an insulating ash layer. These difficulties could be overcome through the above mentioned measures.

(c) Injection into the blast furnace through the tuyeres.

This process has not yet been used in Brazil but Acesita is examining its possible application in a new 900 t/day blast furnace which will commence operation in 1978.

The Australian charcoal blast furnaces at Wundowie inject successfully all their produced charcoal fines, which represent 12% of the charcoal production, in powder form. (Note: The amount of charcoal fines is lower and the fines are cleaner than the average Brazilian figures due to the Australian charcoal manufacturing process and the absence of transportation, as the charcoal is produced right in the steel plant).

The charcoal fines must be dried, screened and ground to approx. 200 mesh.

This process has been used for years with mineral coals.

The replacement value of 1 kg charcoal fines per 1 kg of charcoal in the burden is close to 1.0.

(d) Briquetting

(i) Briquettes for domestic fuel

The charcoal fines must be dried, screened and crushed in a hammermill to a certain size. The fines are hot mixed with a binder such as corn starch; pressed in a rotating press and dried at a temperature of approx. 80°C, to remove the moisture and to give the briquettes the necessary strength. The whole process is simple and cheap.

(ii) Briquettes for blast furnace use

The charcoal fines must be dried, screened and ground to 30% -200 mesh. The correct proportions of the size grading is very important.

The fines are then hot mixed with 25 % to 35 % of pitch (a large amount is needed because of the porosity of the charcoal). Charcoal pitch from wood distillation is an excellent binder.

Other carbonaceous materials may be added to the charcoal. Pressing must be done at very high pressures.

The raw briquettes must be carbonised at high temperatures: 900° to 950° C, to obtain the necessary strength for blast furnace use and to eliminate most of the volatile products contained in the pitch. Raw briquettes cannot be used in the blast furnace.

This kind of briquetting is a complex and expensive method of using charcoal fines because of the large amount of binder required and the heat treatment during which most of the binder is lost.

(iii) Other uses

a. As an addition to mineral coal in coking plants

This method has been successfully used in Brazil by Usiminas in amounts up to 5 % of the total coal mix; the resulting coke has been reported to be of good quality.

The charcoal fines must be previously screened to separate the majority of impurities which are always found in charcoal fines when charcoal is produced in kilns.

b. For direct reduction of iron ore

Numerous successful laboratory and pilot plant experiments made in Brazil and in Germany by the rotary kiln method indicate that charcoal fines, between three and 12 mm size are an excellent reducing agent for the reduction of the high grade Minas Gerais Hematite iron ores with 65 to 69 % Fe, in similar sizes to the charcoal fines.

The advantages of charcoal in this process are:

Its excellent reactivity due to its high content of volatile matters.

Its low ash content and the absence of sulphur.

As a result of these typical charcoal qualities, the operation temperature of the process remains low, under 1000°C, which is lower than the softening point of the charcoal ash and the ore gangue. The process is fast, resulting in a much higher output than when operating with coke breese or mineral coke fines.

Charcoal consumption is estimated at about 600 to 700 kg per ton of sponge iron.

The degree of metallisation for the above mentioned iron ore is about 90 % and the sponge iron is excellent burden for the electric arc furnace.

Up to the present moment no existing industrial installation for direct reduction of iron ores is using charcoal fines.

o. As an addition to the refractory material for blast <u>furnace tap hole clay</u>

Charcoal fines can be used as a major ingredient of taphole clay up to 33 %. The remaining ingredients being quartsite, sand and pitch as a binder.

3. ALTERNATIVE TECHNOLOGIES FOR IRON MAKING USING CHARCOAL APPLIED IN BRAZIL (Bibliography reference 25)

(a) The low shaft charcoal electric reduction furnace based on the Tysland Hole Process (See also Section 4.(a) - Sweden)

The electric low shaft furnace consumes less solid reductant than the blast furnace but, because of its high electric energy consumption which is sometimes considered an unfavourable aspect, the furnace is particularly favoured where electric power is cheap. This is the case for iron and steel companies who own and operate hydroelectric plants, for instance Acesita which has a 50,000 KW power plant.

A favourable aspect of the low shaft electric furnace is its flexibility with regard to the use of solid reductants, as all types of mineral coals, coke breeze and charcoal can be used in any combination. This flexibility is interesting for charcoal based iron and steel plants which, due to great distances from the sources of charcoal supply or for other reasons, suffer sporadic or constant charcoal deficiencies and want to lower their charcoal rate and thus become less affected by the fluctuations of supply.

Brazil has further developed the Norwegian Tysland Hole process started in the beginning of the century and has brought the technology of the electric low shaft furnace to a high degree of productivity. Much research and development work has been done and as a result furnace operation has become very reliable.

The advantage of charcoal over coke in the low shaft electric furnace is characterized by the fact that the electric resistance of charcoal increases with the temperature whilst the resistance of coke decreases with temperature. This increase of electric resistance causes a local rise in furnace temperature which has a favourable effect on charcoal rate and energy consumption and increases furnace productivity about 30% compared with coke.

The quality of the refractory lining must be of a very high grade in order to resist the high local temperatures. Special refractories have been developed by the Brasilian refractory manufacturers with excellent results. The low shaft top gas contains more than 80% of $CO+H_2$ which makes it very suitable for the direct reduction of hematite iron ores. Research is being done to combine the low shaft furnace with a direct reduction process which would produce sponge iron. It is expected that for each ton of hot metal, 0.7 tons of additional sponge iron could be produced but it is too early to make an evaluation of this possibility and its economies.

Data on existing furnaces in Brazil are as follows:
Three existing furnaces, two at Mannesmann and one at Acesita all designed by Demag.

1977 pig iron production:	200,000 t.
Transformer capacity of each furnace:	17,100 KVA (3x5700)
Daily production of the furnaces:	150-220 t each
Power consumption:	1,850 - 2,00 kWh/t iron
Cooling water consumption:	37-42 cubic m/t
Charcoal consumption:	450-550 kg/t iron (300-350 kg fixed C)
Charcoal size	12-25 mm
Slag volume (with Fe-content approx 20%)	400-450 kg/t (Mostly recirculated from the BOF and electric furnaces)
High grade Hematite ore rate	1,350 - 1,400 kg/t iron
Top gas Calorific value:	2,600 Kcal/N cubic m
" " Quantity:	500 - 600 N cubic m/ t iron
Electrode consumption:	3-5 kg/ t pig iron

A fourth Brasilian low shaft electric reduction furnace to produce 75,000 t/yr with an electric power of 33,000 KVA is being built by the Barbará Company, in the State of Rio de Janeiro. This company produces centrifugally spun cast iron pipes.

(b) Rotary kiln reduction furnace

Upto the present, in Brasil, charcoal has not been used in direct reduction rotary kilns despite successful laboratory and pilot scale experiments reported in Section 4.2 "Possible uses for charcoal fines".

From a regional point of view this process would be well suited for certain areas of the State of Mines Gerais where large amounts of charcoal fines are available as well as suitable high grade hematite iron ores and pellets. For economic production of sponge iron ores and pellets must have special chemical and physical properties to reduce to a minimum the slag volume in the subsequent electric arc melting furnace. Chemically the ratio $\frac{SiO_2 + Al_2O_3}{Fe}$ should be less than 5% and the phosphorus content below 0.05%.

Thus, raw materials for direct reduction have an appreciably higher price than the corresponding iron ores for blast furnace use. This factor must also be remembered when comparing the blast furnace with the direct reduction route. From the point of view of present cost comparison the charcoal blast furnace is still the more economical process.

4. THE BABAÇU NUT AS A RENEWABLE SOURCE OF REDUCTANT AND FUEL (Bibliography references 22, 23)

Vast areas of the North and North East regions of Brazil, represented principally by the States of Marenhão, Piauí and Goias, are covered with extensive forests of Babaçu palmtrees which produce an oil-yielding fruit, 5 to 7 cm in diameter and 8 to 15 cm length. The total area covered by these forests is calculated at 170,000 sq. km or 17 million hectares, with an average tree density of 250 per ha. The yield of cocoanuts varies from 0.3 to 9 t per ha/year and, for areas of medium tree density, is 2.7 t/ha/year.
Upto the present time the babaçu cocoanut is exclusively used as food and for its vegetable oil content which represents 6 or 7% of its total weight. The babuçu palmleaves are used as roofing and construction material for houses.

After the cocoanut has been broken and the oil extracted, the remaining shell pieces can be carbonised to yield a charcoal which has excellent chemical properties considered superior to the charcoal made from eucalyptus wood.

Unfortunately the particle sizes of the resulting charcoal are too small for direct use in the blast furnace. They must be agglomerated. Carbonisation of the entire Babaçu cocoanut gives a strong lump charcoal but this process is uneconomical because the high nutritious value of the fruit contained in the shell is lost in such carbonisation.

The total potential of these vast regions is estimated at 40 million tons of cocoanuts per year, corresponding to 10 million tons of charcoal. Approximately one fourth of this quantity, or 2.5 million tons of charcoal, could be made available in concentrated areas and could therefore be economically used industrially.

The principal cocoanut producing regions of the State of Maranhão have numerous navigable rivers. so it is a general opinion that these waterways could easily be used for barge transportation of the cocoanuts to distillation and briquetting plants, to be located on the river banks, and from thence to the consumers, also by boat. Due to the high energy potential of the Babaçu coconut and its availability, it is considered by many experts and by the Brazilian Government as a partial and renewable carbon source for large coke based national iron and steel plants. In consequence, the Secretariat of Industrial Technology charged Siderbras, the Brazilian Holding Company for the State owned Steel Companies to undertake "Babaçu" research and development programme. After intensive studies and pilot plant work in Brazil and abroad, the following preliminary conclusions have been drawn: (1977)

(a) The potentiality of the Babaçu palm forests as a supplier of large and regular quantities of coconuts is a reality and the yield of coconuts in t/ha/year in the areas of medium tree density is sufficient to permit an economical industrialisation .

(b) The carbonisation of the coconut shell, after extraction of its vegetable oil, yields a charcoal of excellent chemical qualities which can be controlled through the distillation temperature.

(c) The distillation by-products can be used as fuel and as raw material for the chemical industry. The gases could be used in the direct reduction process of iron ores.

(d) The use of Babaçu charcoal may be considered in the following iron and steel industry applications:

(i) As sinter-fuel in combination with, or as a substitute for, coke breeze. These two possibilities have proven successful in industrial tests made at the sinterplants of "Siderurgica Nacional" and Usiminas.

(ii) As an ingredient of the coking mixture, probably up to 20%, with mineral coals. Pilot tests have proven the viability of this process.

(iii) As a mixture with mineral coals for the manufacturing of formed coke to be used in foundry cupolas, low shaft electric reduction furnaces and, under certain quality conditions, in the blast furnace.

(iv) As briquettes made from 100 % Babaçu charcoal fines for use in foundry cupolas. Briquetting tests have been made at Usiminas with a rotary press and the briquettes have been tested with success in a cupola. The greatest disadvantage of briquetting is that they must be again carbonised at high temperature to develop the necessary strength for use in cupolas and blast furnaces.

(v) As a reductant of iron ore in rotary kiln direct reduction processes. (SL-RN, Krupp and others).

It is expected that, as a result of the future possible large use of Babaçu charcoal by the coke based iron and steel industry, the country will gradually reduce its dependence on imported coking coal. The necessary investments, of the order of US$ 300 millions, will be largely compensated by the savings in foreign currency for imported coking coal. The installation in the State of Maranhão of an industrial complex based on the use of babaçu coconut is being studied. Charcoal production will be 240,000 t/year.

From a socio-economic point of view the large scale industrialisation of the Babaçu coconut is important to the rural populations of the affected areas as the manual collection of large quantitits of coconuts and their transportation will offer a regular family income for some hundred thousand persons, including men, women, children.

These people already make a living from the Babaçu coconut, but, as the quantities are small, their income is very modest. It is expected that the quantities collected, per capita, in the future will increase tenfold.

5. DESCRIPTION OF FOUR MAJOR BRAZILIAN CHARCOAL BASED IRON AND STEEL PLANTS

(a) Companhia Siderurgica Belgo-Mineira (CSBM)

(i) Introduction

CSBM was the first integrated iron and steel company in South America and to-day is the largest charcoal based steel company in the world.

It was founded in 1921 as a partnership of a Brazilian company "Companhia Siderurgica Mineira" and the Luxemburg company ARBED, To-day ARBED has 30% of the shareholding and the remainder is owned by 45,000 Brazilian citizens.

Iron making activity started with blast furnaces at Sabará near Belo Horizonte; steelmaking and rolling plant were later added. Activities were expanded in 1937 by the construction of the new Monlevade integrated iron and steel plant with an original capacity of 100,000/yr of ingot steel. This was one third of the total Brazilian market at that time.

The technical and economic success of the Sabará plant provided the experience and confidence necessary for the Monlevade expansion and the Sabará plant became the practical training school for a whole generation of Brazilian metallurgical engineers and managers.

The more favourable conditions at Monlevade led to the continuous expansion of that plant and since 1969 the Sabará plant has been limited to ironmaking and general maintenance activity for the whole CSBM group.

(ii) Present Sabará Plant (Usina de Sabará)

This consists of two 150 t/day blast furnaces with blast heating by cowper stoves.

Production is 120,000 t/yr of which 13,000 t are used for heavy iron castings in their own foundry. This is being expanded to 40,000 t/yr. The remainder of production is cast as pig iron for steelmaking. Iron ore comes from the plants' own mine in the vicinity.

An interesting feature is that 10,000 m^3/month of charcoal, 1/3 of total requirements, is transported to the plant by rail a distance of 700 kms in plastic bags of three m^3 capacity. These are loaded and unloaded by travelling crane. The bags are re-used for more than 60 trips. It is proposed to double the capacity of this method of handling and transportation.

Figures:

22- Blast Furnace Plant 1 - Layout.

23- Section through blast furnace 1

24- Section through blast furnace II

25- Section and plan Cowper stove I - II

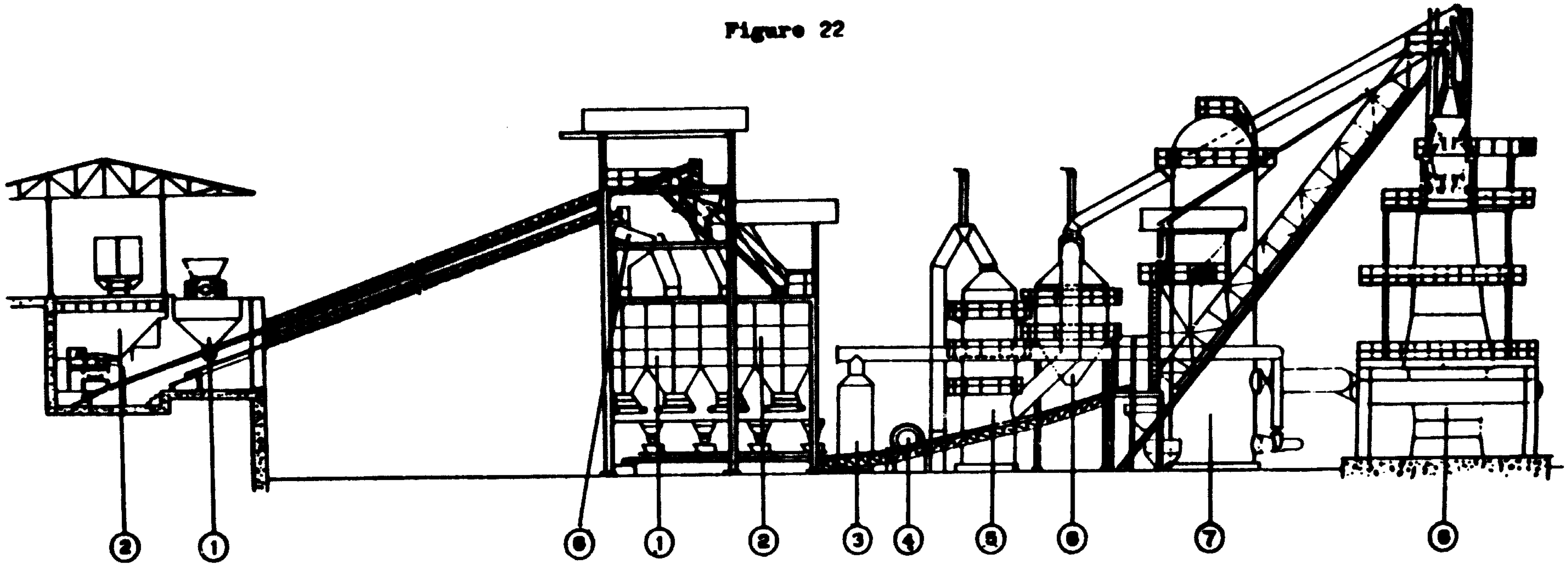
26- Section and plan Cowper stove

27- Casting beds.

COMPANHIA SIDERÚRGICA BELGO MINEIRA
USINA DE SABARÁ

BLAST FURNACE I

Figure 22



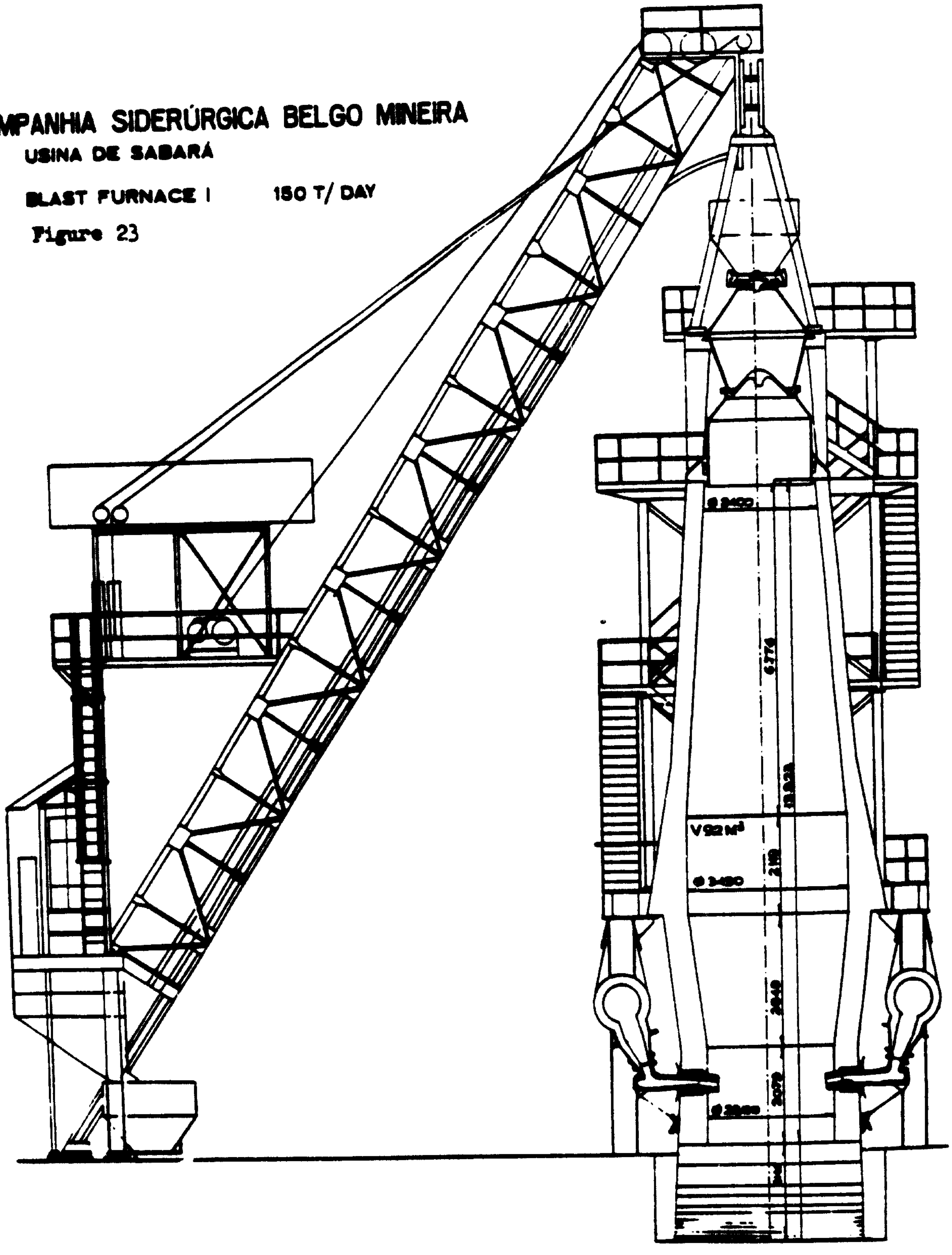
1 - IRON ORE BIN
2 - CHARCOAL BIN
3 - MOISTURE TRAP
4 - THEISEN DESINTEGRATOR
5 - WASHER
6 - DUST CATCHER
7 - COWPER STOVE
8 - BLAST FURNACE
9 - SCREENING

COMPANHIA SIDERÚRGICA BELGO MINEIRA

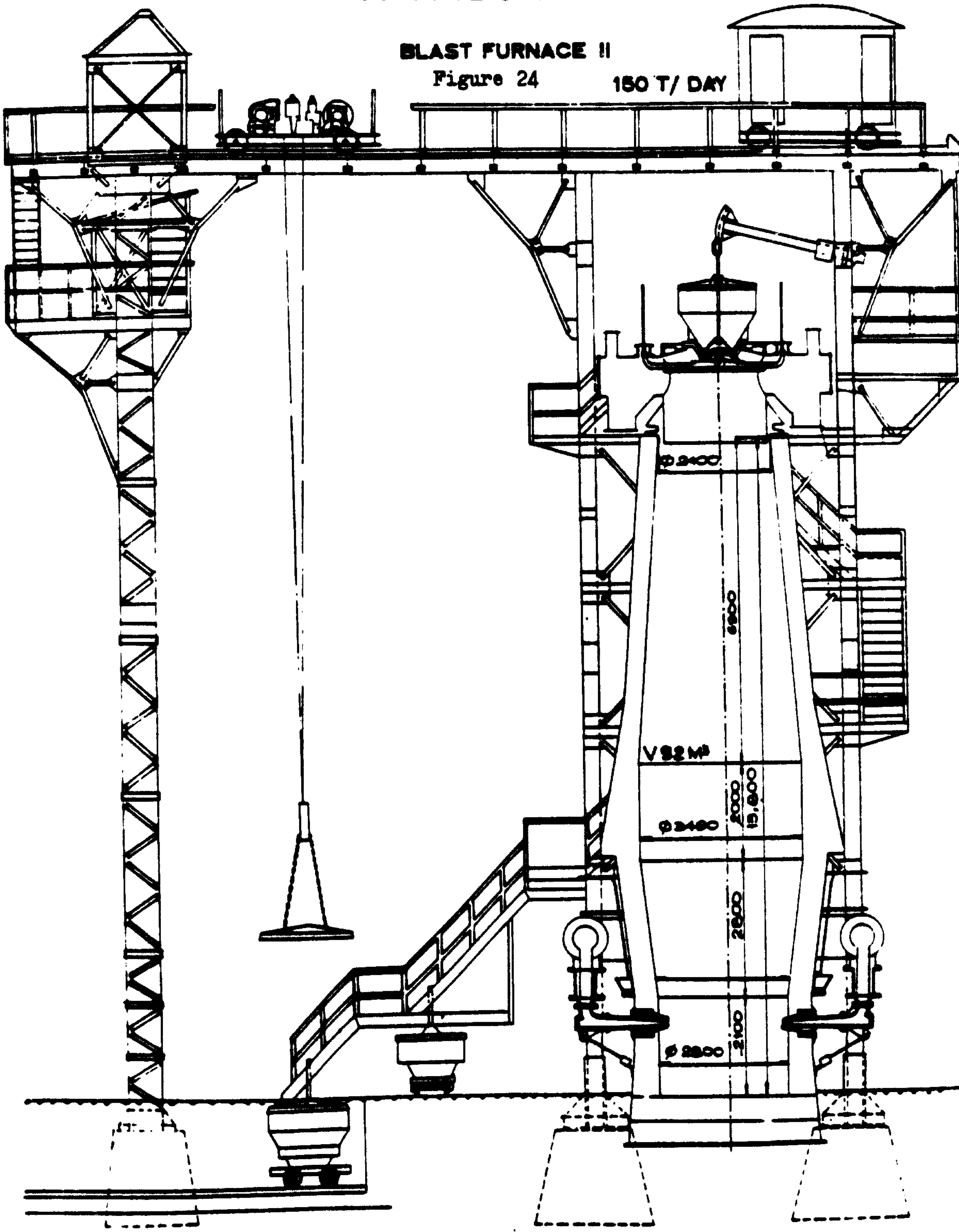
USINA DE SABARÁ

BLAST FURNACE I   150 T/ DAY

Figure 23



COMPANHIA SIDERÚRGICA BELGO MINEIRA
USINA DE SABARÁ



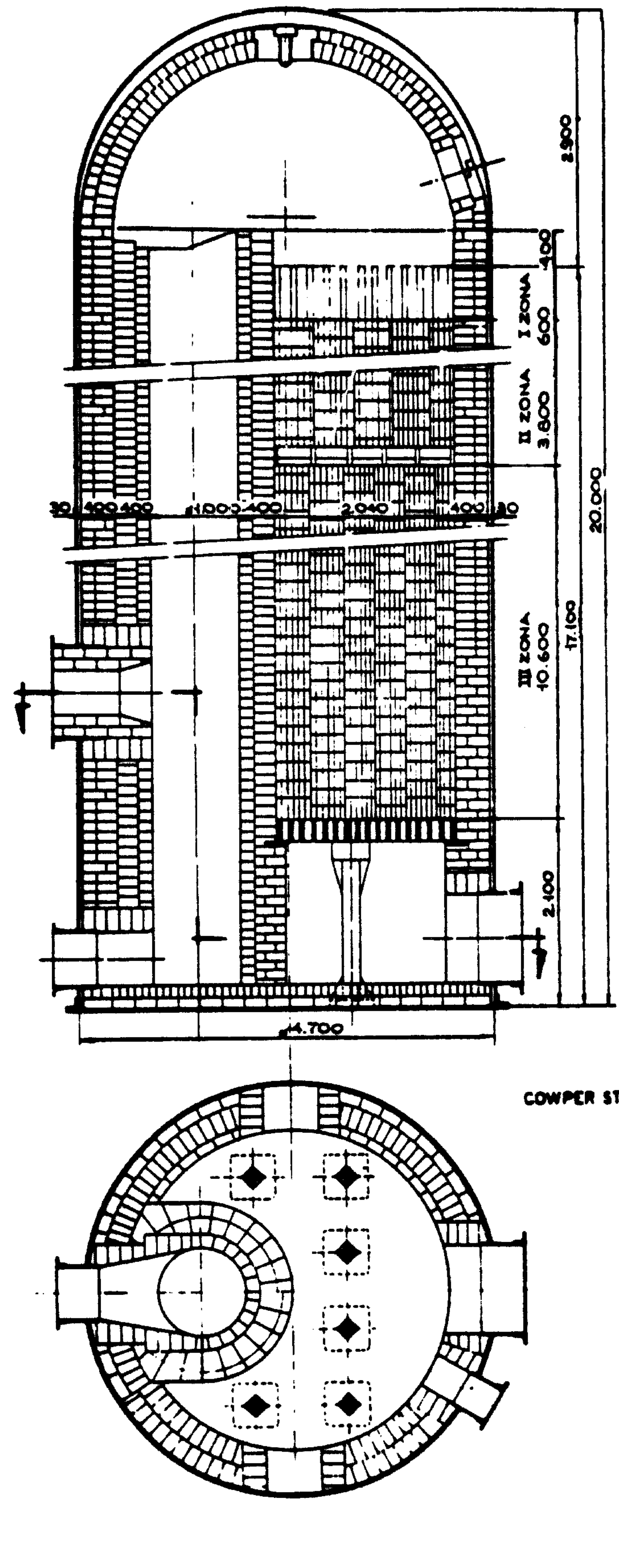
BLAST FURNACE II 150 T/ DAY

Figure 24

COMPANHIA SIDERÚRGICA BELGO MINEIRA

USINA DE SABARÁ

Figure 25

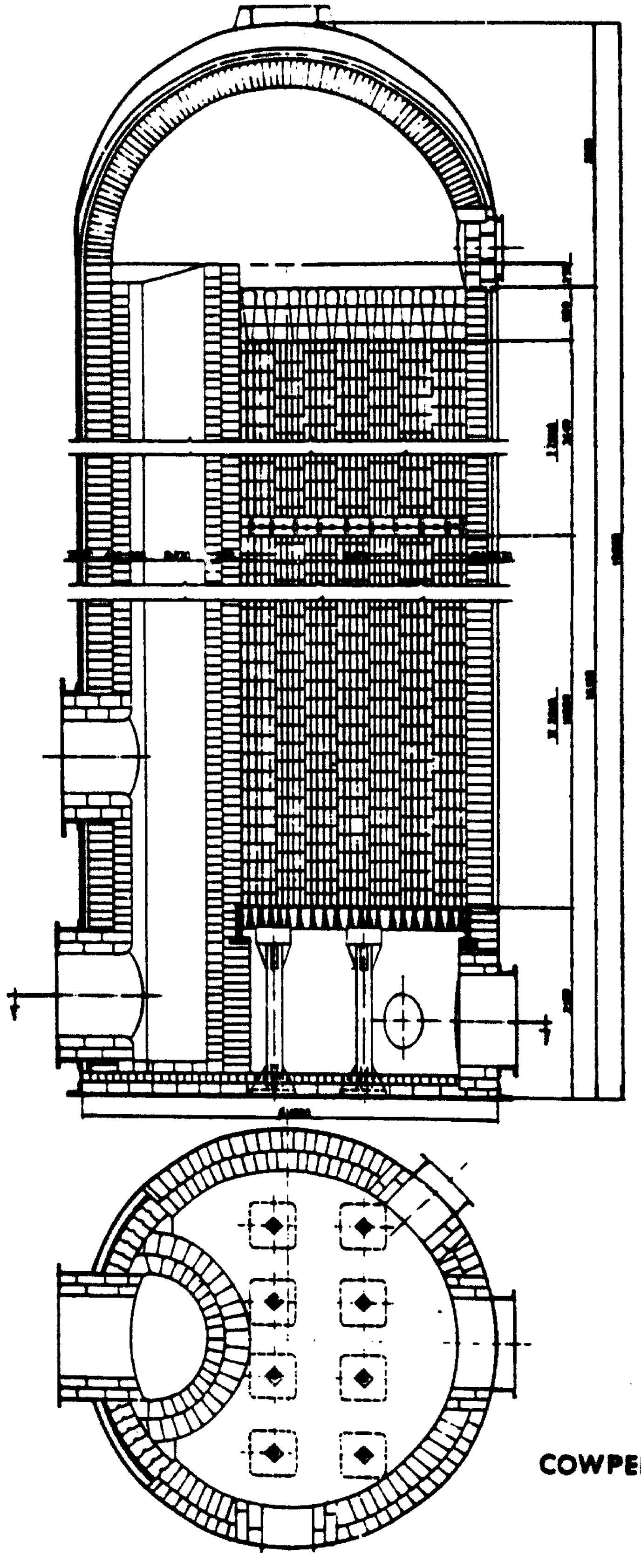


COWPER STOVE I · II

COMPANHIA SIDERÚRGICA BELGO MINEIRA

USINA DE SABARÁ

Figure 26

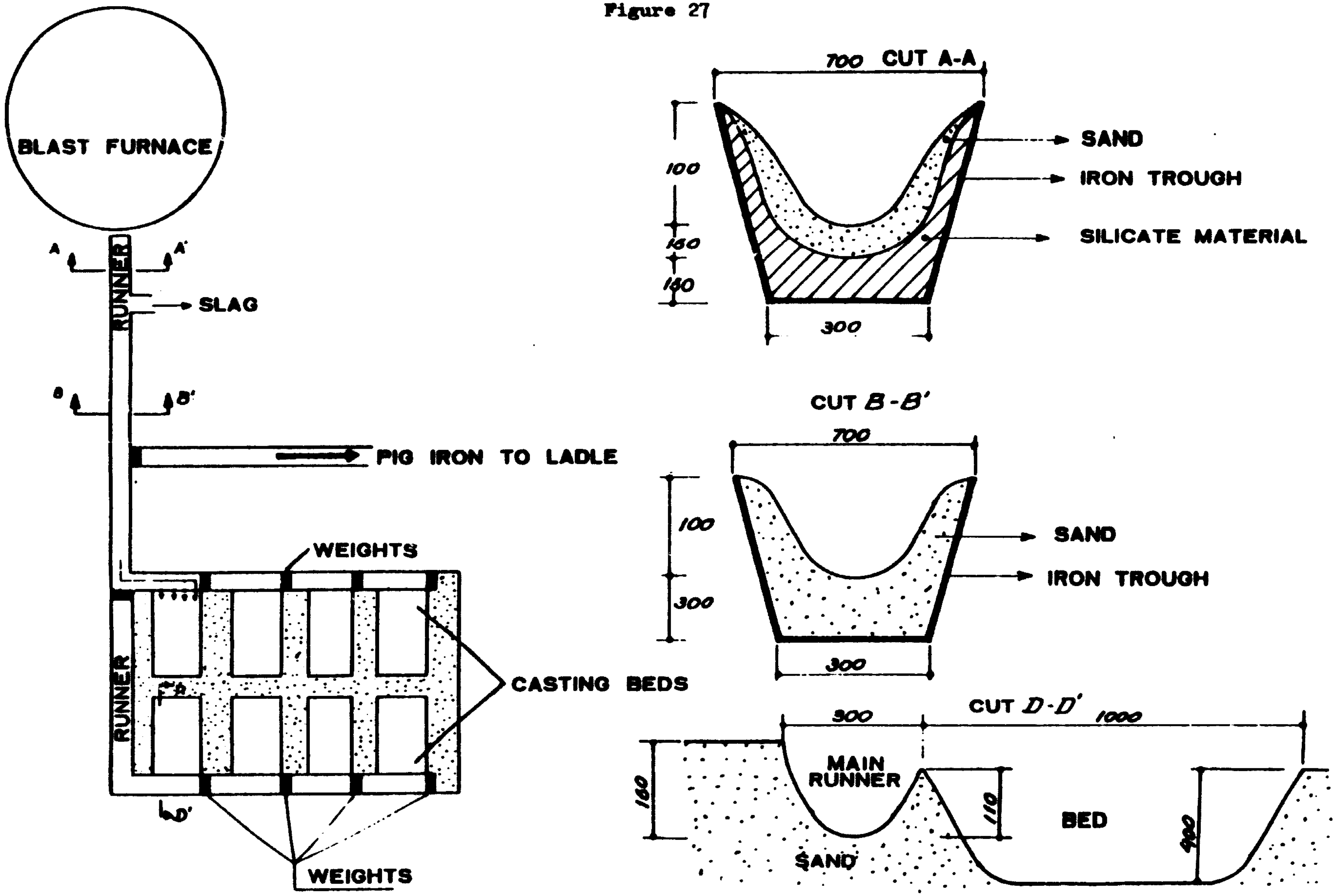


COWPER STOVE

COMPANHIA SIDERURGICA BELGO MINEIRA - USINA DE SABARÁ

CASTING BEDS

Figure 27



(iii) The Monlevade Plant (Usina de João Monlevade)

The Monlevade plant is situated 130 kms from Belo Horizonte in the eastern region of Minas Gerais State in the Piracicaba river valley. It was chosen to be close to the Andrade iron ore deposit with large forest reserves in the vicinity. The Piracicaba river offered hydro-electric potential, and good rail connections were made available. The plant has four blast furnaces and a fifth has been designed and ordered. Present pig iron output is 600,000 t/year and crude steel 800,000 t.

a. Charcoal supply.

From 1937 to 1952, when the pig iron production reached 100,000 t/year, the quantities of charcoal produced from natural forests in the plant vicinity, were sufficient for the plant's needs.

As the former forests were gradually transformed into pasture and agricultural land, and the natural regrowth of the forests took approximately 25 years, the company management became convinced that, in the long run, only man planted forests could guarantee a continuous and regular charcoal supply.

Another serious problem was poor transportation and insufficient storage capacity. During the rainy season, lasting from October to April, the earth roads and the two narrow gauge railways were frequently interrupted, causing sporadic difficulties in the charcoal supply, and so limiting blast furnace production. The charcoal quality also suffered during long rainy periods. Moisture contents reached 30 and sometimes 40%.

To meet the ever increasing demand of charcoal and to relieve the transport and storage deficiencies, the following successful measures were taken:

i. To develop eucalyptus reforestation in the Monlevade, Rio Doce and other regions, and so gradually make the company independent of natural forests.

ii. To build an aerial cableway to transport to Monlevade the charcoal produced in the main manufacturing areas then situated, in the Rio Doce Valley.

iii. To build a large charcoal depot in the vicinity of the plant to store the charcoal necessary for a long period, principally during the rainy season.

iv. To install in the charcoal manufacturing centers a series of intermediate storing depots to protect the charcoal against the rain during prolonged periods. Charcoal manufacture, reforesting and administration of the company's land is done by a subsidiary, Companhia Agricola e Florestal Santa Barbara (CAF).

Table XXXIX Present and future charcoal activities of CAF

Year	Yearly Charcoal Needs (m^3)	Yearly Charcoal produced by CAF (m^3)	Total reforested area (ha)	Yearly forestation (ha)
1977	1,800,000	720,000	130,000	12,000
1983	2,100,000	1,400,000	190,000	12,000

The company employs 8,300 people in reforesting and charcoal manufacture.

It is produced in thousands of beehive kilns. Yields over the years have improved through better operation and design, from 2.2 to 1.6 steres of wood per m^3 charcoal. The company maintains a pilot plant for test and development work. Charcoal arrives at Monlevada by aerial rope way, rail and trucks , at a peak monthly rate of 200,000 m^3 (1,600,000 m^3/yr) and is received and stored in a 240,000 m^3 capacity concrete storage depot.

This depot is shown in figures 29,30 and 31.

It is divided into equal 20 sections each of 25 m length thus permitting separate storage of different charcoal qualities and reducing losses in case of fire. The whole area of the depot can be reached by the incoming distributors and belt conveyors which are mounted on two cross carriages each spanning half the storage area.

Charcoal is discharged by two travelling extractor machines, located in tunnels under the whole length of the depot. The whole system of unloading, storing, discharging and transfer to the blast furnaces is very flexible and allows a great variety of simultaneous operations, like discharging of the depot and unloading of railway cars, trucks, aerial cableway.

A very complete fire extinguishing system by means of sprinklers and waterhoses has been installed to rapidly combat the occasional, but rare, fires. Still the best method consists in emptying immediately the cell which has caught fire through the conveyor system.

Before storage all incoming charcoal is measured by volume and the weights are also checked.

50% arrives as lump charcoal in trucks

25% arrives in rail wagons

10% arrives by aerial cableway.

All discharging is mechanised.

Charcoal can be delivered from arrival point directly to blast furnace bins or to the storage depot. Before delivery to the furnace bins it is screened on double deck vibrating screens and separated into three sizes.

Coarse - greater than 30 mm

Fine - between 10 and 30 mm

and Breeze - less than 10 mm.

Table XL Charcoal characteristics (1974). CSBM -

As received at depot	Coarse	Fine	Breeze
Moisture %	9.8	12.9	14.7
Bulk weight kg/cubic m	255.8	272.0	346.5
Average size (mm)	37.02	15.67	3.68
Chemical analysis %			
Ash	3.2	5.0	11.9
Volatile matter	26.1	26.4	27.2
Fixed carbon as received	70.3	68.6	60.5
Bulk weight dry	230.6	237.2	296.2
Chemical analysis of ash			
SiO_2	13.33	16.14	41.19
Fe_2O_3	4.04	4.43	4.87
MnO	0.76	0.74	0.51
Al_2O_3	3.15	4.66	6.37
CaO	30.66	33.88	21.45
MgO	6.31	5.73	1.63
P_2O_5	3.27	2.58	1.63

The coarse and fine sizes are taken by separate conveyors to 12 concrete blast furnace bins having a total of 12,500 m^3 capacity which is two days blast furnace requirements.
The breeze - 10 mm is rescreened at 4 mm and the - 10 mm + 4 mm is used as fuel for sintering. The - 4 mm charcoal is discarded as it contains too many impurities.
Before charging into the blast furnace bucket, the coal is rescreened at 6 mm opening and the resulting breeze is also used as sinterfuel.
Most charcoal fines are produced at the manufacturing centers and during the charcoal transport but some fines are produced as a result of the handling at the storing depot, total is 18 - 20%. At present (1978) all the fines are absorbed in the new sintering plant.

b. Iron Ore.

A subsidiary company operates the Andrade mine which is situated about 10 kms from the plant and connected by the company's electrified one m gauge railway. Mining is by open pit and all operations are mechanised.
The mine has a proven reserve of 100,000,000 t of which 80,000,000 are high grade Hematite of 66 - 68% Fe which is used in the plant.
A 300 t/hr ore crushing and screening plant at the mine provides sized ore 19-31 mm for the blast furnace
6-19 mm as hearth layer for sinter plant and blast furnace
0-6 mm for sintering.

c. Sinter.

To use the fine ore - 6 mm a pan type sinter machine was installed in 1945. This had two pans each 14 m^2 giving a daily sinter production of 760 tons or 250,000 t/yr. The fan suction was 1,100 mm w.g.

Typical wet sinter mix was:

Ore (0 - 6 mm)	50 - 60 %
Lime and Limestone	2 - 3 %
Granulated BF slag	2 %
Mill scale	1.0 - 1.5 %
Fine manganese ore (30 - 35 % Mn)	1.0 - 1.5 %
Return fine sinter (0-6 mm)	30 - 40 %
Charcoal fines (0-6 mm)	7.0 - 8.0 %
Moisture	8 - 10 %

Ore, sized 6 to 19 mm is used to protect the pan grate bars. A goethite ore, - 6 mm, from the company's Alegria mine has been recently added to the sinter mix. This is a hydrous iron oxide with 62% Fe and 10% combined water; it has a large grain size which gives greater permeability to the sinter mix so that sinter output has risen from 250,000 t to 320,000 t/yr permitting a high percentage of sinter in the blast furnace burden and giving an increase in iron output and savings in charcoal.

A new, continuous grate, Lurgi sinter plant has been commissioned early in 1978. This has a total grate surface of 120 m^2 and will produce 1,000,000 t/yr. This permits the blast furnace burden to be 100% sinter and all the arising charcoal fines are being used.

d. **Blast Furnaces**

Furnaces I, II and III are of the self-supporting type, a variation of the European design. In furnace IV the stack is independently supported from the hearth and bosh. All have steel shells with external spray cooling.

The furnaces are charged by vertical 7 m^3 bucket hoists, Staehler design, total charging cycle four minutes. They have single bell tops and a fixed burden distribution device of simple design.

Oxygen enrichment of the blast and fuel oil injection through the tuyeres is operated on all four furnaces.

Table XLI

Furnace Characteristics	Blast Furnaces I - II - III	Blast Furnace IV
Production (t/24 h)	400 - 450	200 - 220
Hearth diameter - m	4,654	3,900
Working volume cubic m	214	164
Number of tuyeres	12	8
Number of cowper stoves	3	2
Heating surface sq.m.	4,834	4,677
Volume of blast cubic m/h	22,000	11,000
Pressure of blast kg/sq.mm	0.65	0,40
Temperature of blast °C	830 - 850	700 - 750
Oxygen content of blast %	23 - 25	23 - 25

Table XLII Furnace burdens and productivity -

Blast Furnace No.	Sized Ore 19-31 mm	Natural Pellets 6-19 mm	Sinter 6 - 100 mm	Productivity t/m^3/d
I-II-III	30%	25%	45%	1.77-1.96 * 2.03
IV	100%	-	-	1.22-1.34

*) Productivity

Blast Furnaces I-II-III 1.77 - 1.96 without rescreening t/m^3/d.
2.03 with "

Charcoal rates/t iron and oil rate /t iron			Fixed Carbon -kg/t/iron		
Blast Furnace	Charcoal Cubic M	Oil Kg	Charcoal	Oil	Total
I - II - III	** 2.592 2.46	44	425	37	462
IV	** 2.55 2.50	40	432	32	464
I,II,III,IV	2.581	43	427	36	463

**) Average 1974

Slag volume 100 - 140 kg/t hot metal

Flue dust 25 kg/t hot metal.

Pig iron analysis:

Fe = 94-95%; C = 4.0 - 4.3%; Si = 0.2 - 0.6%; Mn = 0.3 - 0.6%
P = 0.20% max.; S = 0.012% without oil and 0.025% with oil.

Gas cleaning in primary dust catcher, followed by stationary water spray tower, Theissen disintegrator and de-humidifier.
All the pig iron goes as hot metal to the LD steelmaking plant.

e. Steelmaking plant

Monlevade has two steel plants:

i. Four oil fired Siemens Martin furnaces of 42 t capacity each, using cold pig iron and uprising scrap. The company is studying the replacement of the open hearth furnaces by electric arc furnaces.

1977 production ....230,000 t

The furnaces have basic (magnesite) roofs and regenerative checker work chambers for preheating the combustion air.

ii. Two LD basic oxygen top blown vessels of 42 t each,

1977 production .... 521,000 t

The Sabará plant supplies additional 60,000 t of steel.

All steel is poured into 3.5 t Sq moulds - bottom filled -

rolling mills.

Ingot soaking pit furnaces.

Ten gas fired furnaces. Several more to be installed to increase heating capacity to one million tons/year.

Roughing mills.

Two two-high reversing mills, 1000 mm and 750 mm diameter.

Bloom size: 120 x 120 mm.

Billet mill.

One continuous 3 stand mill for the rolling of 80 x 80 mm billets for the Morgan rod mill.

Semi-continuous wire rod and bar mill.

Sizes: Bars and coils 6.5 mm to 16 mm diameter.

Capacity: 150,000 t/year. Production 1977: 130,000 t

Continuous wire Morgan rod mill.

Rod sizes: 5.5 mm to 12.5 mm diameter.

Capacity: 600,000 t/year

Production 1977: 550,000 t.

The company's wire drawing plant at Cidade Industrial, the industrial city in the vicinity of Belo Horizonte, produces 500,000 t/year of low, medium and high carbon wire products from wire rod produced at the Monlevade Morgan Mill.

f. Company Amenities

The employees of the Monlevade plant live in the town of the same name and in the surrounding small communities. The population of Monlevade is 40,000 people. The town has been totally built by the company. It has several thousand houses, a hospital, church, public buildings, hotels, recreational facilities. Since 1960 most of the houses have been sold to the employees.

Commercial and financial aspects of the company.

Sales in 1976:

	Tons	
Cold drawn wire	468,025	
Wire rod	141,595	
Bars	60,393	
Cast iron products	3,487	
Total	673,500	US$ 270 million

Sales value per t: ....US$ 400/t

Profits after taxes: ....US$ 65 millions.

In 1976 a total of US$ 70 millions have been reinvested in own and subsidiary plant equipment and in forestry activities.

<u>Figures</u>

28 - General layout of blast furnaces and steel shops

29 - Charcoal storing place

30 + 31 - Charcoal storing and regulating depot (2 figures)

32 - Charcoal screening

33 - Charcoal screen house

34 - Schematic arrangement of blast furnace charging

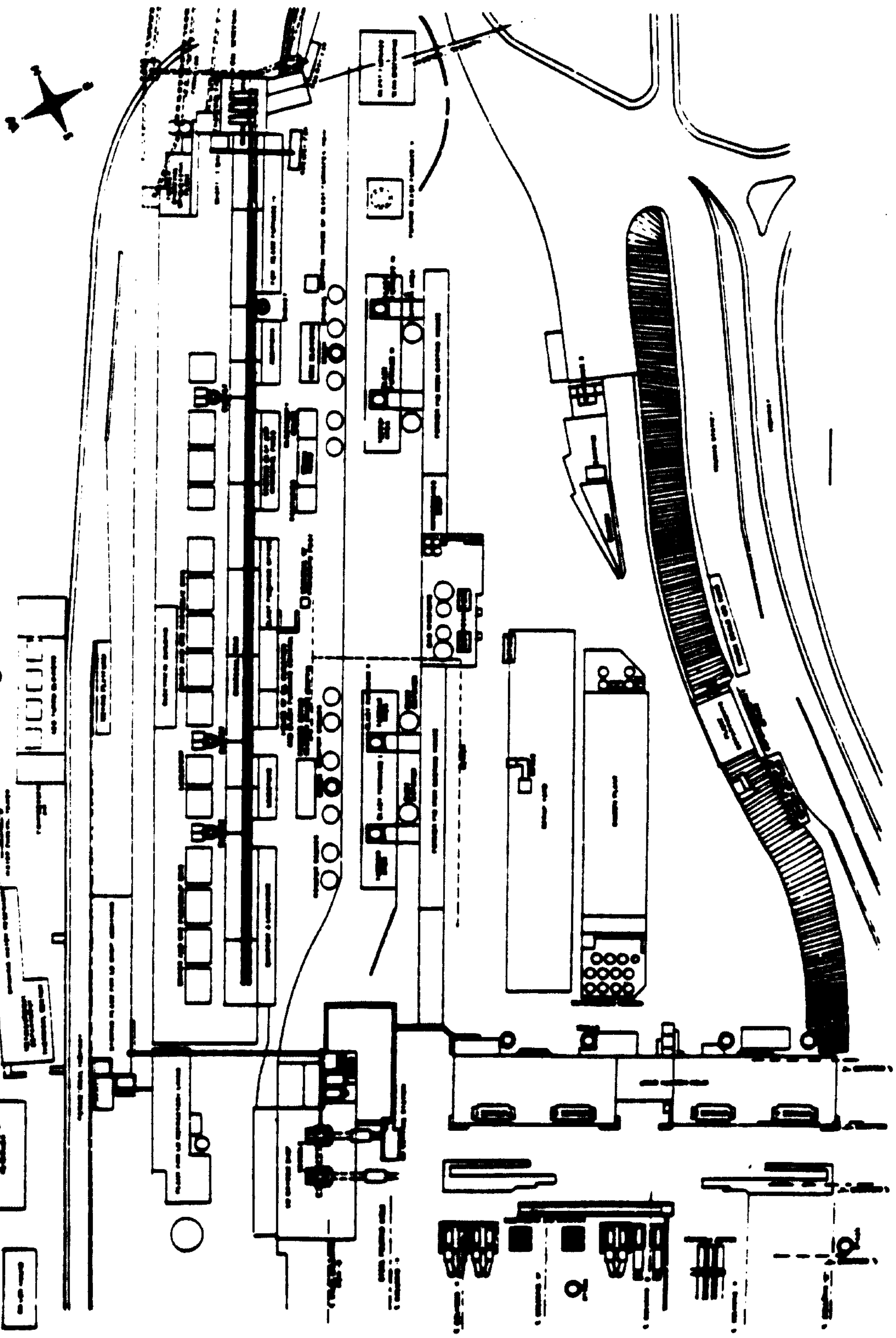
35 - Blast furnace 1

36 + 37 - Blast furnace (2 figures).

COMPANHIA SIDERURGICA BELGO MINEIRA-MONLEVADE PLANT

GENERAL LAY OUT OF BLAST FURNACES AND STEEL SHOP

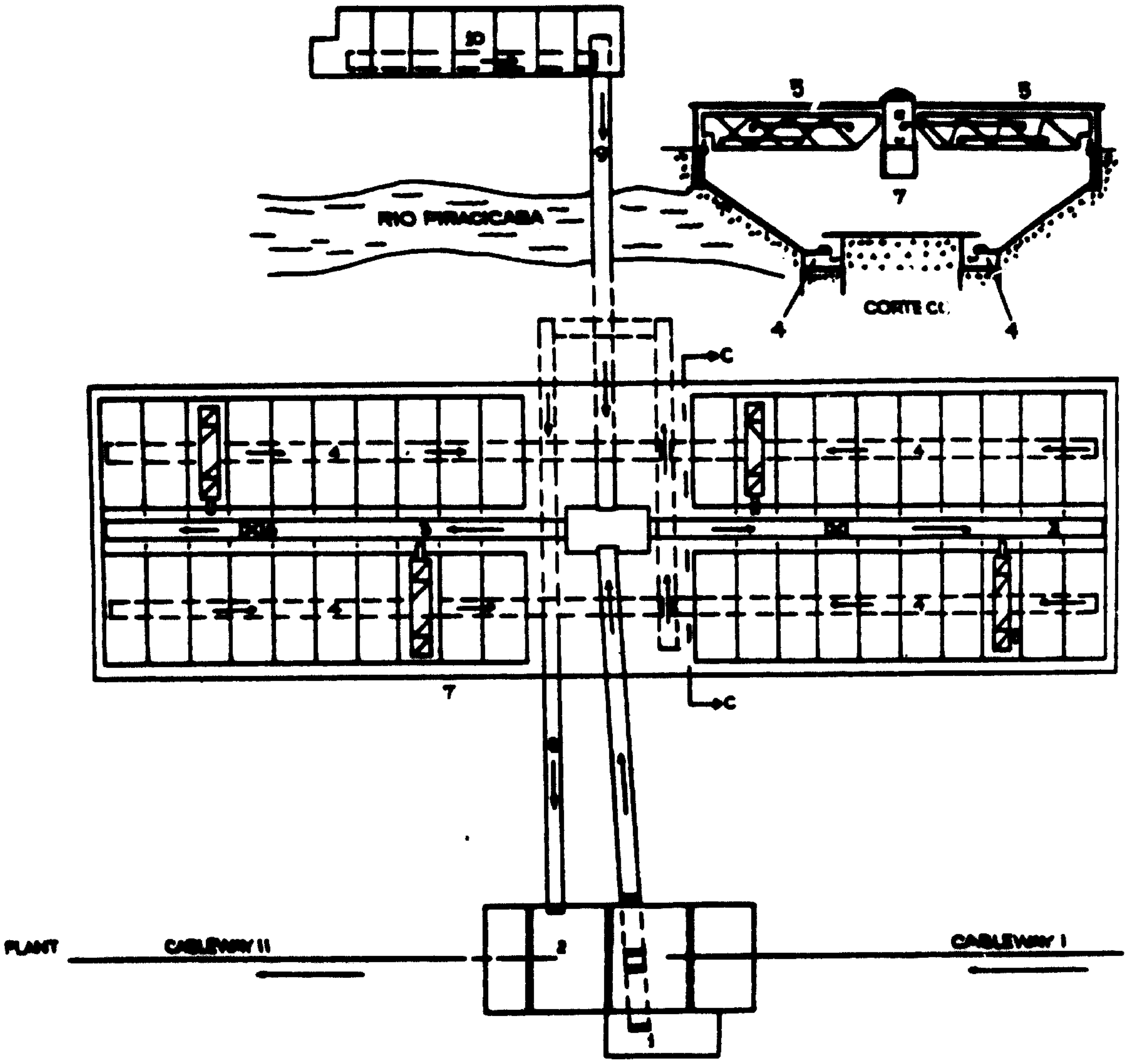
Figure 28



COMPANHIA SIDERÚRGICA BELGO MINEIRA MONLEVADE PLANT.

CHARCOAL STORING PLACE.

Figure 29 CAPACITY · 240.000 M³.



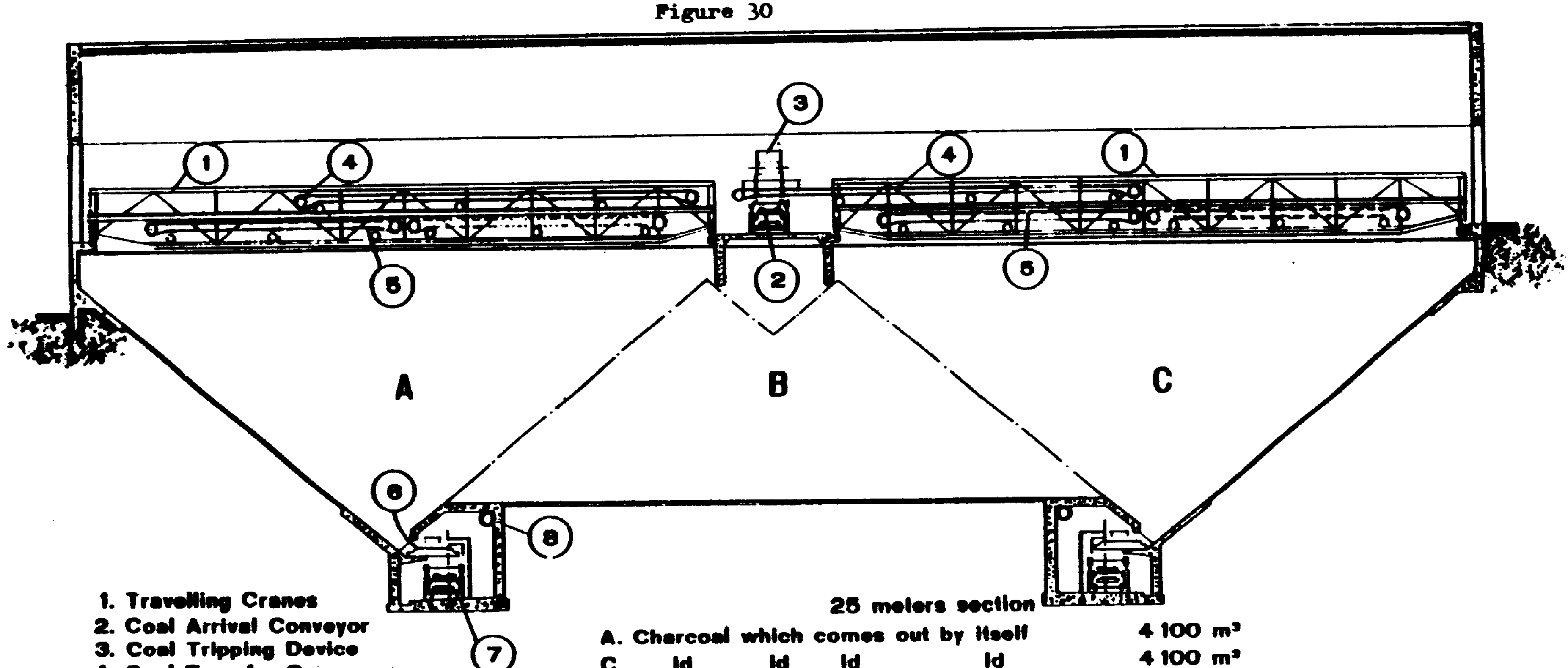
1. TRUCK TIPPING AND BAG UNLOADING STATION.
2. OVERHEAD CABLEWAY ARRIVAL AND LEAVING STATION.
3. MAIN DISTRIBUTION BELT CONVEYOR.
4. UNLOADING BELT CONVEYOR.
5. TRAVELLING CRANES FOR CHARCOAL DISTRIBUTION.
6. CHARCOAL TRIPPERS.
7. CHARCOAL STORAGE PLACE: TEN RESERVOIRS ON EACH SIDE.
8. MAIN CHARCOAL BELT CONVEYOR. TO CABLEWAY II.
9. BELT CONVEYOR CROSSING PIRACICABA RIVER.
10. RAILWAY UNLOADING STATION AND BINS.

COMPANHIA SIDERURGICA BELGO MINEIRA, MONLEVADE PLANT

CHARCOAL STORING AND REGULATING DEPOT

TOTAL VOLUME: 240.000 m³

Figure 30



1. Travelling Cranes
2. Coal Arrival Conveyor
3. Coal Tripping Device
4. Coal Transfer Conveyors
5. Coal Distributing Conveyors into depot
6. Coal Extracting Machine
7. Coal Extracting Conveyor
8. Water Pipe

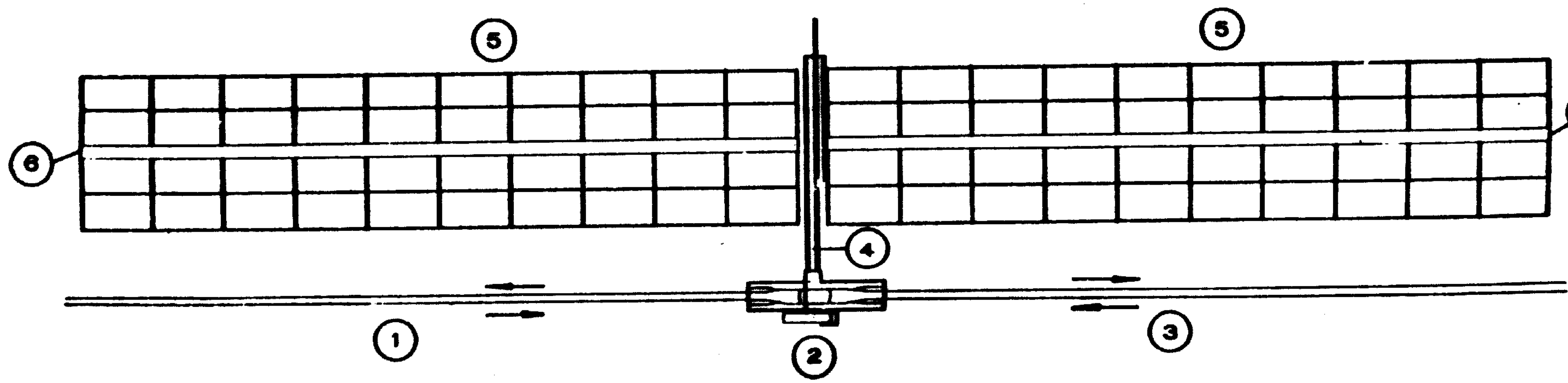
	25 meters section	
A. Charcoal which comes out by itself		4 100 m³
C. Id Id Id	Id	4 100 m³
	Total	8 200 m³
B. Charcoal which must be pushed out by means of a tractor		3 100 m³
	Total	11 300 m³

COMPANHIA SIDERURGICA BELGO MINEIRA-MONLEVADE PLANT

CHARCOAL STORING AND REGULATING DEPOT
TOTAL VOLUME: 240.000 m³

Figure 31

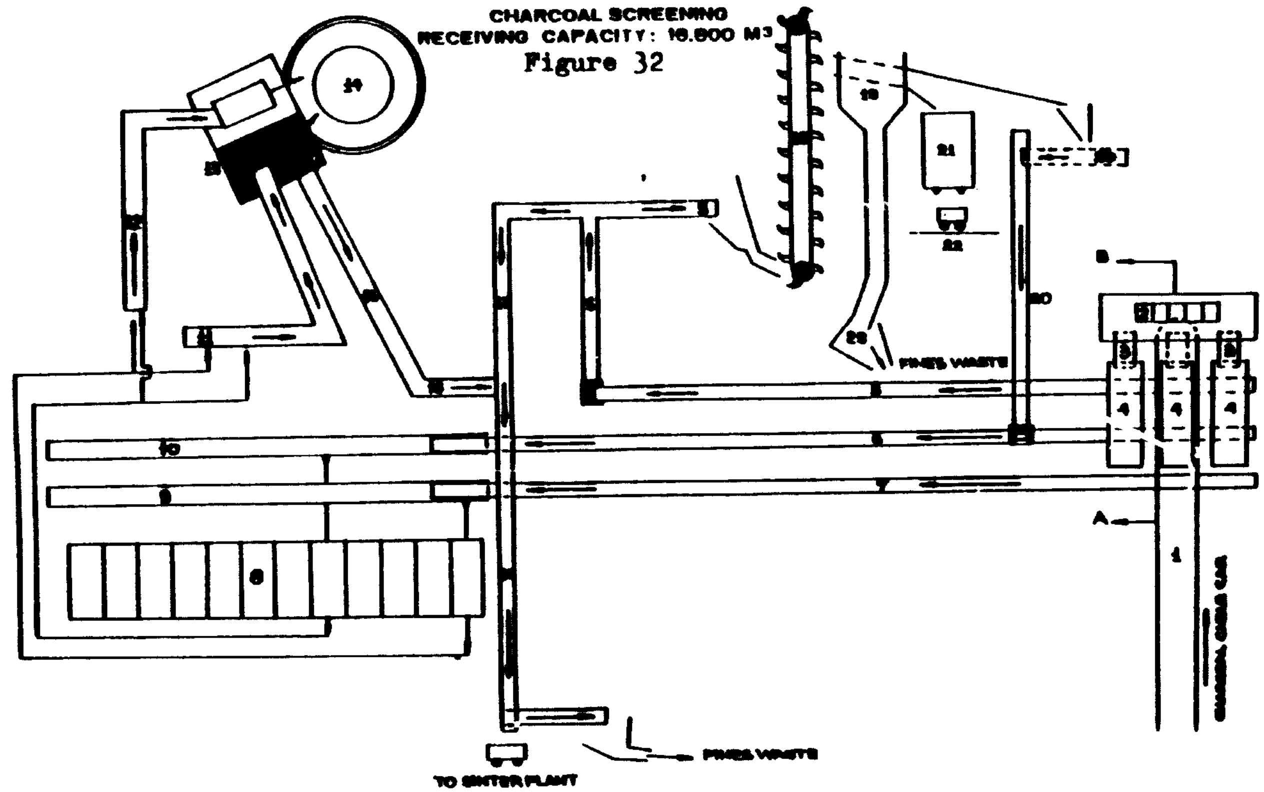
1. Charcoal Arrival Cableway I, 30 Miles Length.
2. Charcoal Unloading Station.
3. Charcoal Leaving Cableway II, 1 Mile Length.
4. Conveyor to Charcoal Depot.
5. Charcoal Storing and Regulating Depot.
6. Charcoal Conveyor into Depot.



COMPANHIA SIDERURGICA BELGO MINEIRA - MONLEVADE PLANT.

CHARCOAL SCREENING
RECEIVING CAPACITY: 16.800 M3

Figure 32

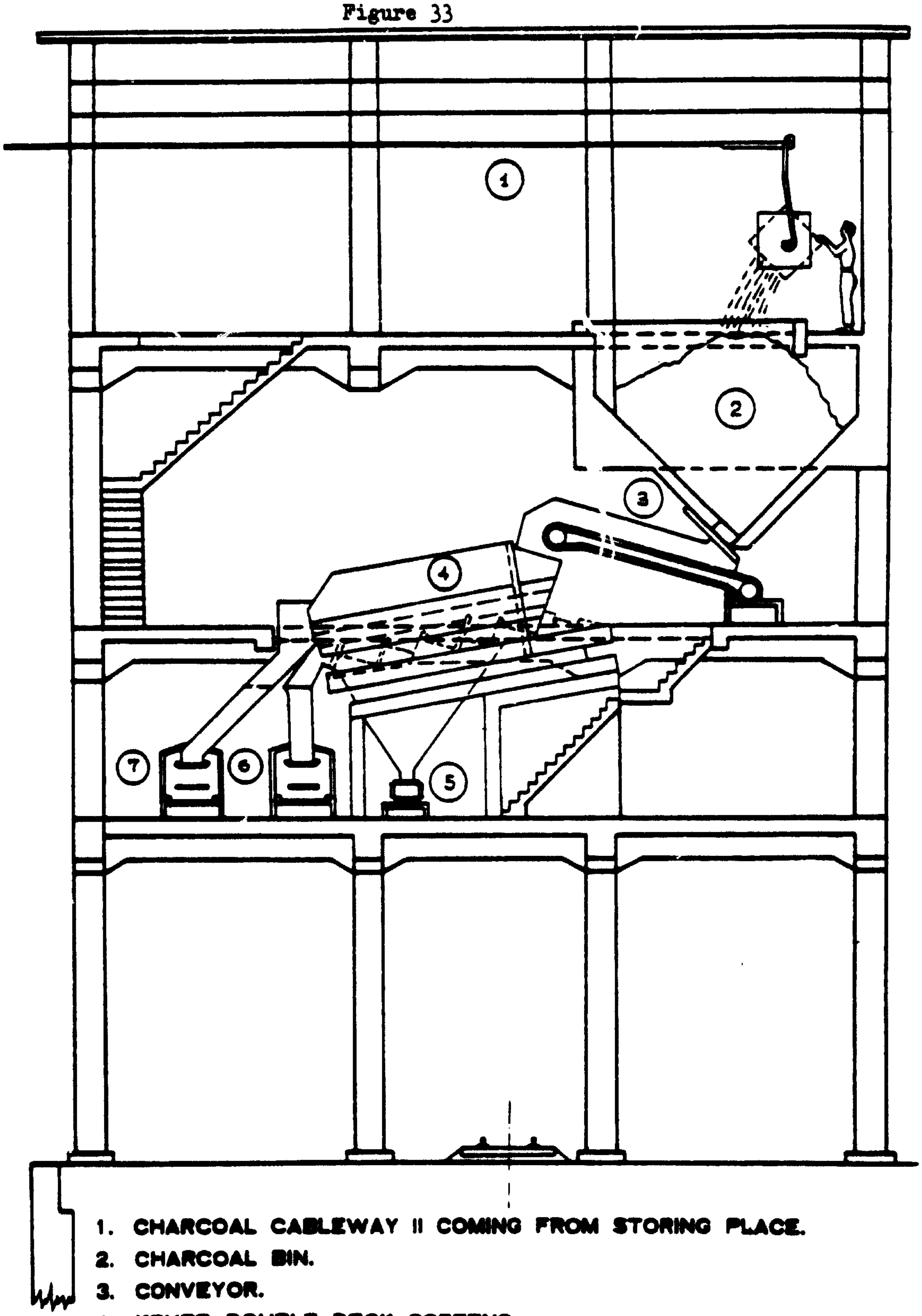


1. Charcoal cableway II coming from storing depot
2. Charcoal Bin
3. Conveyors
4. Krupp Double Deck Screens
5. Charcoal Fines, <8 mm, conveyor to Bucket Elevator 18 for Rescreening and to Sinter Plant via Conveyor 17
6. Charcoal, 8 to 15 mm, Conveyor to Blast Furnace Bins
7. Charcoal, 16 to 50 mm, Conveyor to Blast Furnace Bins
8. Blast Furnace Charcoal Bins for two sizes: 8 to 15 mm and 16 to 50 mm
9. 10. 11. Charcoal Conveyors
12. Screen By Pass Conveyor
13. Charcoal Screen
14. Blast Furnace Charging Bucket
15. 16. 17. Charcoal Fines Conveyor to: Sinter Plant-Re Screening and Waste
18. Bucket Elevator for Charcoal Fines
19. Re Screening of Charcoal Fines. Opening of Screen: 8 and 4 mm
20. Conveyor for Charcoal > 8 mm to Blast Furnace Bins
21. Bin for Charcoal Fines < 8 mm, > 4 mm to Sinter Plant
22. Railway Car for Fines to Sinter Plant
23. Fines Waste <4 mm

COMPANHIA SIDERÚRGICA BELGO MINEIRA - MONLEVADE PLANT.

CHARCOAL SCREEN HOUSE. CUT A:B.

Figure 33

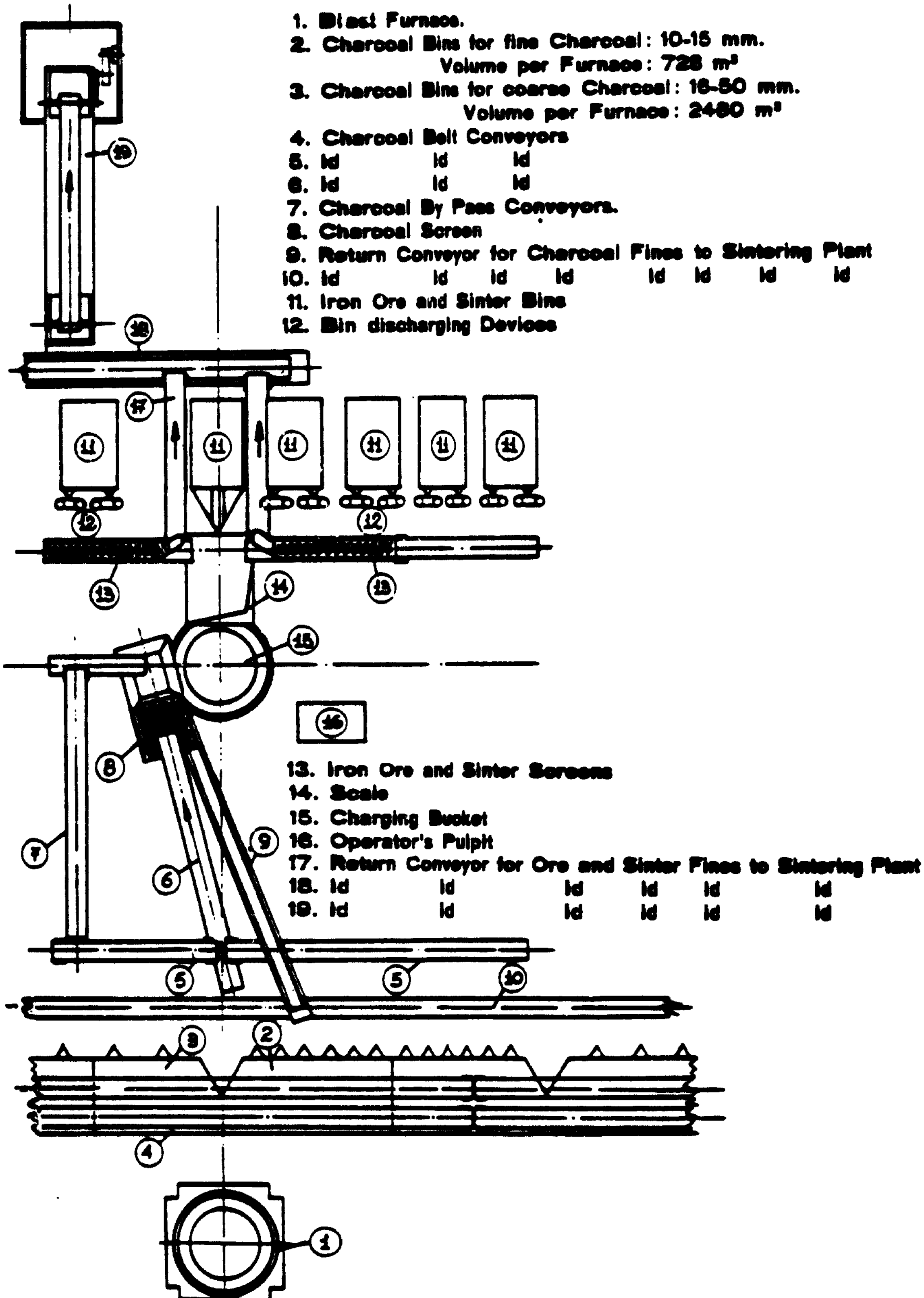


1. CHARCOAL CABLEWAY II COMING FROM STORING PLACE.
2. CHARCOAL BIN.
3. CONVEYOR.
4. KRUPP DOUBLE DECK SCREENS.
5. CHARCOAL FINES, <8 MM, CONVEYOR.
6. CHARCOAL, 8 TO 15 MM, CONVEYOR TO BLAST FURNACE BINS.
7. CHARCOAL, 16 TO 50 MM, CONVEYOR TO BLAST FURNACE BINS.

COMPANHIA SIDERURGICA BELGO MINEIRA-MONLEVADE PLANT

SCHEMATIC ARRANGEMENT OF BLAST FURNACE CHARGING

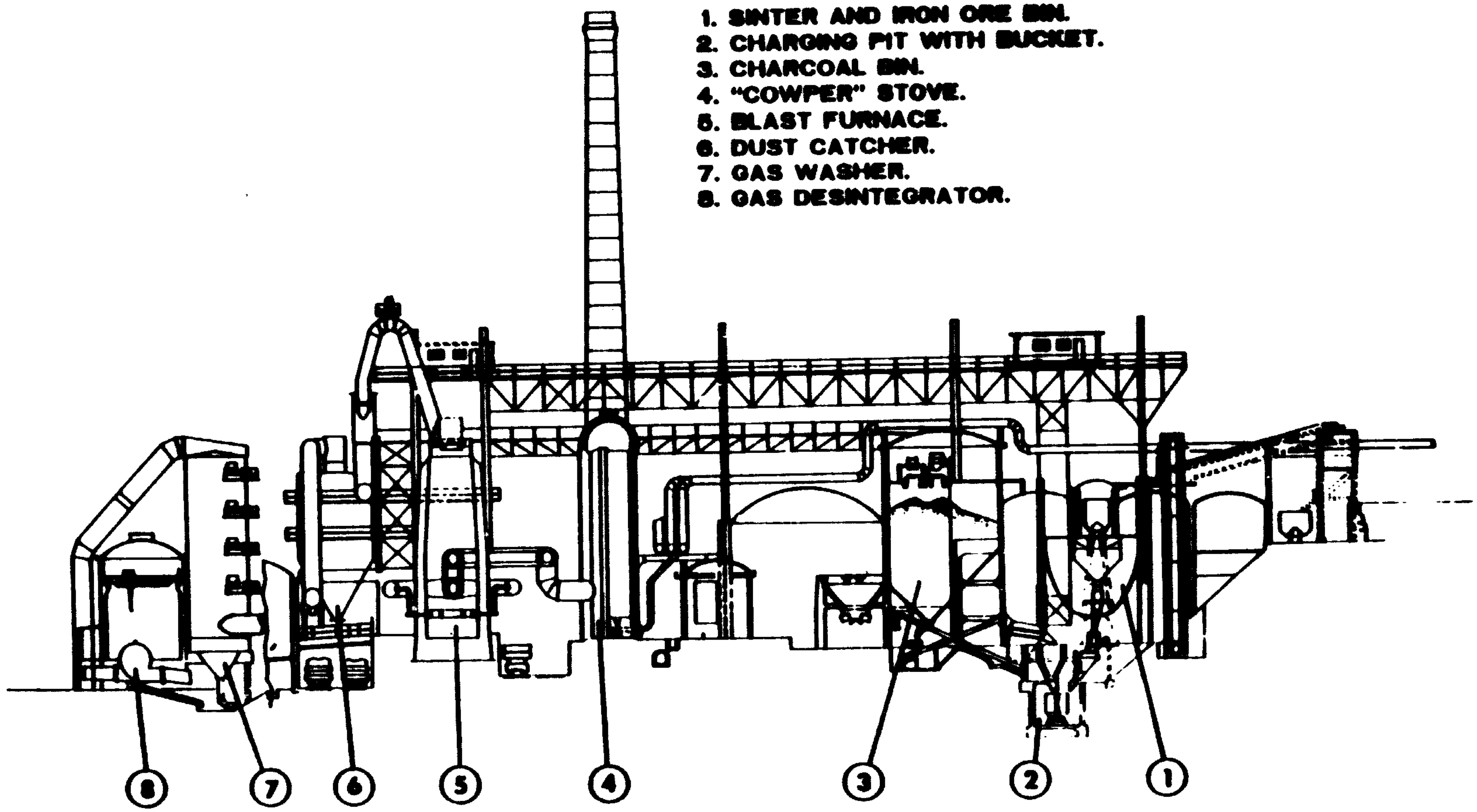
Figure 34



COMPANHIA SIDERÚRGICA BELGO MINEIRA USINA DE JOÃO MONLEVADE

BLAST FURNACE I

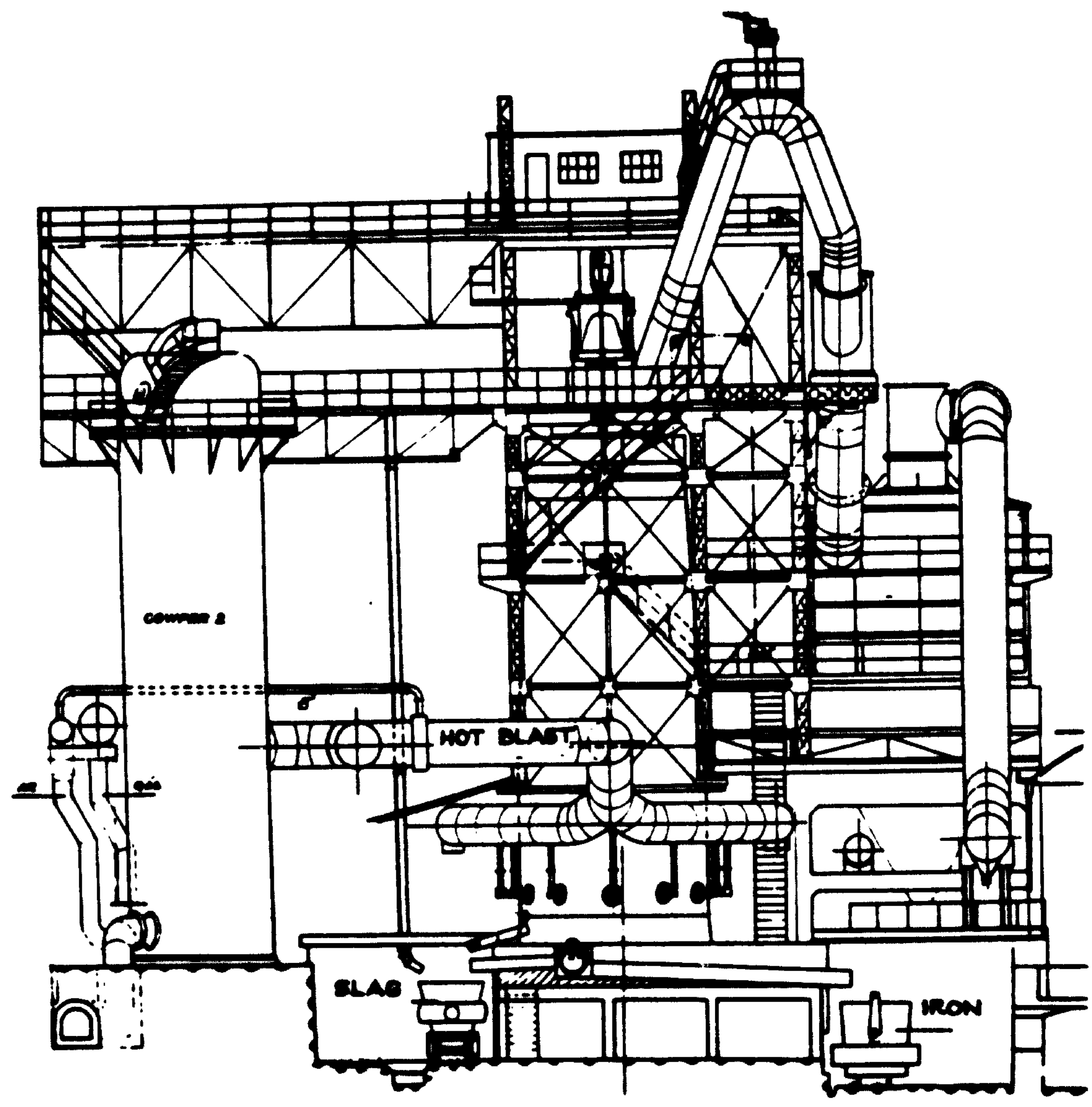
Figure 35



COMPANHIA SIDERURGICA BELGO MINEIRA
PLANT JOÃO MONLEVADE

BLAST FURNACE

Figure 36

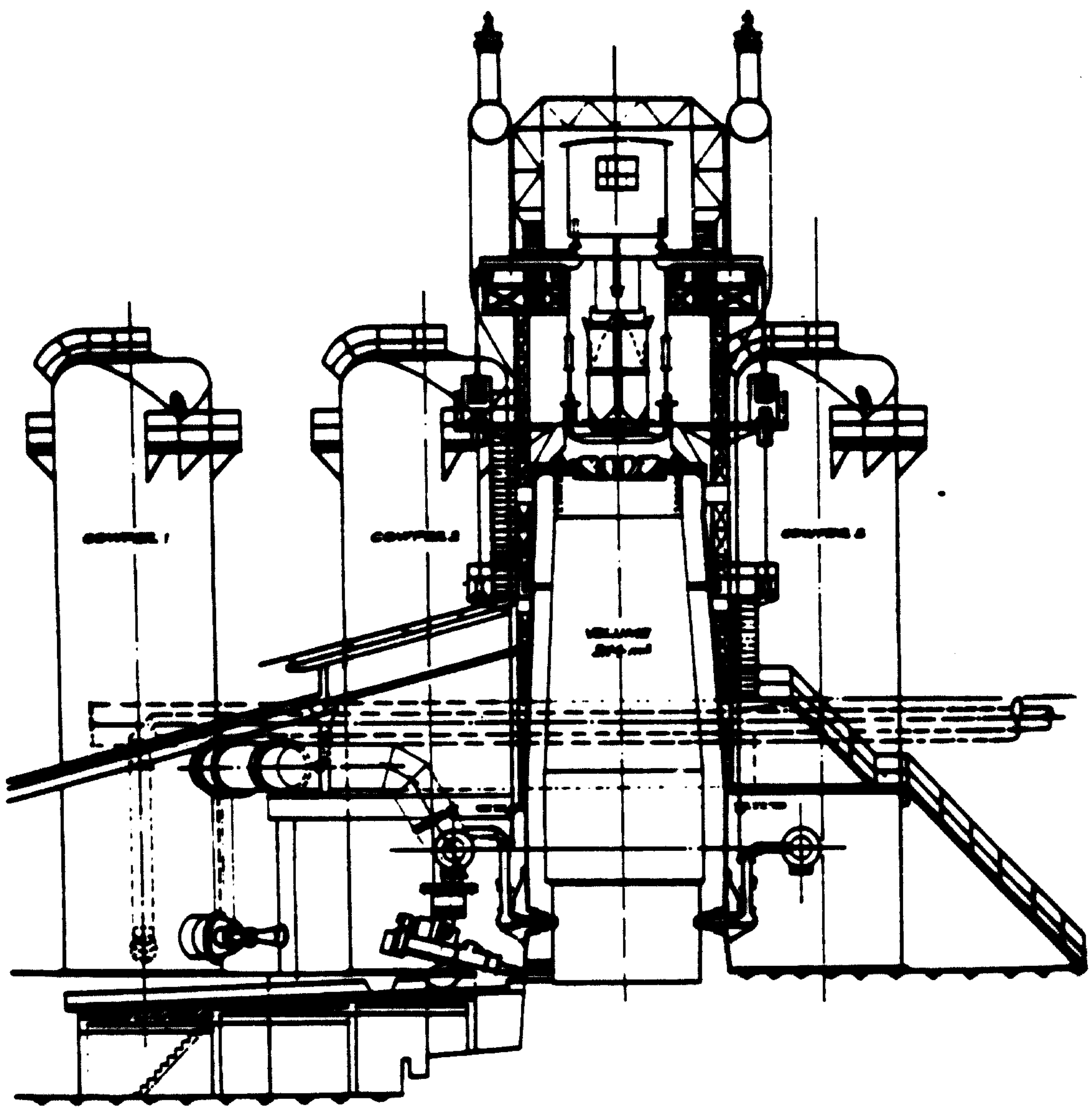


COMPANHIA SIDERÚRGICA BELGO MINEIRA

USINA DE JOÃO MONLEVADE

BLAST FURNACE

Figure 37



(b) Companhia Acos Especiais Itabira (ACESITA)

(i) Introduction

The company was established in 1944 in order to supply the growing needs of the country in special steels by means of an integrated steel plant based on charcoal. The plant location was chosen at the right bank of the Piracicaba River, 16 km from its merger with the Rio Doce. The location (on the Vitoria Minas railway) has electric potential on the Piracicaba river, and large forest reserves in the plant vicinity for charcoal manufacture and a large flat area for the plant development. There were initial difficulties due to the problems of building a steel plant in a totally underdeveloped region. These difficulties were overcome and at present the company has a favourable position as one of the major Brasilian suppliers of special steels.

The company operations have continuously expanded since the first operation of the blast furnace (200t/day) in 1949 and the steel production in 1976 was 293,000 t. A new 900 t/day blast furnace is coming into production in 1978.

(ii) Charcoal Supply

Since 1974 a wholly owned subsidiary company FLORESTAL ACESITA, is in charge of the charcoal supply to the steel works and of the forestry activities. The company's aim is to become self-sufficient, in a few years, in charcoal manufacture. 25 million eucalyptus trees per year are planted, on an area of 15,000 ha.

All the charcoal is produced in beehive brick kilns. Charcoal physical and chemical characteristics are similar to those of Belgo Mineira.

Charcoal arrives at the plant by rail and road truck. Charcoal is unloaded at the plant in a covered depot with four individual cells for the purpose of storing and blending different moisture contents.

The present storage capacity of 75,000 m^3 is being increased by 80,000 m^3 in a new depot on the plant periphery.
Charcoal is discharged through gates located at the bottom of the depot on two belt conveyors travelling beneath the depot and delivering the charcoal to the blast furnace bins.
Charcoal is screened into 3 sizes:

Coarse charcoal	+19 mm for blast furnace
Fine charcoal	-19 mm +12.5 mm for the low shaft reduction furnaces.
Breese:	-12.5 mm for sinter plant

(iii) Iron Ore

In 1974 a subsidiary company ITAVALE has been founded in equal shares with CIA. VALE DO RIO DOCE for the operation of a part of the company owned mines in Itabira with reserves of 340 million tons.
The ore is a compact hematite.

Fe	67-69%
SiO	0,5-1%
Al_2O_3	0,6-0,8%
P $<$	0,100%

It is transported to the plant, 90 kms, by rail in 50 ton wagons with bottom discharging.
The ore is screened at the plant into three sizes

+ 30 mm for blast furnace
- 30 mm + 10 mm for blast furnace and low shaft reduction furnaces
- 10 mm for the sinter plant.

A powdery hematite iron ore (similar in composition to the compact hematite) is mined at the company owned Baratinha mine and transported 22 kms to the plant by trucks and rail. It is all -10 mm and used exclusively on the sinter plant.

(iv) **Sinter plant**

This is a pan type sinter plant with one pan of 14 m^2 area and a yearly production of 180,000 t. Self fluxing sinter is made with $\frac{CaO}{SiO_2}$ ratio 1.2 - 1.30. Charcoal fines -6 mm are used as fuel. The sinter is screened at 8 mm and the -8 mm used in the mix as return fines.

(v) **Blast Furnace Characteristics**

Production t/24/hr	460	
Hearth diameter m	4.70	
Working volume m^3	293	Productivity 1.57t/day/ m^3 Working Volume
Number of tuyeres	12	
Number of stoves	3	
Heating surface m^2	4,400	
Volume of blast m^3/hr	25,500	
Pressure of blast kg/cm^2	1.07	
Temperature of blast	800°C	

(vi) **Furnace Burden**

Hematite ore	600 kg/t iron
Sinter	860 kg/t
Dolomite 42 kg/t	Quartz 65 kg/t
Charcoal rate	2.85 m^3/t
Slag volume	150 kg/t

Hot metal analysis

Fe 94-95% C = 4-4.5%; Si = 0.3-0.5%; Mn = 0.4-0.6%; P = 0.05-0.20%; S = 0.020% max.

Blast furnace gas production. 46,000 Nm^3/hr at 900-1000 Kcal/Nm^3. Consumption 14,000 Nm^3/hr for stove heating, remainder used for soaking pits, rolling mill reheating furnaces and boilers. Gas cleaning dust collectors followed by spray tower, Theissen disintegrator and dehumidifier. Gasometer - with pressure regulated at 300mm w.g.

(vii) Electric Low Shaft Reduction Furnace

Type Tysland - hole.

Production 160 t/day

Conical shaped hearth diameter Bottom 7.90 m

Top 9.40 m

Height 4.20 m

Electrode diameter 1,250 m

Power consumption 2,100 kWh/t Transformer capacity 17,500 KVA

Fixed carbon rate 300 kg/t (charcoal used)

Electric reduction furnace for FeSi production

Power capacity 4,000 KVA three phase.

(viii) Steelmaking plant

Three electric arc furnaces of 8, 26 and 30 t capacity. Total production 115,000 t/yr. 3.5 - 4.5 hours tap to tap time.

Oxygen consumption - 15 Nm^3/t ingot steel

Power consumption 600 kWh/t ingot steel.

1 LD oxygen top blown 30 t vessel

Production 135,000 t/yr - tap to tap time 50 minutes

Oxygen consumption 50 m^3/t ingot steel.

1 Bessemer bottom air blown 70 t vessel.

Operates only when LD vessel is re-lined

All steel poured into 2.6 t square ingot moulds - bottom filled.

Rolling mills

Soaking pits

a. Electric heated, individual cell furnaces four times 10 cells.
   Ingot capacity: 80.

b. Gas fired soaking pits.
   Ingot capacity: 48

Roughing mills

a. One, two high, one stand, reversing mill.

b. One, two high, 3 stands, reversing mill for the rolling of sheet bars, billets and rounds.

Break down mill with one stand, 3-high,
Finishing mill, 4 stands 3-high,
Small bar mills, consisting of:
Break down mill, two stands, 3-high,
Finishing mill, two high, 6 stands,
Sheet mills, consisting of:

a. One, three high, one stand mill for the rolling of sheet bars,
b. One, two high, one stand mechanised reversing mill for pack rolling of sheets.
c. One manual mill, 3-high, 3 stands,
d. One finishing mill, 2-high, 2 stands,

Finishing department:

The manufacture of special and alloy steels requires complete conditioning of the semi-finished products and a rigourous quality control of the finished products. The ACESITA department in charge of this activity is well equipped in machines and trained personnel.

Stainless cold rolling department.

In 1977 the company started production of cold rolled stainless steel sheets 1,200 mm wide, starting initially from imported hot coils. The production will soon be integrated after erection of two slab casters and one Steckel hot strip mill.

(ix) <u>Company Amenities</u>

A comfortable and well designed city of 33.000 people, has been built by the company on the bank of the Piracicaba River and offering all community facilities. Total plant personnel 5,000; Head office and sales staff 480.

(x) Commercial and financial aspects:

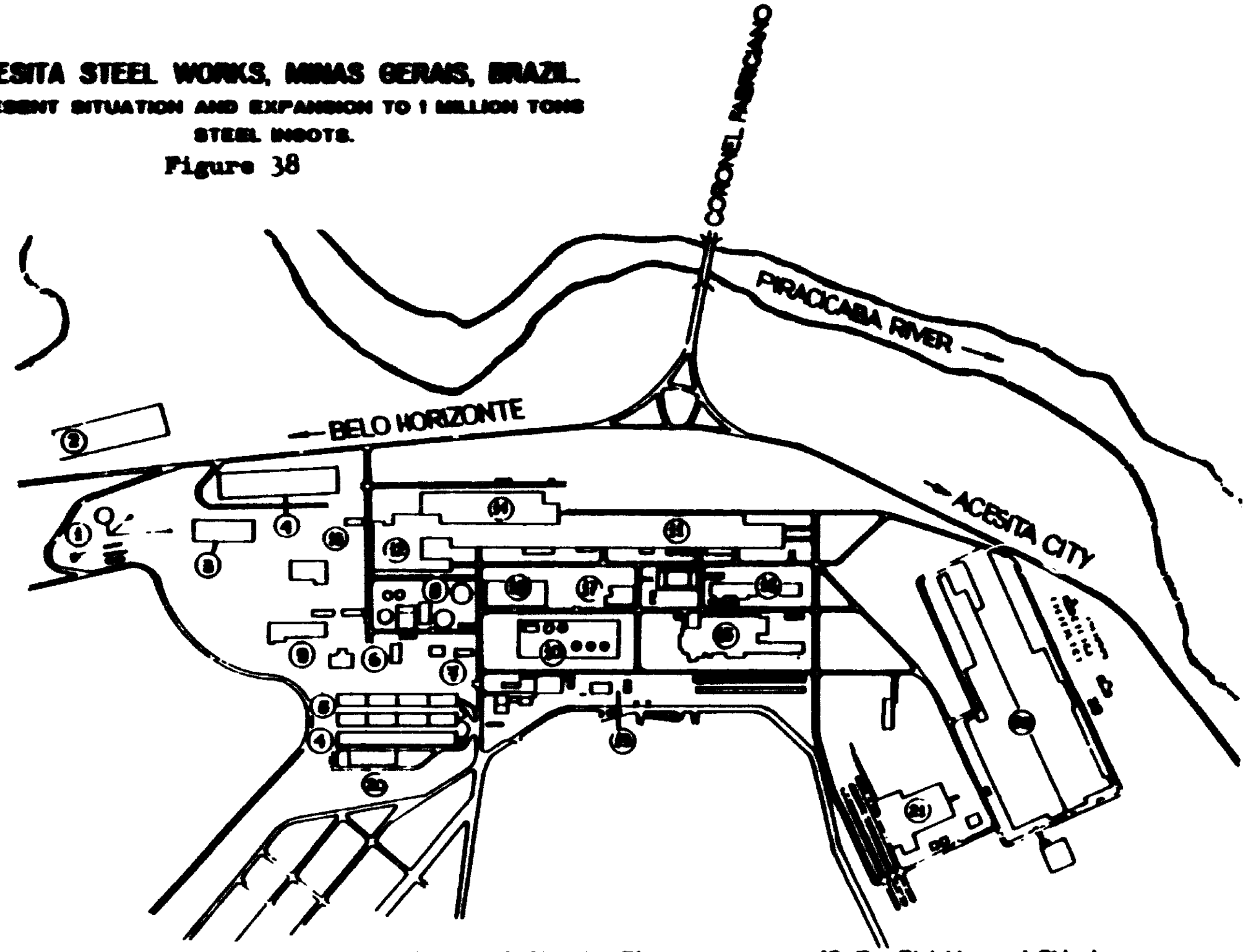
1976 figures:	Sales:	185,000 tons
	Value	US$ 100 millions
	per t:	US$ 540

Figures

38 - Present Layout and Future Expansion
39 - Fluxogram for 240,000 t/yr ingot steel
40 - Blast Furnace

ACESITA STEEL WORKS, MINAS GERAIS, BRAZIL.
PRESENT SITUATION AND EXPANSION TO 1 MILLION TONS STEEL INGOTS.

Figure 38

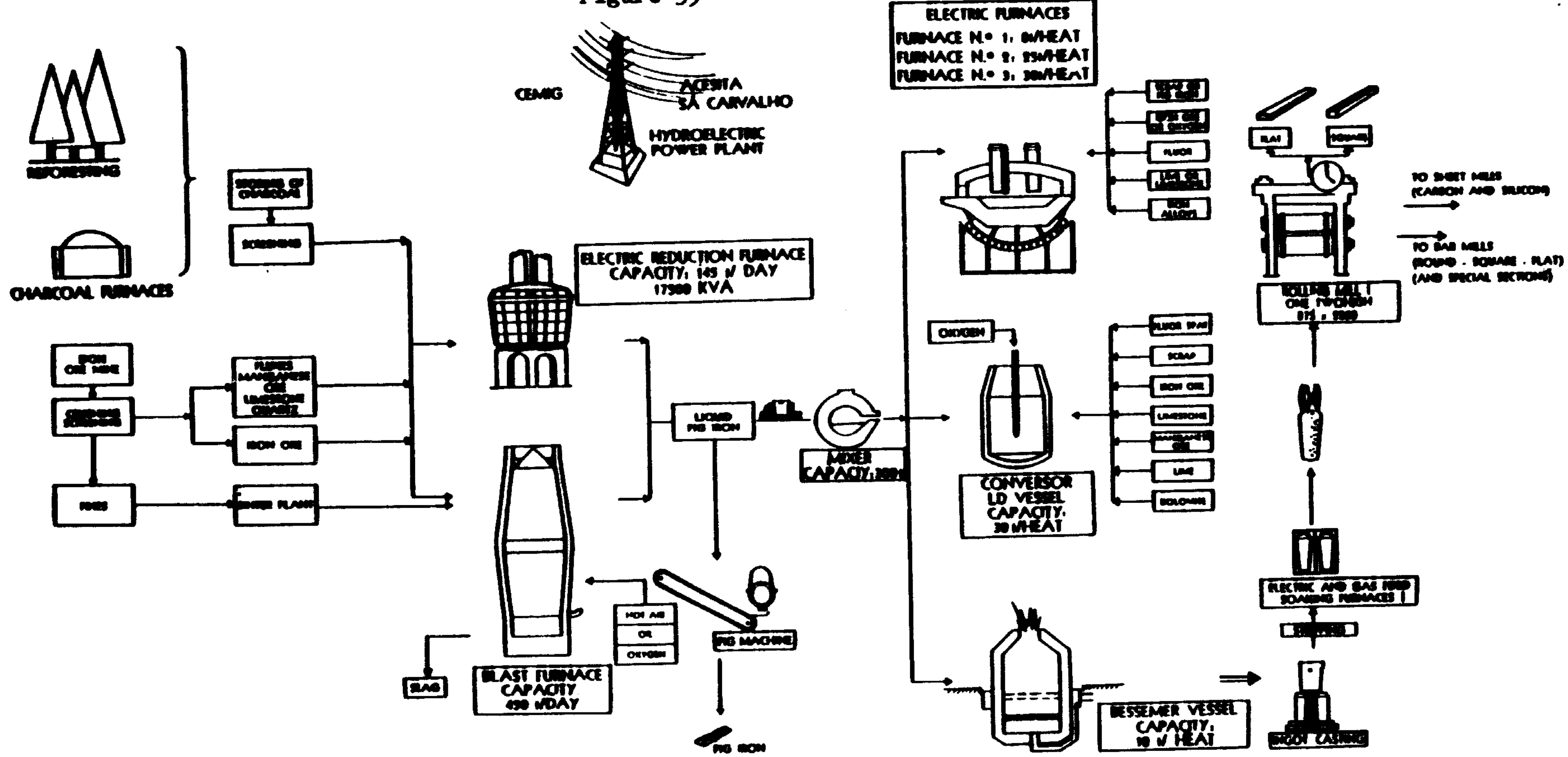


1. Present Greenawalt Sintering Plant.
2. Future Iron Ore Storage Place: 160.000 Tons.
3. Future Sintering Plant.
4. Future Charcoal Storage Depot: 80.000 m³
5. Present Charcoal Storage Depot: 80.000 m³
6. Electric Reduction Furnace.
7. Present Blast Furnace.
8. Future Blast Furnace.
9. Iron Foundry.
10. Steel Shop: LD-Bessemer-Electric.
11. Rolling Mills: Roughing-Intermediate-Finishing.
12. Bar Finishing and Shipping.
13. Quality Control.
14. Future Rod Mill.
15. Sheet Rolling.
16. Heat Treatment of Silicon Sheets.
17. Forging Shop.
18. Machine Shop.
19. Main Offices.
20. Pattern and Carpenter Shop.
21. Future Melt Shop.
22. Future Expansion: Hot and Cold Strip Mills.

COMPANHIA AÇOS ESPECIAIS ITABIRA

FLUXOGRAM FOR 240.000 - TONS PER YEAR INGOT STEEL CAPACITY.

Figure 39

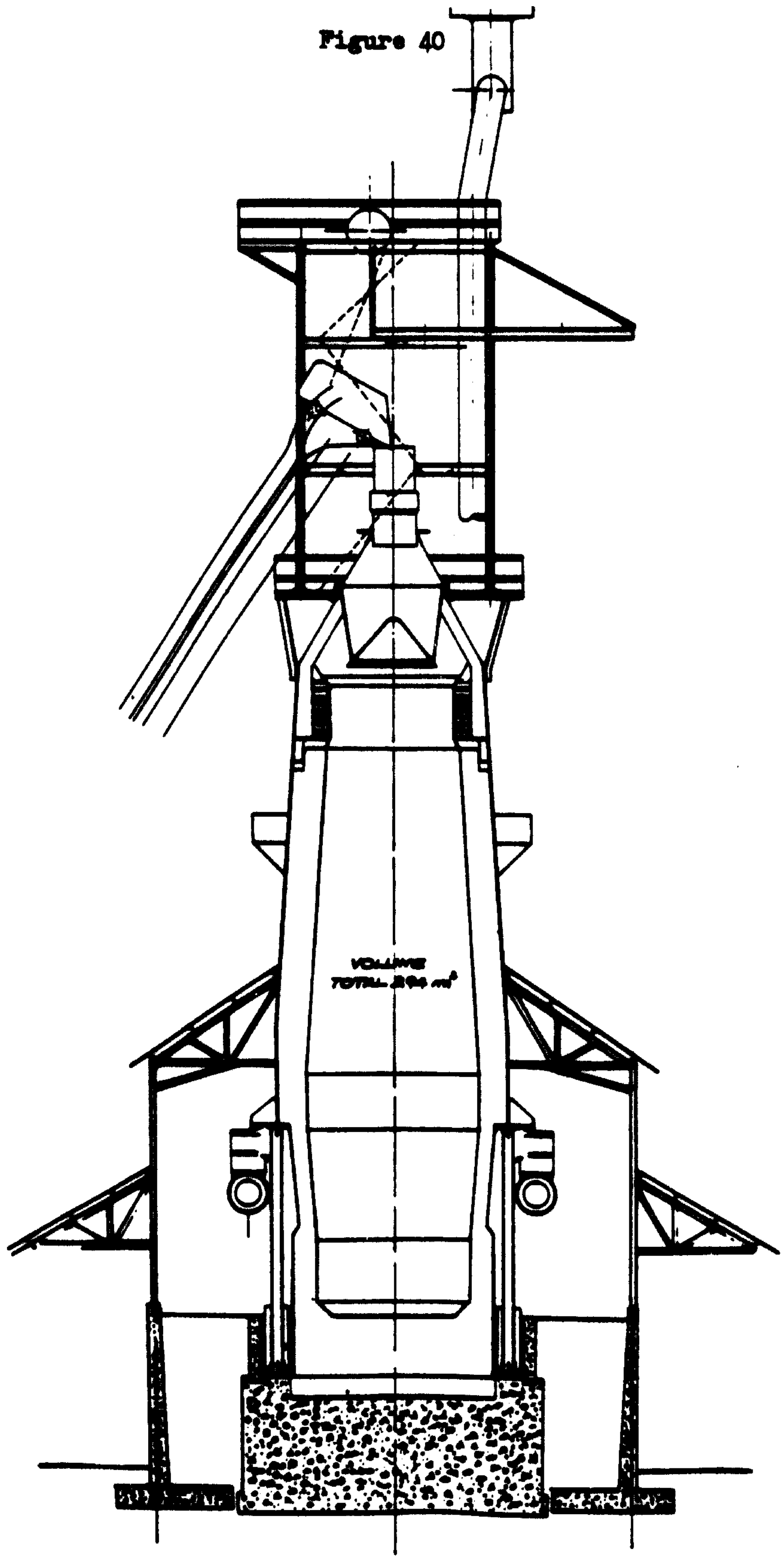


COMPANHIA DE AÇOS ESPECIAIS ITABIRA

ACESITA

BLAST FURNACE

Figure 40



(c) Companhia Ferro Brasileiro (CFB)(plant José Brandão)

(i) Introduction

The company was established in 1925 and in 1937 started making centrifugally spun iron pipes. Today, it is one of the two largest manufacturers of iron pipe.

The plant was founded on an agreeable, cool, site 44 km east of Belo Horizonte at Caeté, a town located on the Central Brazil Railway.

Production has expanded continuously and today, the company operates three blast furnaces of total capacity 160,000 tons/yr making nodular and grey centrifugally cast pipe in a fully mechanised plant.

(ii) Charcoal supply

From the beginning, the management was convinced that man made forests were essential for its charcoal needs. The forestation was therefore started many years ago, financed partly from tax incentives but majorly from the company's own resources.

Present yearly reforestation 1,400 ha.

The company uses 410,000 m^3 of charcoal/yr of which 30 % is produced by a subsidiary company "Rual Mineira" and 70% is purchased from private manufacturers who use wood half coming from naturally re-grown forests and half from bush forests.

By 1995 the company expects to be 100% self-sufficient in charcoal production from eucalyptus wood. All charcoal is produced in beehive kilns. Charcoal physical and chemical characteristics are similar to those of Belgo-Mineira.

On arrival at the plant the charcoal is screened into three sizes.

Coarse +25 mm (75% of total)

Fine -25 mm + 9 mm (25% of total)

and Breeze, -9 mm, which is used as sintering fuel and for boiler fuel after pulverizing.

(iii) Iron ore

Similar characteristics to that used by Belgo-Mineira and Acesita.

(iv) Sinter plant

Pan type machine, two pans, production 100,000 t/yr.

(v) Blast furnaces - three furnaces - belt conveyor charging with rotary top burden distribution devices. Shell cooling by water spray on lower third of bosh and downwards.

Production t/day	100/140/250
Productivity t/day/m^3 working volume	0.8 - 1.0
Tuyeres - diameters - mm	70 and 90
Number of stoves/furnaces	3
Heating surface m^2	8,300
Blast temperature I and II	500 - 600°C
III	700 - 800°C
Blast volume I and II m^3/hr	26,000
III m^3/hr.	35,400
Blast pressure·1000 mm w.g.	2.5, 8.0 and 10.0

(vi) Furnace burden

Sinter plus ore	1400 - 1500	kg/t iron	
Limestone	50 - 60	kg/t iron	
Quartz	60 - 70	kg/t iron	
Uprising scrap	40	kg/t iron	(occasionally up to 400 kg/t)
Charcoal rate	3.4-3.7	m^3/t iron	

Hot Metal Analysis

Si = 1.5 - 1.8%; Mn = 0.35 - 0.45%; C = 4.15 - 4.25%; S = .025% max.

Slag Analysis

SiO_2 = 40-43%; CaO = 27-30 %; Al_2O_3 = 13-15 %.

Hot metal is poured into two hot metal mixers, 60 and 120 t capacity. capacity. A continuous pig casting machine is also used.

(vii) Foundries

Grey iron and nodular iron for high and low pressure, water, gas, oil, etc. pipe in diameters from 50 mm to 900 mm
Two production lines - 3 m long pipe (50 mm to 150 mm dia.) and six m long pipe (200 mm to 900 mm dia.)

Six m pipe production line includes one canal type induction heated furnace of 40 - 60 ton capacity and one crucible type. These furnaces permit the addition of uprising scrap and alloys to successive casts and smooth out irregularities of temperature and chemical analysis of hot metal.
Five centrifugal casting machines and an annealing furnace.
Production capacity 125,000 t/yr.
Three m pipe production line includes 6/15 t canal type induction heating furnace which receives hot metal from blast furnace or from two seven-ton cupola melting furnaces.
Five centrifugal casting machines. Production capacity 45,000 t/yr
In addition, the company has a large foundry for conventional iron castings from 20 to 15,000 kg each. Production capacity 18,000 t/yr.

(viii) Company Amenities

The company has built a complete city with 800 houses and all community facilities such as hospital, church, high and professional schools, etc. - Total company personnel 2,400.

(ix) Commercial aspects

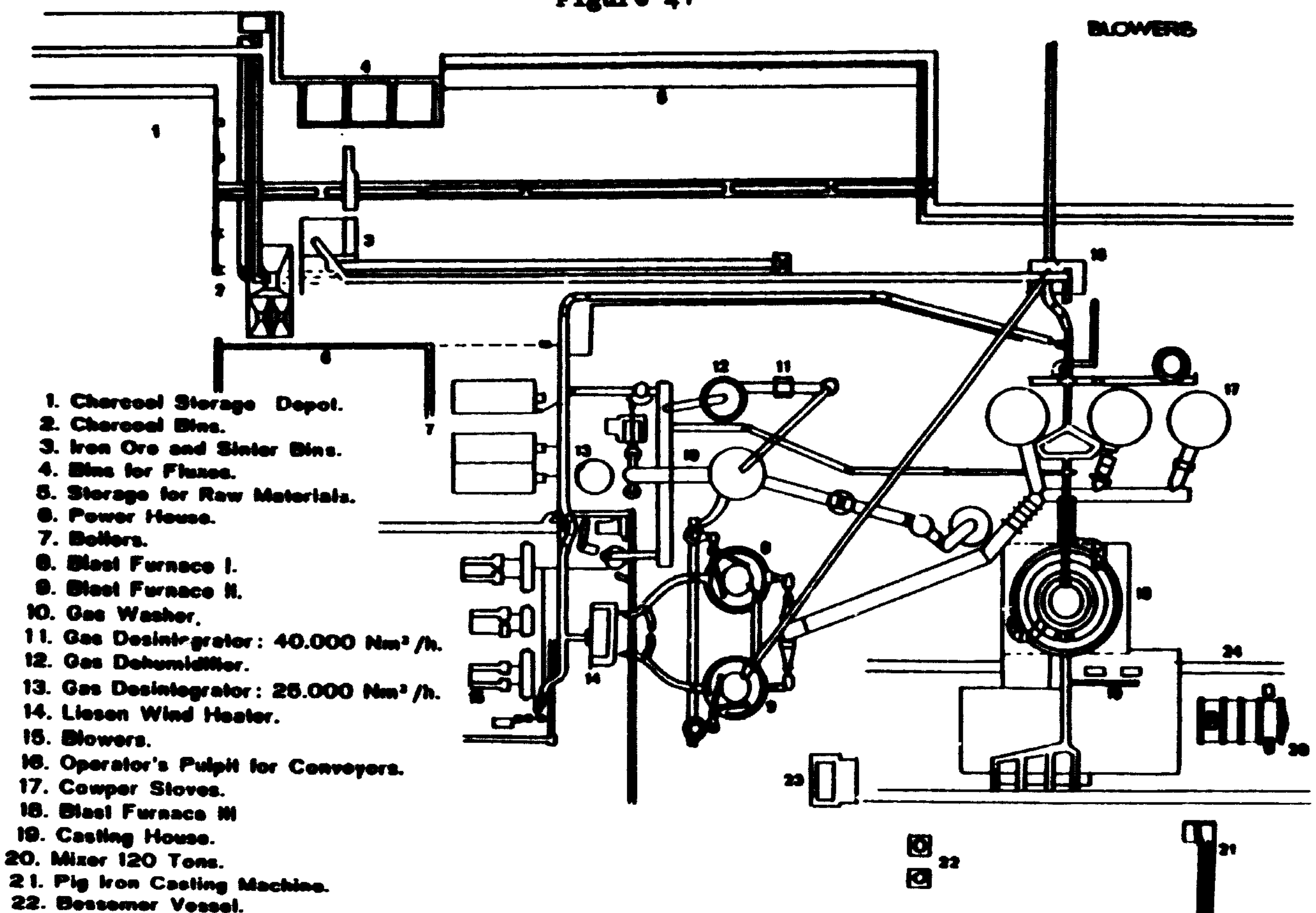
Sales 1976	-	88,500 tons
US$	-	51,000,000
per ton	-	US$ 575
Profits after taxes		US$ 10,000,000

Figures

41 - General layout of blast furnaces
42 - Blast furnaces 1, 2 and 3

COMPANHIA FERRO BRASILEIRO, JOSE BRANDÃO, MINAS GERAIS, BRAZIL
GENERAL LAY OUT OF BLAST FURNACES

Figure 41



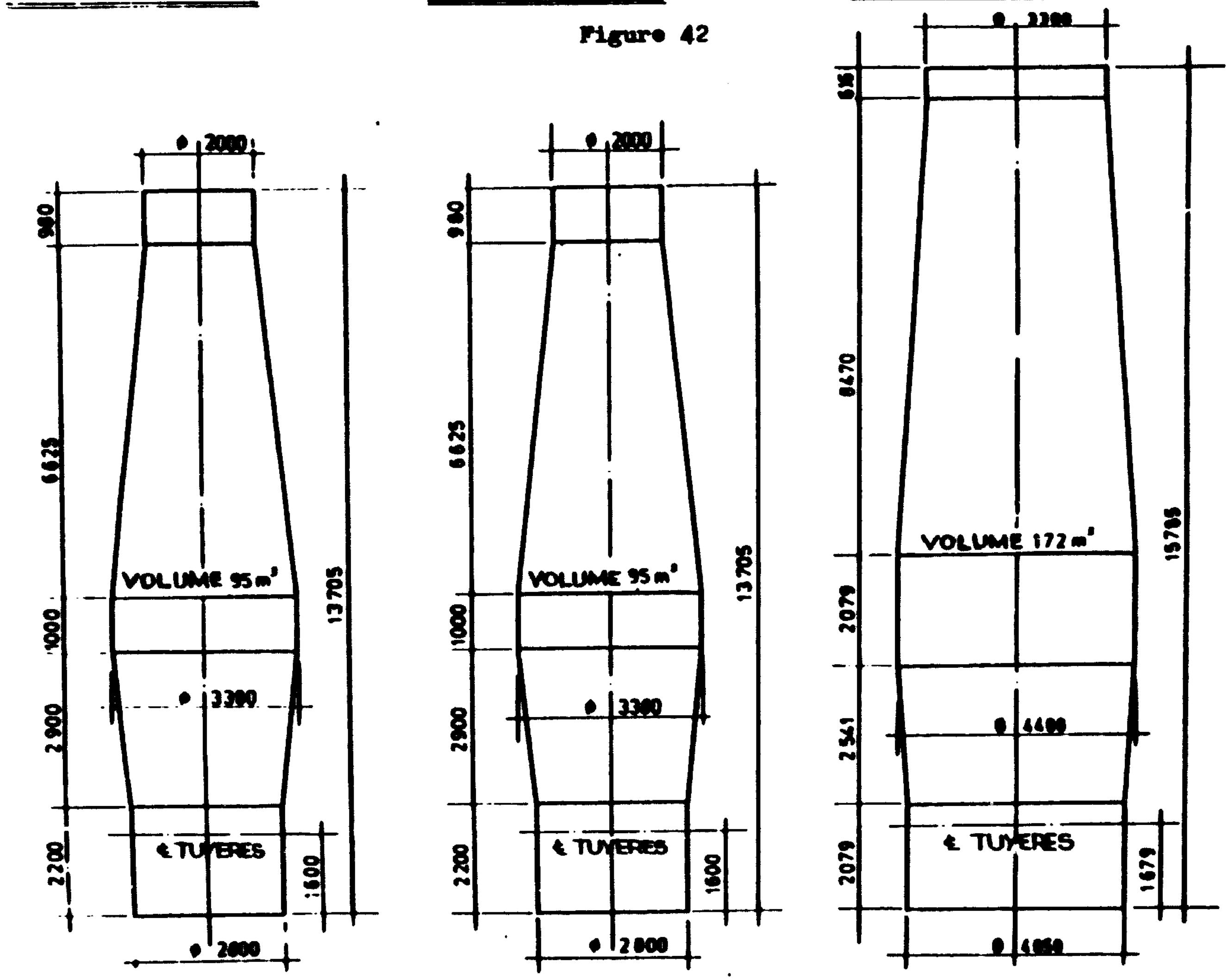
1. Charcoal Storage Depot.
2. Charcoal Bins.
3. Iron Ore and Sinter Bins.
4. Bins for Fluxes.
5. Storage for Raw Materials.
6. Power House.
7. Boilers.
8. Blast Furnace I.
9. Blast Furnace II.
10. Gas Washer.
11. Gas Desintegrator: 40.000 Nm³/h.
12. Gas Dehumidifier.
13. Gas Desintegrator: 25.000 Nm³/h.
14. Liesen Wind Heater.
15. Blowers.
16. Operator's Pulpit for Conveyors.
17. Cowper Stoves.
18. Blast Furnace III
19. Casting House.
20. Mixer 120 Tons.
21. Pig Iron Casting Machine.
22. Bessemer Vessel.
23. Mixer 60 Tons.
24. Blast Furnace Instrumentation Room.

COMPANHIA FERRO BRASILEIRO

PLANT JOSÉ BRANDÃO

BLAST FURNACE 1 | **BLAST FURNACE 2** | **BLAST FURNACE 3**

Figure 42



(d) CIMETAL Siderurgica

(i) Introduction

CIMETAL is the largest Brasilian non-integrated producer of pig iron (400,000 t/yr). The company also owns a small integrated steelworks (formerly Cia. Siderurgia Hime) now being modernised and expanded to 240,000 t/yr of crude steel production.

The company has three pig iron plants.

Sete Lagoãs	- Minas Gerais	- three blast furnaces
Itauna	- Minas Gerais	- seven blast furnaces
Neiva	- Espirito Santo	- two blast furnaces

Plus the integrated steelworks at Barão de Coca is with two blast furnaces, a third one building, and an LD plant under construction.

The company designs and builds all its own charcoal blast furnace plants based entirely on their own know-how and experience.

(ii) Description of Sete Lagoas Plant.

It is located near the city of Sete Lagoas 70 kms north west of Belo Horisonte on the highway to Brasilia. It has no rail connection and all raw materials and products are moved by road trucks.

(iii) Charcoal Supply

The company maintains offices in different regions of the State of Minas Gerais for the purchase of charcoal from local producers.

Charcoal is transported by 30-60 m^3 trucks and 80 m^3 trailers for distances of 200 to 600 km. Most is loaded in bags which must be manually unloaded at the plant. The volume of charcoal is checked by unloading the bags into a measuring wagon of 3 cubic m volume. Charcoal is stored in two depots, one of 8,000m^3 capacity near blast furnaces 1 and 2 and a second of 17,280 m^3 capacity near blast furnace 3. The larger storage depot is divided into five equal compartments and each subdivided into three cells of 1,152 m^3.

These cells can be individually isolated in case of fire. Great care is taken for fire protection. There are independent truck unloading stations.
From the depots charcoal is manually transported to a small bin and then by belt conveyor to charcoal screens. The charcoal is hand picked on the belt to remove uncharred wood and charcoal larger than 150 mm. The charcoal is screened into three sizes.

Coarse	+ 30 mm
Fine	- 30 +6 mm
Breeze	- 6 mm - 5 to 15 % of total output.

(iv) Iron ore

Hematite iron ore is purchased from independent mines situated 100 km from the plant. Transport is by trucks. The ore is supplied crushed and screened in two sizes and washed. The ore is re-screened at 6 mm before charging into the blast furnaces. Fines - 6 mm amount to 3-5%. In the future these will be used in a sinter plant.

Ore analysis is:

Coarse 13-32 mm - Fe = 64%; SiO_2 = 2.9%; Al_2O_3 = 1.2%; P = 0.032%.
Fine 6-13 mm - Fe = 65%; SiO_2 = 2.4%; Al_2O_3 = 1.2%; P = 0.032%.

Proportion of fines to coarse is 2:1.

(v) Blast furnaces

Total production 175,000 t/yr of pig iron for steelmaking and foundries.

Furnaces are fitted with double bells charged with "Staehler" type bucket hoists. Each bucket contains a complete mixed charge with ore on the bottom and charcoal on top. Furnace No. 1 has a 1 m^3 bucket and Nos. 2 and 3 a 2 m^3 bucket.

Table XLIII **Blast Furnaces at Sete Lagoas**

Characteristics	1	2 and 3
Production t/day	80	200 each
Hearth diameter m	2.28	3.50
Working volume m^3	76	150
Number of tuyeres	4	8
Diameter of tuyeres mm	90	90
"Glendon" recuperators /furnace	2	4
Blast volume m^3/hr	6,000	14,000
Blast temperature	450-550°C	450-600°C
Blast pressure 1000 mm w.g.	5	6

Furnace Burden

Iron ore	1,650 kg/t iron
Limestone	70 kg/t iron
Quartz	40 kg/t iron
Charcoal rate	3.3 m^3/t iron
Power consumption	70 Kwh/t

Slag volume for foundry iron - 100-140 kg/t
for steel grade - 190-200 kg/t

(vi) Gas cleaning and pig iron casting

Cyclone type dust catchers. Part of gas is used in the "Glendon" recuperators and for drying hot metal sand runners. The remainder is burnt to waste.

After tapping the iron is poured into a covered tilting type, oil heated ladle supported on a travelling crane. In the ladle the hot metal becomes more homogenous. From the ladle it is cast on a circular pig casting machine.

(vii) Commercialisation

The plant employs 300 people and an important part of the production is exported to Europe and Latin American countries.

Figures
43 - Layout of blast furnace
44 - General layout of blast furnace
45 - Blast furnace
46 - Fluxogram
47) 48) - Glendon air heaters (two figures)

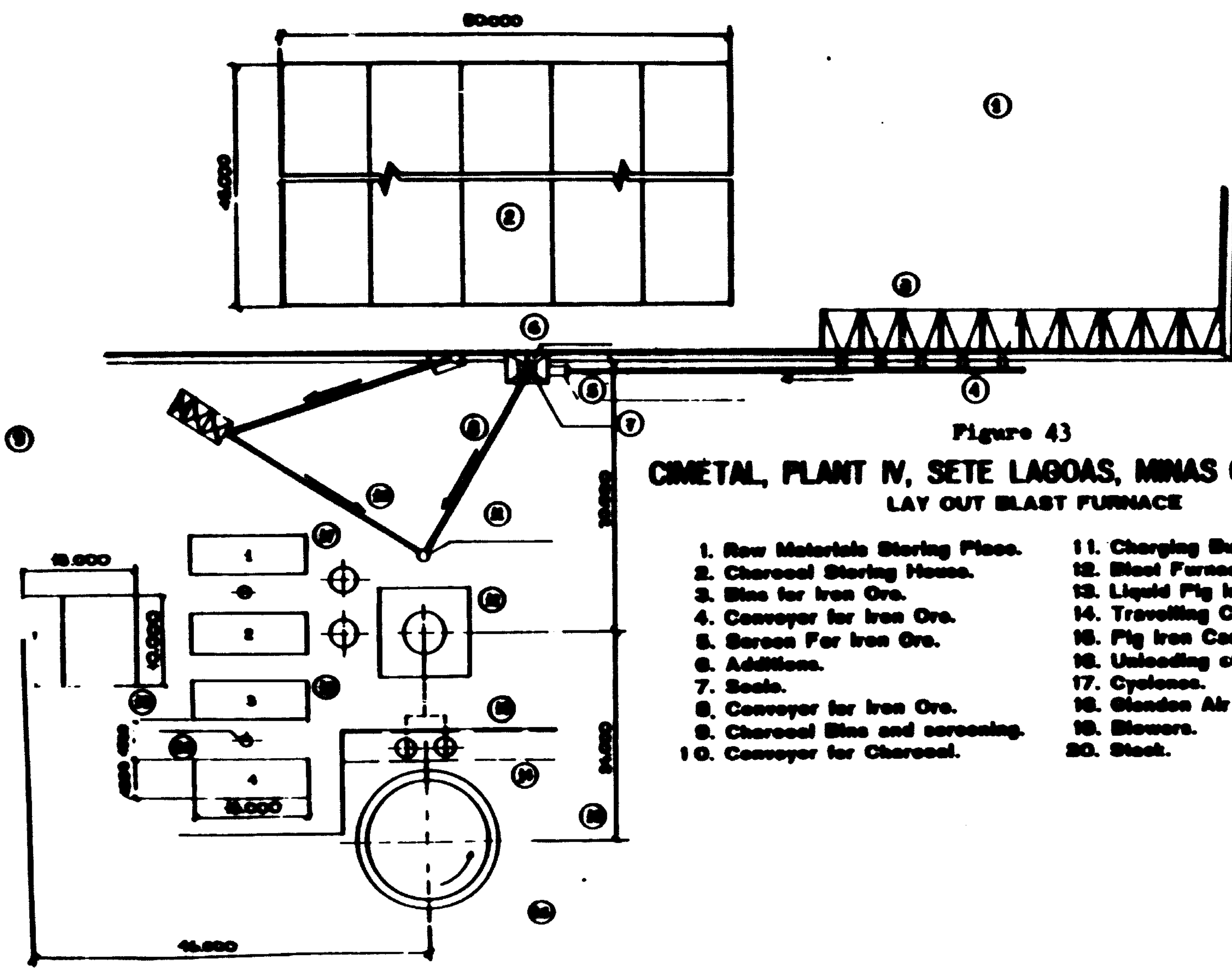


Figure 43

CIMETAL, PLANT IV, SETE LAGOAS, MINAS GERAIS, BRAZIL

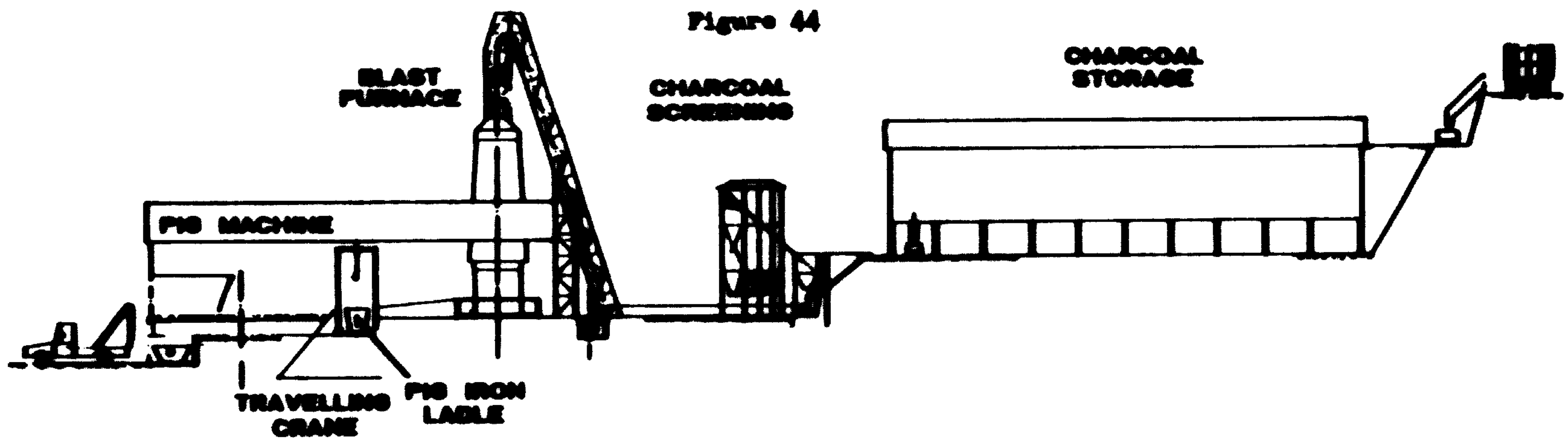
LAY OUT BLAST FURNACE

1. Raw Materials Storing Place.
2. Charcoal Storing House.
3. Bins for Iron Ore.
4. Conveyor for Iron Ore.
5. Screen For Iron Ore.
6. Additions.
7. Scale.
8. Conveyor for Iron Ore.
9. Charcoal Bins and screening.
10. Conveyor for Charcoal.
11. Charging Bucket.
12. Blast Furnace.
13. Liquid Pig Iron Ladle.
14. Travelling Crane.
15. Pig Iron Casting Machine.
16. Unloading of Pig Machine.
17. Cyclones.
18. Glendon Air Heaters.
19. Blowers.
20. Stack.

CIMETAL, PLANT IV, SETE LAGOAS, MINAS GERAIS, BRAZIL

GENERAL LAYOUT OF BLAST FURNACE

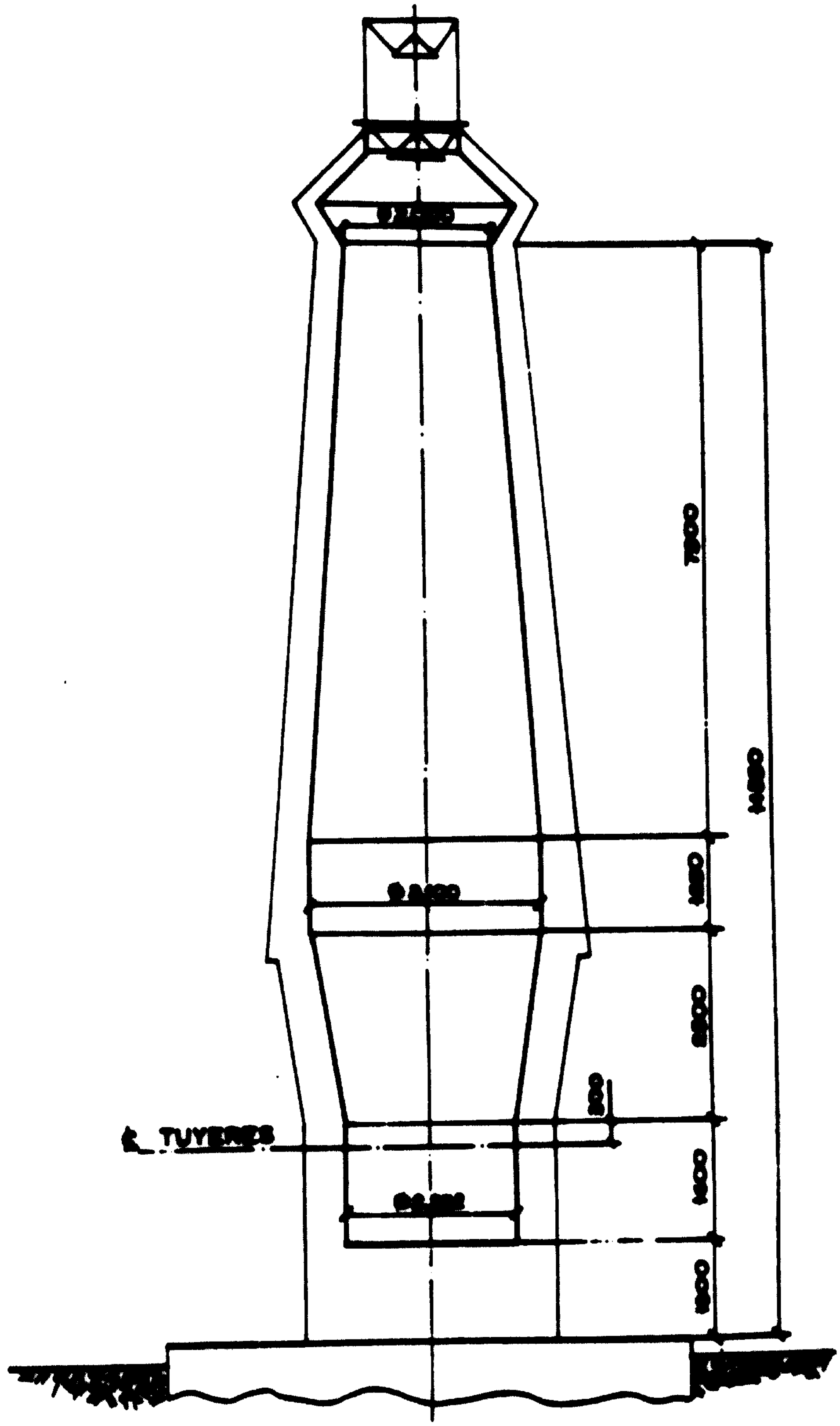
Figure 44



CIMETAL PLANT IV, SETE LAGOAS

BLAST FURNACE

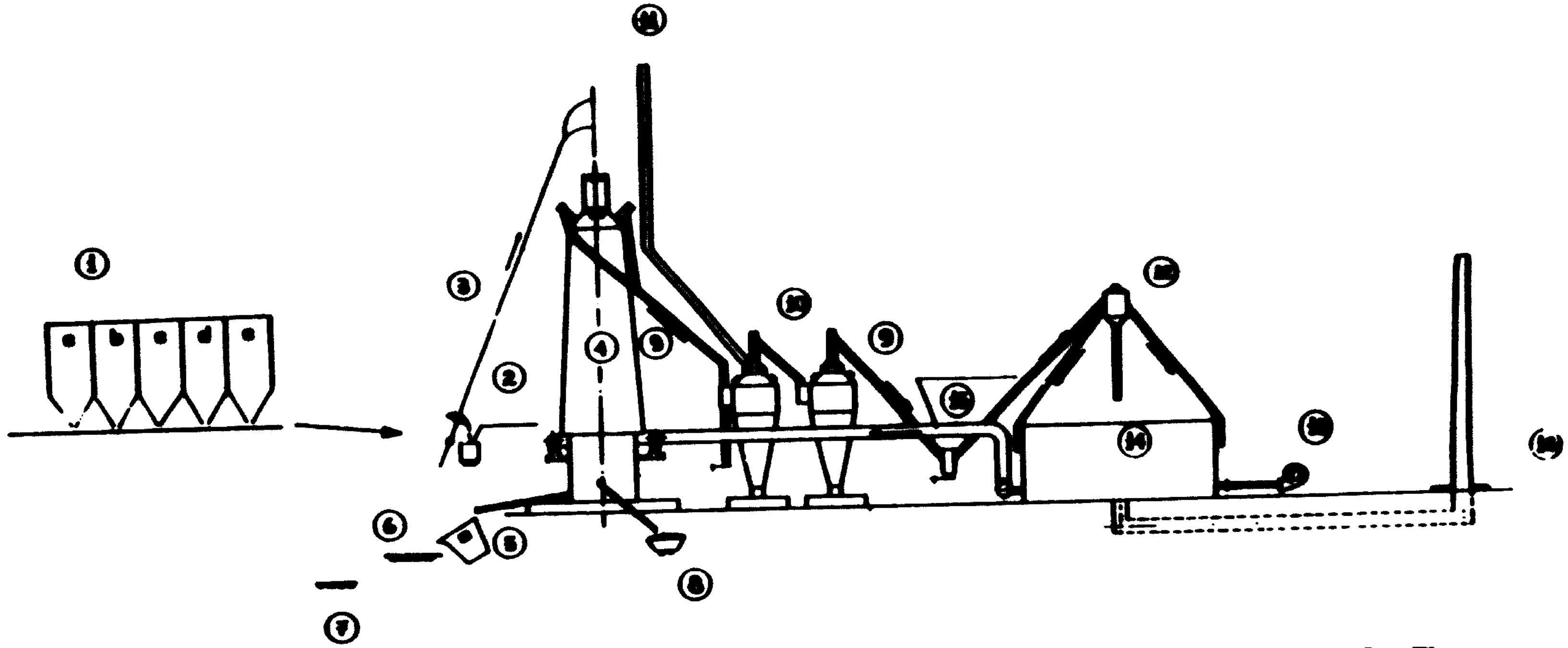
Figure 45



CIMETAL, PLANT IV, SETE LAGOAS, MINAS GERAIS, BRAZIL

FLUXOGRAM

Figure 46

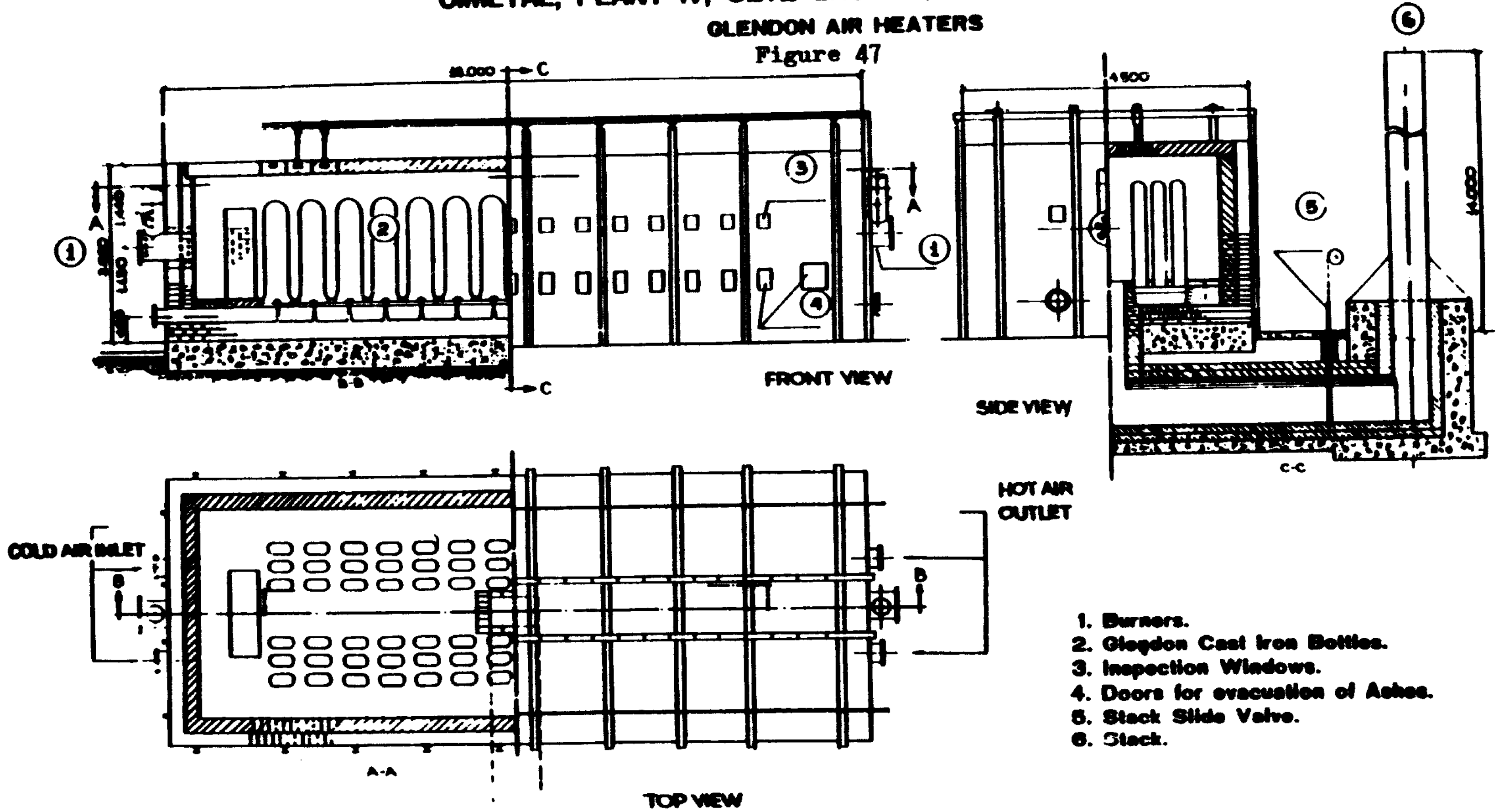


1. Raw Materials: a. Charcoal
   b. Iron Ore.
   c. Manganese Ore.
   d. Limestone.
   e. Quartz.
2. Charging Bucket.
3. Skip.
4. Blast Furnace.
5. Pig Iron Ladle.
6. Pig Iron Casting Machine.
7. Pig Iron.
8. Slag.
9. Blast Furnace Gas Pipe.
10. Cyclones.
11. Excess of Blast Furnace Gas.
12. Gas Distributor.
13. Blowers.
14. Glendon Air Heaters.
15. Hot Air Pipe to Blast Furnace.
16. Stack.

CIMETAL, PLANT IV, SETE LAGOAS, MINAS GERAIS, BRAZIL

GLENDON AIR HEATERS

Figure 47

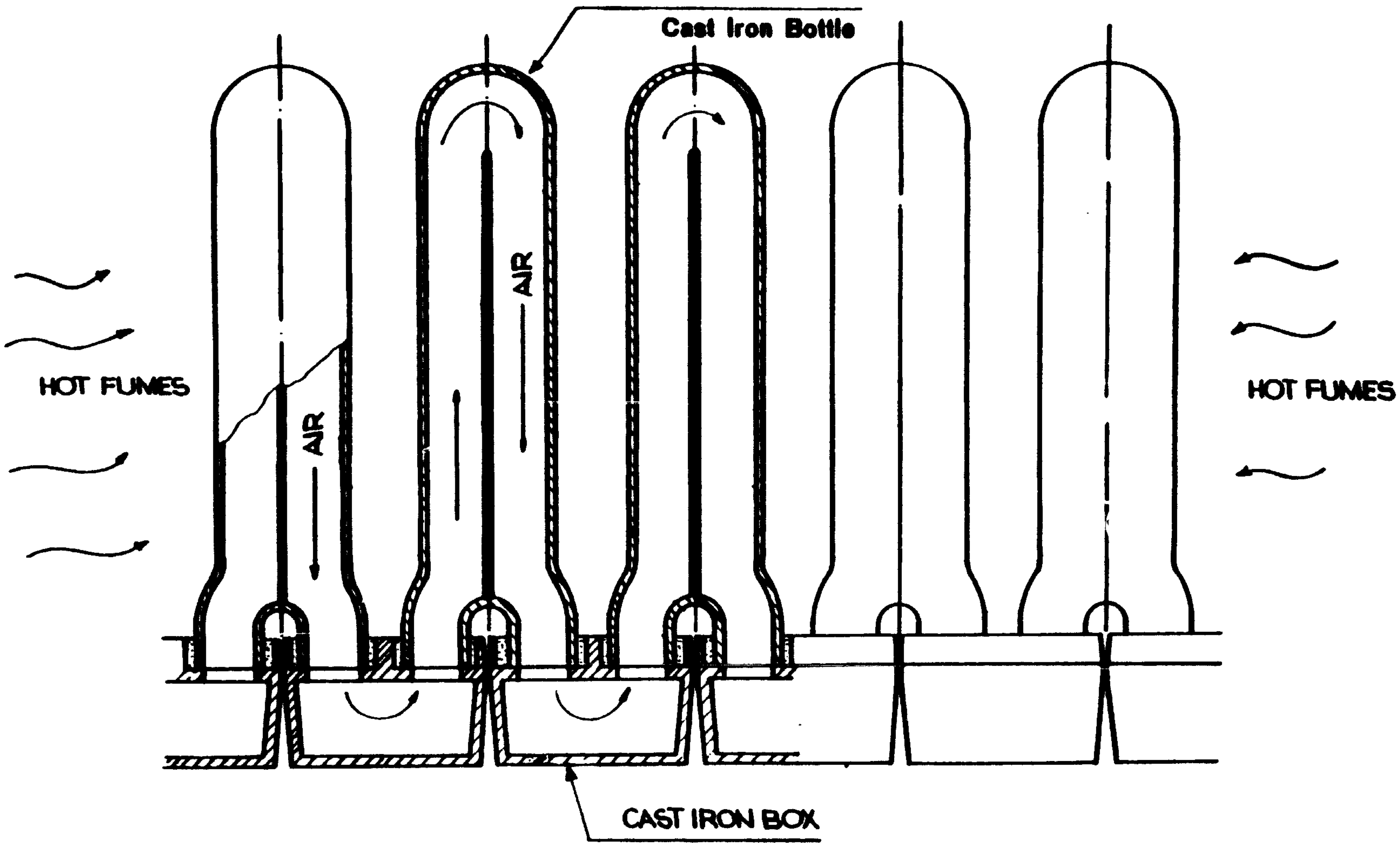


1. Burners.
2. Glendon Cast Iron Bottles.
3. Inspection Windows.
4. Doors for evacuation of Ashes.
5. Stack Slide Valve.
6. Stack.

CIMETAL, PLANT IV, SETE LAGOAS, MINAS GERAIS, BRAZIL

GLENDON AIR HEATERS

Figure 48



6. SOURCES OF KNOW-HOW AND TECHNOLOGY

In the course of several decades Brazil has created an efficient, reliable and unsophisticated metallurgical technology for charcoal iron and steel plants and all co-related activities. This technological experience is well adapted to local Brazilian conditions and has reached a reasonable degree of perfection. New operational ideas and innovations are continuously being adopted.

Brazil is thus able to make its metallurgical know-how in charcoal based iron and steel plants available to other countries.

The following services and equipment can be supplied:

- Technical consultancy.
- Planning, engineering and design of charcoal blast furnaces and related activities in the fields of mining, charcoal manufacture, reforestation, sintering, etc.
- Construction of equipment for iron and steel plants and their related activities.
- Erection and commissioning of the plants.
- Training of local personnel in Brazil and in the destination country.

Efficient and reliable transfer of metallurgical know-how is guaranteed to developing countries through associations or co-operation between Brazilian charcoal based iron and steel companies, engineering firms and manufacturers of metallurgical equipment. This aspect is most important for the training of technical personnel and the start-up period of a new plant and its initial operation.

7. BRAZILIAN COMPANIES ABLE TO SUPPLY KNOW-HOW AND EQUIPMENT FOR CHARCOAL BASED IRON AND STEEL PLANTS

(1) An association of the three companies: USIMEC-CIMETAL-TENENGE for planning, engineering, erection and export of charcoal iron and steel plants and direct reduction plants; the latter for yearly capacities of up to 600.000 tons of sponge iron.

(a) USIMEC - Usiminas Mecanicas S.A., Belo Horizonte

A wholly owned subsidiary of Usiminas, Usinas Metalurgicas Minas Gerais. Usiminas is a state owned, Siderbras holding, coke based iron and steel company.

Type of activities:

- basic and detailed engineering
- supply of equipment

Engineering offices in Belo Horizonte.

Mechanical shops for construction of heavy steel mill equipment, located at Ipatinga, Minas Gerais, 210 km East of Belo Horizonte. Short term association with several internationally famous foreign companies for acquisition and transfer to Brazil for most advanced technology.

Types of equipment: Industrial steel buildings, steel bridges, grate type sinter plants, basic oxygen steel shops, complete coke and charcoal blast furnace plants, continuous casting machines, rolling mills for flat products, sheet and strip finishing lines.

Work force: Engineering: Graduate engineers: 150.

Technicians and draftsmen 250.

Mechanical shops: 2000 employees.

Some projects executed: Grate-type sinter plant 180 sq. meters, coke breeze fuelled, for Usiminas. Charcoal blast furnace, 900 tons/day nominal capacity, for Acesita (now being erected). Hot metal mixer, 1,000 tons capacity, for Belgo Mineira. Basic oxygen vessel, 70 tons capacity for Usiminas. Basic oxygen steel plant for Cimetal plant, with 20 tons capacity vessel (in execution). Shell of electric low shaft furnace for Mannesmann plant. Slab continuous casting machine for Cosipa plant (Siderbras Holding). Billet continuous caster for Cimetal plant (in execution)

Large projects now being executed:

Basic oxygen steel shop for Acominas, state-owned, Siderbras controlled coke-based iron and steel works, under construction at Ouro Branco, 80 km south-east from Belo Horizonte.

(b) CIMETAL - Cimetal Siderurgia, Belo Horizonte

Largest Brazilian producer and exporter of foundry pig iron with 12 blast furnaces, also one charcoal based iron and steel plant which is being expanded. Large experience, good performance own know-how in projecting, erecting and operating charcoal blast furnaces.

Type of services which can be offered: feasibility studies, technical assistance in charcoal manufacture, forestry activities, charcoal blast furnace projects and operation. Training of personnel. Start up operation.

References: has projected and built most of its own blast furnace plants.

(c) TENENGE - Tecnica Nacional de Engenharia S.A. São Paulo

Engineering company.

Activities: civil works, plant erection.

Some references: Studies and project for charcoal iron and steel plant "ACEPAR", Aceros del Paraguay, close to Asunción, capital of Paraguay. Plant capacity - 100,000 tons/year. Research, studies and projects for direct reduction plant in South Brazil, 600,000 tons/year nominal capacity, to use reducing gases obtained from gasification of Brazilian coal with high ash and sulphur content. Construction of several hydro-electric plants.

(2) A co-operation between Companhia Siderurgica Belgo Mineira and Paul Wurth, Luxembourg, for the planning, engineering, export, erection and start-up of charcoal based iron and steel plants and foundries.

(a) Companhia Siderurgica Belgo Mineira

Oldest and largest charcoal based iron and steel company in Brazil and in South America. Great experience, proven performance and own know-how in the design, construction and operation of charcoal blast furnaces plants and all activities related to charcoal iron and steel production.

(i) Manufacture of charcoal:

Own production	700,000 cubic m.
Being expanded to	1,800,000 cubic m.

(ii) Reforestation:

Total planted until 1976	120,000 ha
Present yearly plantation	12,000 ha (20 million trees)

(iii) Pig iron production:

Present production	600,000 tons/year
Being expanded to	750,000 tons/year

(iv) Steel production:

Present production	800,000 tons/year
Being gradually expanded to	1,000,000 tons/year

Basic oxygen, open hearth, being changed in the future to electric arc furnaces.

(v) Iron foundry:

Present production	15,000 tons/year
Being expanded to	30,000 tons.

Services which can be offered comprise:

Consultancy, planning, transfer of know-how and technology, plant start-up, training of personnel in its Brazilian plants and/or abroad, in all the above mentioned activities from (i) to (v).

(b) Paul Wurth, Grand Duchy of Luxembourg

Engineering and construction company of iron and steel mill equipment, since 1870. Belongs to the Arbed group, Luxembourg. Headquarters and mechanical construction shops in Luxembourg. Work force: 200 graduate engineers, 600 technicians and employees. A Brazilian subsidiary in Belo Horizonte since 1976.

Co-operation with COBRAPI for projecting, engineering and supplying charcoal blast furnace plants for Latin America (1977). Many years specialised in projecting, building and modifying complete charcoal and coke blast furnace plants.

Inventors of a universally known patented bell less blast furnace top and with a continuous charging device.

Some references:

Built and modified in 1935, 1936 and 1956 in close co-operation with Belgo-Mineira, several charcoal blast furnaces for the same company and for other Brazilian companies.

Now projecting (1977) for Belgo Mineira, and in close co-operation with this company, a charcoal blast furnace of 800 tons/day nominal capacity.

Coke blast furnaces: projected, built and modified most blast furnaces in Belgium and Luxembourg and many furnaces in other parts of the world.

Services which can be offered: Feasibility studies, engineering and supply upto after commissioning of complete charcoal blast furnace plants.

(3) Companhia Aços Especiais Itabira (ACESITA) - Belo Horisonte

One of the largest Brazilian charcoal based iron and steel companies, producing special steels including alloy billets and bars, stainless and silicon flat products, castings and (through a subsidiary company) drop forgings.

Reforestation - 110,000 ha planted in eucalyptus.

Pig iron production - 200,000 tons/year being expanded to 500,000 tons/year.

Raw steel production - 300,000 tons/year being expanded to 600,000 tons/year.

Facilities - blast furnace, electric reduction furnace, melt shop with LD, electric, vacuum and argon oxygen refining. Slab casters, blooming and billet mills, bar mills, steckel hot strip mill, Sendzimir mills for silicon and stainless cold rolling, steel and iron jobbing foundry.

A large engineering group with 1,000 employees, of which 275 engineers, was formed to manage the expansion programme and is now available for the sale of services.

Types of services which can be offered:

Technical consultancy, feasibility studies and basic engineering for reforestation, charcoal production, charcoal based iron making, melt shops, rolling mills, foundries and forging shops. Co-ordination and detail design. Procurement. Construction project management. Commissioning. Training of personnel in the company's plants.

(4) Companhia Brasilsira de Projetos Industriais (COPRAPI)
(Brazilian company for industrial projects)

An engineering company, subsidiary of "Companhia Siderurgica Nacional" (National Steel Company), Government owned steel company, Siderbras holding. Founded in 1963. Five engineering offices with 250 graduate engineers and 750 technicians and employees. Offices in: Volta Redonda, State of Rio de Janeiro, where steel works are located, in São Paulo, Rio de Janeiro , Belo Horizonte, Victoria.

Types of activities: industrial projects, studies, basic and detail engineering of iron ore mines, blast furnace and steel plants. Recent particular interest in mini steel mills. Since 1977 co-operation with Paul Wurth for planning and engineering charcoal blast furnace plants for Latin America.

Some services executed:

Detailing of charcoal fines fuelled continuous grate, Lurgi design and equipped sinter plant for Belgo Mineira, 1,000,000 tons per year nominal capacity.

Detailing of charcoal blast furnace of 800 tons/day nominal capacity, Paul Wurth design for Belgo Mineira.

Studies for a 500 tons/day capacity charcoal blast furnace for another Brazilian customer.

Studies for increase of efficiency of Siderama, Manaus, charcoal based iron and steel works, now Siderbras Holding, project includes: production of charcoal, forestry activities, mining, sinter plant. Studies for a "Babaçu" industrial project in the State of Maranhão for the production of oil, charcoal, and by-products.

(5) Montec - Belo Horizonte

Subsidiary of Magnesita S.A., largest Brasilian and South American manufacturer of refractories.

An engineering, construction and erection company of industrial furnaces for the iron and steel industry. Equipment for transportation, treating and storing of minerals. Builder of steel buildings. Mechanical shops for construction of charcoal blast furnace shells, stoves and their auxiliaries, industrial furnaces and their auxiliaries.

Types of services and equipment available for charcoal based iron and steel plants: Projects, studies, basic and detail engineering of charcoal blast furnaces, stoves, industrial furnaces. Construction and erection of such equipment and their refractory linings. Start-up of charcoal based blast furnace plants and training of personnel with the aid of associated Brazilian charcoal blast furnace companies.

Some services executed: Change of design of the refractory lining of a coke fired blast furnace to charcoal. Projects for supply of special basic refractory for the hearth of electric reduction furnaces. Various studies for refractory linings of small and medium sized Brazilian charcoal blast furnaces. Projects for refractory linings of the two largest charcoal blast furnaces presently being built for Acesita and Belgo Mineira. Calculations and studies of new and modified blast furnace stoves.

(6) Demag Industrial Equipments

Subsidiary of Demag, Fed. Rep. of Germany (FRG), which is affiliated to Mannesmann, FRG and also to Siderurgica Mannesmann, Barreiro, Belo Horizonte. Established in Brazil since 1976. Plant located at Vespasiano, 20 km. north-west of Belo Horizonte. Demag is an engineering, construction and erection company of the following equipment : blast furnace plants, blowers, electric low shaft reduction furnaces, basic oxygen and electric arc steel plants, continuous casting machines, rolling mills, pipe manufacturing machines, travelling cranes, steel buildings, foundry plants.

Types of services which can be offered: engineering, construction, erection of complete iron and steel plants.

References: BOF vessel 75 tons capacity for new steel plant for Mannesmann, Barreiro, Belo Horizonte.

(7) Krupp - Industrial Equipment Manufacturer

Subsidiary of Krupp, Germany. Plant located at Betim, 15 km west from Belo Horizonte. Founded - 1975.

Construction of complete iron and steel mill equipment and their erection. Mining, treatment of minerals and their transportation and storing.

Types of services which can be offered: engineering and construction of installations for: mining, crushing, screening, transportation of iron ores, blast furnace plants, basic oxygen and electric arc steel plants, rotary kilns for the production of sponge iron, rolling mills. Some references: parts of Lurgi grate type sinter plant for Belgo Mineira, steel ladles.

(8) Pohlig Heckel do Brasil

Subsidiary of Pohlig Heckel - Bleichert, Federal Republic of Germany and Arbed Group, Luxembourg. Relationship with Belgo Mineira, Brazil.

Plant located at Cidade Industrial, Belo Horizonte. Since 1955. Engineering and construction company specialized in transportation and handling equipments for all kinds of materials.

Types of services and equipment which can be offered: projects, engineering and equipment for: travelling cranes, blast furnace shells and charging hoists, steel buildings, transportation, handling and storing of charcoal, iron ores, minerals. Iron foundry cupolas and foundry equipment.

Some services executed: equipment for charcoal storing, treating and handling at the Monlevade plant. Equipment for blast furnace burden preparation at the same plant. Charcoal aerial cable conveyor, 50 km long, at Monlevade plant. Equipment at various Brazilian sea ports for handling of iron ores and loading of ships at Vitoria and other ports. Treatment and transportation equipment of ores at various large Brazilian iron ore mines.

(9) Schenck do Brasil

Subsidiary of Schenck, Federal Republic of Germany.

Plant: São Paulo. Builders of equipment for transportation, measuring and weighing of raw materials and other products in iron and steel mills

Some services executed: The supply of iron ore and sinter screens and scales to many Brazilian steel plants.

(10) Isomonte Equipmentos e Montagens Industriais
(Isomonte industrial equipment and erection).

Founded 1963. Since 1974: majority of shares by Salzgitter Group, Federal Republic of Germany. Factories: Cidade Industrial, Contagem, Belo Horizonte. Employees: 2,000.

Activities: engineering, construction, erection of steel buildings and equipment for mining, iron and steel plants, petrochemical and chemical industries.

Mining: special cranes, stackers, reclaimers.

Iron and steel industry: special travelling cranes, hot blast stoves for blast furnaces, torpedo ladle cars, blast furnace gas lines and holders, liquid fuel lines, tanks and distribution systems.

Some services executed: detailing of projects, building and erection of steel buildings, erection of equipment for sinter plants, blast furnaces, basic oxygen shops, forges for several Brazilian charcoal and coke based steel works.

(11) Companhia Brasileira de Caldeiras-Industrias Pesadas (CBC)
(Brazilian Boiler Co. Heavy Industries).

Subsidiary of Mitsubishi group, Japan. Founded in 1955.

Factories: (a) Varginha, State of Minas Gerais, 300 km south west of Belo Horizonte

(b) Jundiai, State of São Paulo, 100 km north of São Paulo. Largest factory in Latin America for the construction of boilers and other heavy equipment.

An engineering and manufacturing company of equipment for: mining industry, crushing mills.

Iron and steel industry: sinter plants, blast furnaces, steel shops, iron and steel ladles, torpedo cars, gas holders, reheating furnaces, auxiliary equipment for hot and cold rolling mills.

Chemical and petrochemical industries.

Hydro-electric and thermo-electic power plants.

(12) Mecanica Pesada (Heavy Mechanical Industries)

Subsidiary of Schneider Group, France. Founded in 1954.

Factory: Taubaté, State of São Paulo, 125 km north-east of the state capital. Technological assistance by Creusot Loire Group, France.

An engineering and manufacturing company of heavy machinery for all basic industries, principally the iron and steel industry.

Types of services which can be offered: sinter plants, mixers, iron and steel, ladles, torpedo cars, ingot cars, rolling mills, travelling cranes, basic oxygen vessels, job work.

Some services executed: 200 tons/day charcoal blast furnace for Ferro Brasileiro. Three hot metal mixers for "Barbara" State of Rio de Janeiro. 120 tons hot metal mixer for Ferro Brasileiro. Various steel mill equipment for Brasilian Charcoal and coke based iron and steelworks.

(13) Nipocon (Nippon Steel - Confab)

An association, since 1978, between two companies.

CONFAB INDUSTRIAL (majority share holding), an important Brasilian manufacturer of large diameter welded pipe, steel vessels and machinery for basic industry. Several factories in the region of São Paulo.

NIPPON STEEL CORPORATION, largest steel producer in the world and an important manufacturer of heavy machinery.

The association represents the technological experience and know-how of Nippon Steel and the manufacturing facilities of Confab. Nipocon is an engineering and manufacturing company of equipment for the iron and steel industry. The company also undertakes erection.

Types of services which can be offered:

Planning, projecting, construction of new and modification of existing plants: coke ovens, fixed and mobile hot metal mixers, BOF vessels, rolling mills, soaking pits, reheating furnaces, heat treatment furnaces, sheet, strip and pipe processing lines, equipment for pollution control.

(14) Other Engineering Companies in the State of Minas Gerais

In the middle sized towns situated west and north west of Belo Horisonte, a region where most of the independent non-integrated blast furnace plants are located, there exist several small, mostly family owned companies, specialised in projecting and constructing small and medium sized charcoal blast furnace plants. Most of the existing blast furnaces in this region have been constructed by these companies in their local mechanical shops and foundries. Some examples:

(a) Siderurgica Itatiaia, City of Itauna, Minas Gerais. The company operates three charcoal blast furnace plants. Is the inventor of a device for continuous running of hot metal for charcoal and coke blast furnaces which it has patented in Brasil, Venesuela and France. More than 30 blast furnaces in Brasil have been equipped with this device.

(b) Engineering office Glauco Machado de Canvalho, City of Itauna. Specialised in projecting and engineering of charcoal blast furnaces, up to 200 tons/day capacity.

(c) Mechanical shops and foundries with experience in the construction of charcoal blast furnaces.
Oficina Mecanica Freitas (mechanical shops), I una
Oficina Mecanica Santa Rita (" "), Itauna
Delp-Engenharia Mecanica, Cidade Industrial, Belo Horisonte,
Charcoal handling and storing, supplier to Cimetal.

References of all these companies: several blast furnaces built and operating in the region.

(15) Other Equipment Available in Brasil

All the following services and equipment for the charcoal iron and steel industry are now available in Brasil, mostly in the great industrial centres of São Paulo, Rio de Janeiro, Belo Horisonte:

- equipment for forestry and charcoal operation.
- civil construction.
- blowers, mixers, casting machines, auxiliary equipment .
- electrical equipment .
- hydraulic and pneumatic transportation systems.
- control and measuring equipment .
- transportation equipment for water, rail, road, continuous conveying of materials.
- foundry equipment.
- rolling mill equipment and their auxiliaries.

The share of locally built machinery in new, modern Brasilian iron and steel plants is now approximately 70% and in a few years, sponsored by Government influence, will reach 80 to 90%. For charcoal based iron and steel plants which are generally of simple design, 90% are now built in Brasil.

(16) <u>Hydro-electric power plants</u>

Brasil is one of the most advanced countries in the field of building and operating hydro-electric power plants and occupies an important world position in the production of hydro-electric energy.

Existing power plants of more than one million KW - six
Plants under construction of more than one million KW - nine

Due to this large experience, the technology in building dams, power plants and power distribution has reached a high degree of efficiency. This technology, comprising civil, mechanical and electric engineering as well as all the necessary services and equipment can be supplied to other countries by numerous companies of international fame and experience.

8. ACKNOWLEDGEMENTS

The completion of this document was made possible by the helpful co-operation of the following persons and companies:

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Details of Brasilian Charcoal Based Works

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Henrique Marigo
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CIMETAL SIDERURGIA

Grad, engs. Romero Machado Corrêa - President
José Poluceno Braga

COMPANHIA SIDERURGICA MANNESMANN

Grad. eng. Rolf Bredt

COMPANHIA AÇOS ESPECIAIS ITABIRA, ACESITA

Grad. engs. Frederico Albuquerque
Rubens Corrêa Silveira
Vilmar Oliveira

COMPANHIA FERRO BRASILEIRO

The late
grad. eng. Roberto Paes Leme

BRAZILIAN STEEL INSTITUTE

Grad. eng. Eduardo Euler

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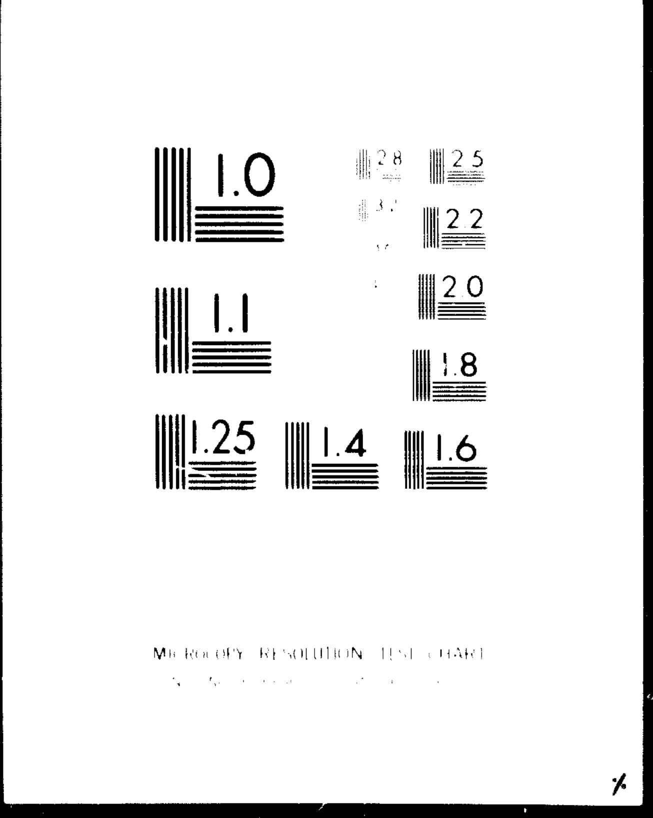

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G-563

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