RESEARCH AND DEVELOPMENT IN COAL AND COKE IN THE CONTEXT OF BRAZILIAN IRONMAKING INDUSTRY (1)

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1. INTRODUCTION

In order to position the present state of Research and Development (R & D) in coal and coke in Brazil, it is necessary to characterize the Brazilian experience in ironmaking technology throughout the years, once the coal and coke system was not an exception within such context.

One can say that the first effective technology absorption in large scale ironmaking in Brazil occurred in 1938, when a group of engineers was sent to Europe with the purpose of carrying out viability studies to implement a coke-based steelmaking works in the Country. A very rapid development which had its mark with the start up of CSN's Presidente Vargas Works in 1946, the first of the five SIDERBRAS coke-based integrated works (Figure 1) (2). The present Brazilian hot metal production is 23 Million tons per year of which about 70% correspond to the coke-based integrated works share (Figures 2 and 3) (2).

Traditionally known as an agricultural country, Brazil is currently positioned as the seventh major steel producer in the world (Table I) (1). Within that scenario, the SIDERBRAS Group occupies the second position among independent producers.

They operate with modern installations, being worth mentioning blast furnaces with inner volumes varying from 885 (USIMINAS 1 and 2) to 4,415 cubic meters (CST), equipped with very updated facilities which include computer controlled operation and burden distribution via movable armour (USIMINAS 2, COSIPA 2, CSN 3 and CST) and bell-less top (CSN 1 and 2 and AÇOMINAS). Productivity indexes greater than 2 t/m3/day and low fuel consumption, lower than 580 kg coke/ton hot metal confer to the Brazilian ironmaking industry high degree of competitiveness.

Hence, in this half century, the Brazilian ironmaking industry evolved from the complete technological dependence to a situation close to self-sustained competence. The specific situation of the coal and coke system is not different. The SIDERBRAS Group relies on a 8.59 Mt/year installed battery capacity, with about 80% of the ovens having less than 10 years.

The Brazilian coal reserves, although of satisfactory amounts for our production levels, possess neither compatible production nor quality. For this reason, Brazil has to import about 90% of its own needs, this way becoming one of the largest world coal importers. The SIDERBRAS Group imported 9.1 million tons of coal in 1986, for approximately a Million ton domestic coal consumption.

As shown in Figure 4 (2), the ironmaking industry has been developing a wide diversification programme of sources of coal supply in the last 41 years, making the technological approach of the coal and coke system even more complex.

2. RESEARCH AND DEVELOPMENT IN BRAZIL

The complexity of the ironmaking technology has been limiting R & D activities for the appropriate technology absorption and adaptation, leading to projects of short and medium duration. They essentially aim at optimization of processes and at utilization of available resources to a better revenue, cost reduction and increase of quality level of final products. This situation made research activities in Brazilian ironmaking industry to evolve from the integration model shown in Figure 5, where different sectors of the productive system are involved. This integration has been responsible for the achievement of significant results in terms of research and development as we intend to show throughout this papaer, specifically for the case of coal and coke.

Only the Brazilian National Steel Company (CSN) and USIMINAS have captive Research Centres (Annexes I and II). CO-SIPA is implementing a Technological Research Group, Whose philosophy may be followed by CST and AÇOMINAS, which have recently had their start up. In addition to SIDERBRAS available means, we have been pursuing the utilization of technological background existing in the Country trough contracting services from independent Research Institutions and Universities.

Regarding manpower capacitation, we have been investing in specialization not only through post graduation courses both in Brazil and overseas, but also through specific training programmes in Research Centres and related institutions. On the other hand, capacitation of medium level personnel follows a cooperative programme between the companies and technical schools, involving practical classes inside the plants, teaching by companies qualified employees and hiring of graduates.

3. RESEARCH IN COAL AND COKE

The coal and coke system is highly complex and is responsible for about 50% of hot metal cost. As mentioned earlier, it is also very diversified, once coals from the United States, Poland, Australia, Canada, Colombia, and more recently, from China and USSR are imported. The total amount of domestic coal used comes from the southern Santa Catarina State.

Thus, regarding R & D efforts, this paper will emphasize coal cleaning, selection of coals and blends, alternative raw materials and process control, besides environmental protection.

3.1. BENEFICIATION

Although the main problem for domestic coal utilization in ironmaking is the high ash and sulphur levels, besides its low washability recovery, the research efforts towards improving coal quality have not been made by ironmaking companies. Traditionally, such studies have been carried out by independent institutions as CETEM (Mineral Technology Centre) in Rio de Janeiro and the CIENTEC (Foundation for Science and Technology) in Rio Grande do Sul State, besides universities. SIDERBRAS is currently engaged in a cooperative project aiming at optimizing the process of domestic coal cleaning.

One can conclude that a major contribution can be given by mining companies once there is enough room to increase domestic coal utilization on coal blends, especially considering its high fluidity levels (greater than 50.000 ddpm), once the present characteristics of such coal brings a detrimental effect upon the coke-rate and blast furnace productivity, as well as upon the mechanical properties of steel. This would be an extraordinary contribution towards decreasing foreign exchange credits remittance.

3.2. SELECTION OF COALS AND BLENDS FOR COKEMAKING

Initial R & D efforts in coal by the Brazilian ironmaking industry were concentrated in evaluating the different analytical methods available. One can even say that these efforts were for implementing the necessary infra-structure to an appropriate characterization of the coals consumed at that time. The SIDERBRAS Group has about 30 coals under contract, selected by cost and quality optimization criteria from 250 filed coals.

A considerable part of these efforts was placed towards adapting internationally accepted models for selection of coals and blends to the Brazilian conditions.The petrographical model developed by Shapiro and Gray was used for some time. However, utilization of Australian and Canadian coals of high inert content when compared to American coals, led to a much higher dispersion os stability results, so that "Composition Balance Index" (CBI) and "Strength Index" (SI) are today merely indicative. Studies are still underway to further adapt such model to the Brazilian conditions.

The model developed by Simonis was also widely studied. Difficulties in adapting it to Brazilian standards and in the establishment of optimal crushing conditions discouraged continuation of studies on this line.

The fact that the Brazilian standard for coke strength assessment is derived from the Japanese equivalent, made the Group decide for the proposal of Miyazu and coworkers through the MOF diagram, also of easier modelling.

The models currently followed by SIDERBRAS Companies essentially consider restrictions of:

- available tonnages (minimum and maximum);
- diversification of sources of supply;
- the need for combining cargoes among the Companies to reduce the freight cost impact;
- volatile matter content that answer the needs for the equilibrium between coal chemicals production and coke yield;
- maximum ash and sulphur contents as specified;
- maximum phosphorous content (in the case of CSN);
- adequate fluidity and reflectance ranges, essentially

according to the MOF diagram, but with figures adapted to the Brazilian operational routine;
- parameters related to the development of coking pressure and coke high temperature properties.

The evaluation criteria are individual (per Company).The effective carbon concept introduced by Flint,although adopted in some cases, is being questioned for excessively penalizing ash and sulphur of coals. We have been pursuing a new concept for comparing coals which minimize such effect besides considering the event of self-fluxing sinters and external desulphurization of hot metal, processes which were not considered by Fiint at that time.

3.3 ALTERNATIVE INPUTS FOR COAL BLENDS

Great efforts have been conveyed to introduce "inert materials" in the coking blend, aiming essentially at reducing the influence of coal cost upon the cost of steel production. Pioneer studies on this line in Brazil were carried out by USIMINAS and CSN since 1971, when they tryed to use charcoal and babaçu coconut breeze respectively. Many other inerts such as anthracite, coke breeze, subbtituminous coals from Rio Grande do Sul State and petroleum coke were further studied (3,4). The technical viability for coke breeze utilization after classification to less than 0.60 mm (28 M), was studied by CSN in conventional cokemaking (5). The project is currently under economical analysis for a potential industrial implementation. Figure 6 illustrates this alternative which was applicable up to 7% coke breeze in pilot scale.

USIMINAS, by its turn, studied in pilot scale, charcoal utilization through the briquette-blend process (6), where charcoal was introduced up to 9 per cent. However, among all the inert materials studied, only petroleum coke got to achieve industrial utilization,rather for economical than for technical reasons. In such case, the inert was used up to 10% with no detrimental effects upon the high quality coke required by large blast furnaces. (4).

Currently, the preference is being to pursue the usage of weak and soft coking coals, basically due to the attractive price these coals have been offered. Different coals of this type have already been successfully tested both in laboratory and in industrial cargoes (CST and USIMINAS). Based on these encouraging results, we can expect such coals to be compounding Brazilian coal blends in a routine basis.

3.4. THE COKEMAKING PROCESS

The mechanism of coke formation has been studied in laboratory through microscope connected to a heating stage and through the evaluation of the formation of coke porous structure.

Yet regarding coke properties, factors such as microfissuring and mechanical strength were widely investigated. Recently, studies have been directed towards adopting new parameters for assessing coke behaviour within the blast furnace. Coke strength after reaction (CSR) and coke reactivity index (CRI) were incorporated to routine, although new tests are under development.

Coke petrography is currently a field of great interest for Brazilian investigators. The SIDERBRAS Group actively participates of standardizing efforts by ABNT (Brazilian Association for Technical Standards) through interlaboratory programmes involving Brazilian and foreign Institutions. It is worth mentioning that a microtexture classification proposed by the Brazilian Group to the International Commission for Coal Petrography (ICCP), simplified for industrial applications (Table II), is under appreciation. Investigations for correlating microtexture and reflectance analysis in coke with its properties, reactivity for example, is a major objective, perhaps for providing a new parameter for coal selection. Results an shown in Figure 7 encourage the studies to proceed.

Another point of interest is the influence of rank and operational conditions upon the formation of the coke porous structure. We have recently incorporated sophisticated apparatuses to our laboratories (automatic picnometer, surface area analyser and mercury porosimeter) to permit a full characterization (Figures 8 and 9).

In the last few years, there has been an increasing consciousness regarding the cost of energetic inputs, and at the same time, data aquisition systems are assuming paramount importance. As a consequence, process automation is playing a major role in development programmes.

Cokemaking process is not an exception in this general tendency. Besides the mentioned energy saving advantage, automation is pursued with the purpose of reducing heterogeneity of the coke produced. In this regard, it is worth mentioning the work carried out by USIMINAS which sampled and water quenched representative coke charges (pusher side) by retaining the charge in the coke guide and proceeding a complete characterization through height and width. Besides emphasizing the heterogeneous character of the cokemaking process, the work hopes to furnish information to better accomplishment of coal charge preparation, oven heating procedures, coke quenching and size preparation.On the other hand, studies to establish the end point of the coking cycle are underway through measurements of gas composition and temperature in the ascension pipe, as suggested in literature (7).

Finally, considering the government interest in increasing equipment, product and process nationalization, we can distinguish the efforts towards building (designing and construction) the very first Brazilian coke battery where the most updated conception is being adopted, as well as sophisticated systems for operational control.

3.6. ALTERNATIVE TECHNOLOGIES

The SIDERBRAS Group adopted the process of selective crushing and the process of coke dry quenching respectively at AÇOMINAS and CST. Their experience will be presented in following papers.

Preheating and partial briquetting of the charge,although extensively studied were not adopted. One could say that we are expecting the appropriate opportunity to reinitiate studies on this line, considering the high investment for their implementation.

3.7. ENVIRONMENT

SIDERBRAS has shown to be very much concerned with the impact coke production can cause not only upon the environment, but also upon working conditions. We know that there is a great potential to reduce pollution through optimization of operational conditions and through observation of appropriate maintenance routines. Many antipollution devices were incorporated by the plants such as automatic ignitor in larry cars as well as adoption of new routines for reducing pollution points such as charging holes and oven doors, besides improvement of working conditions through implementation of relaxing rooms for shift battery workers (Figure 10). Biological water treatment also deserves to be mentioned in this context.

R & D Centres of SIDERBRAS Group Companies, as well as all the departments involved in the technological prism, participate in the whole effort through the development of sampling standards for gaseous and liquid products, through investigation of the pollution phenomena and through development of anlytical procedures for quantifying pollution components(9).

4. CONCLUSION

We tried to present a broad view of the main activities of Research and Development in coal and coke in the contex of the Brazilian ironmaking. Despite the limitations of budget and the difficulties in specialized manpower capacitation for this sector, results shown can be considered quite significant through the years. In a first stage, budget was essentially directed to implementing the necessary laboratory infra-structure, manpower capacitation and adaptation of well- known technologies to Brazilian conditions. In a second stage, we aimed at reducing the cost of coal blends through the utilization of alternative inputs for cokemaking which is still a major concern for Brazilian investigators. For this reason, maximum utilization of soft and weak coking coals is being pursued.

The present tendency of phenomenological characterization of coke formation and the role played by operational conditions upon coke properties is a constant concern to orient R & D efforts and to direct budget applications. Hence, the emphasis which is being given to coke petrography, to characterization of porous structure and high temperature properties aiming at the establishment of new parameters of control.

Besides that, the Group tries to keep the appropriate flow of information to establish the means to an optimum selection of coals to purchasing, mainly due to integrated efforts by the different sectors involved in the production cycle (purchasing, research, production and quality control).

5. REFERENCES

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CRUDE STEEL PRODUCTION (Mtons)	1970	1981	1982	1983	1984	1985	1986
World (A)	586.8	707.5	645.2	663.4	710.0	719.9	714.2
Latin America (B)	13.0	27.0	26.7	28.5	33.1	35.7	37.4
Brazil (C)	5.4	13.2	13.0	14.7	18.4	20.5	21.2
C/A (%)	0.9	1.9	2.0	2.2	2.6	2.8	3.0
C/B (%)	41.5	48.9	48.7	51.6	55.6	57.4	56.7
Relative Position of Brazil in the World	20º	13º	13º	11º	8º	7º	7º

TABLE I - WORLD AND BRAZILIAN STEEL INDUSTRY (1)

COKE TEXTURE	ABREVIATION	CHARACTERISTICS
ISOTROPIC	I	From vitrinites with Rst between 0.7 and 0.8% which form a porous network and behave isotropically under polarized light and crossed nicols.
FINE MOSAIC	Mf	From thermoplastic vitrinites with Rst between 0.8 and 1.0% presenting spherical anisotropic units of less than 2.0 μm diameter (Θ)
COARSE MOSAIC	Mc	From thermoplastic vitrinites with Rst between 1.0 and 1.4%, presenting spherical anisotropic units of Θ > 2.0 μm
FLOW TYPE	F	From thermoplastic vitrinites of Rst between 1.4 and 1.7%, exhibiting elongated domains of width < 10.0 μm (fibers) or > 10.0 μm (bands). Reflection of incident light varies in a way similar to a flowing fluid when stage is rotated.
BASIC ANISOTROPY	BA	Vitrinites of Rst greater than 1.7% originated from non-fused particles showing an overall anisotropy, characteristic of the coal precursor
INERT	I	Domains originated from fusinite, inertdetrinite and non-fused semi-fusinite.
ANISOTROPIC INERT	Ia	Domains originated from fusible semi-fusinite, micrinite and anomalous vitrinites
PYROLITIC CARBON	PC	Originated from volatile matter cracking essentially in the free zone of coke ovens
Minerals	M	Particles of the inorganic matter originally present in coals

Rst = random or statistical reflectance.

TABLE II - BRAZILIAN PROPOSED CLASSIFICATION FOR COKE MICROTEXTURES.

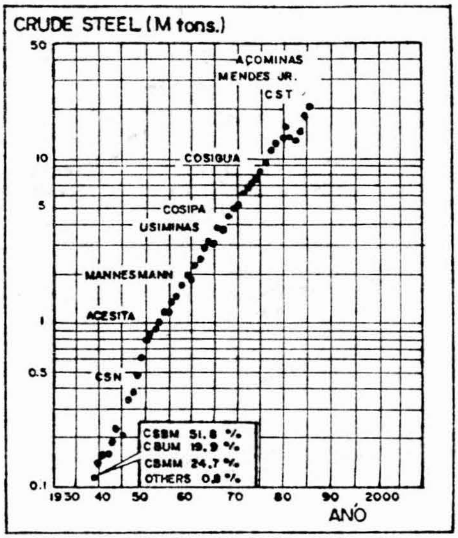


FIGURE I - INCREASE IN BRAZILIAN STEEL PRODUCTION

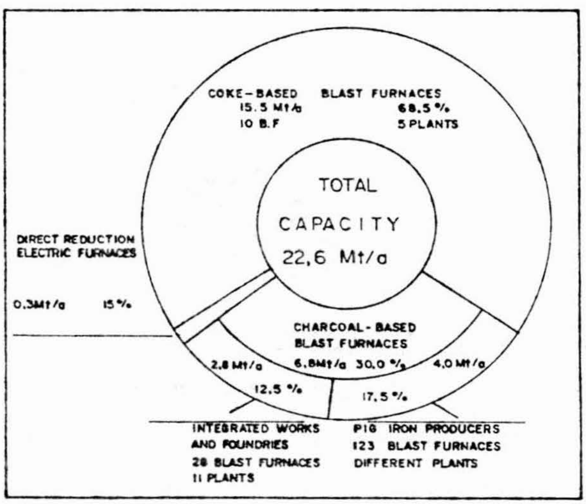


FIGURE. 2 - BRAZILIAN CAPACITY FOR IRON PRODUCTION

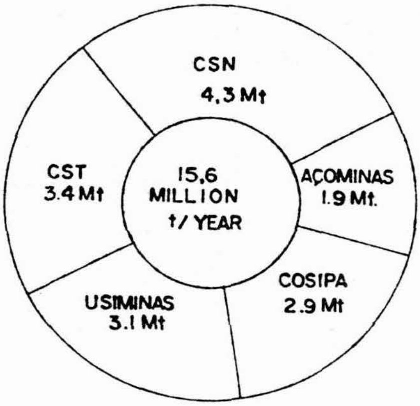


FIGURE. 3 - IRON PRODUCTION CAPACITY OF COKE-BASED INTEGRATED PLANTS.

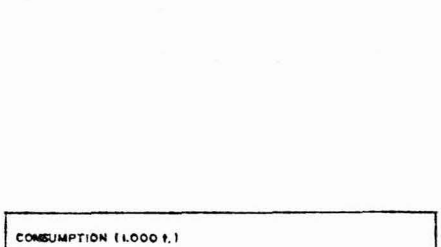


FIGURE. 4 - SOURCES OF COAL SUPPLY FOR THE BRAZILIAN IRON MAKING INDUSTRY.

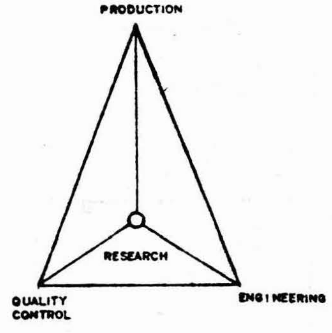


FIGURE. 5 - TECHNOLOGICAL PRISM.

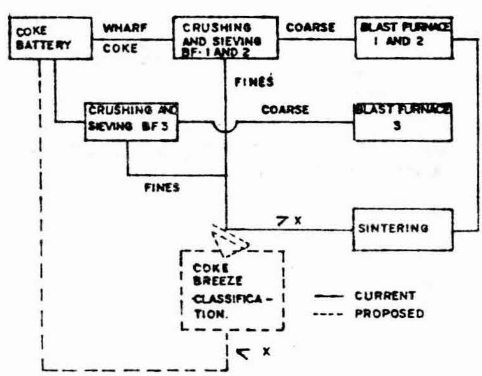
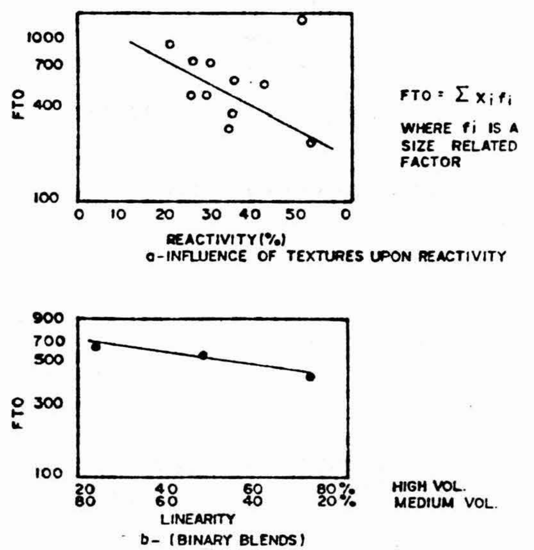


FIGURE 6 - SIMPLIFIED FLOWSHEET OF COKE HANDLING AT CSN.



FIGURE·7 — RELATIONSHIP BETWEEN COKE PETROGRAPHY AND REACTIVITY

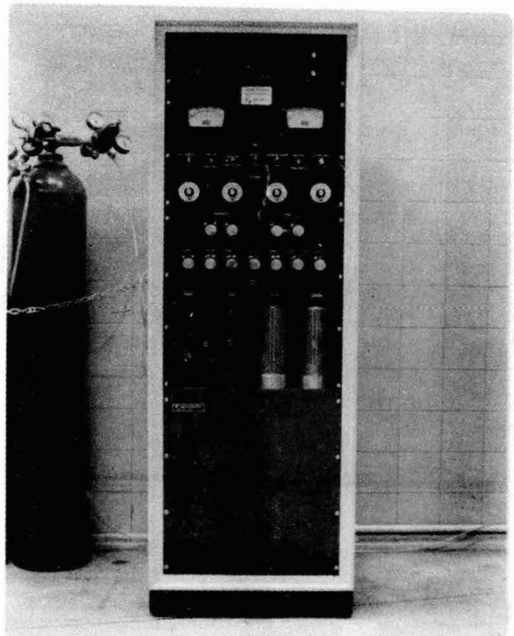


FIGURE 8 – SURFACE AREA ANALYSER

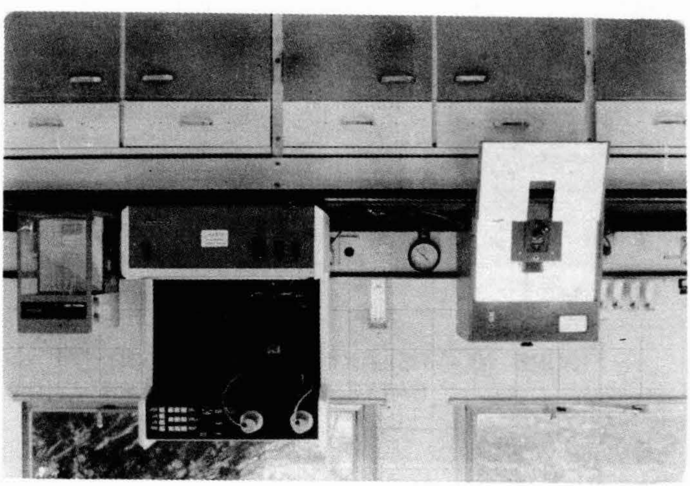


FIGURE 9 – HELIUM PICNOMETER AND MERCURY POROSIMETER

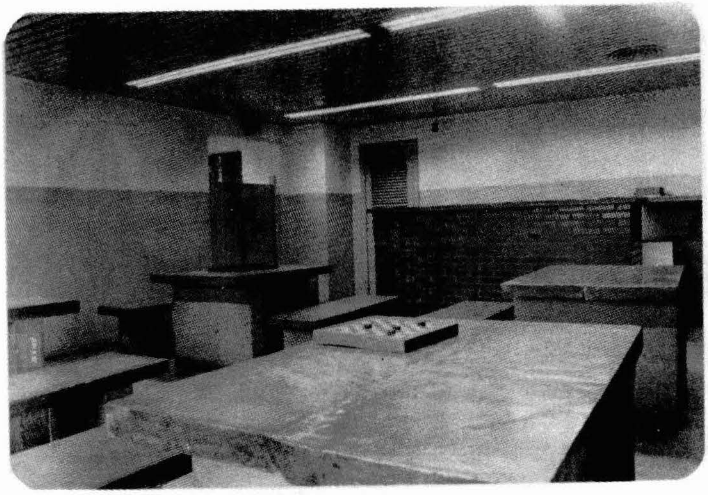


FIGURE 10 – RELAXING ROOMS FOR BATTERY TOP WORKERS.

ANNEX I

CSN's RESEARCH CENTRE

Location:	Rua 4 nº 33 - Conforto Volta Redonda - RJ 27269 Brazil Telex 223 123 CSNCA BR
Area (edification):	6,200 m^2
Personnel:	183 eployees of which 44 are university graduate researchers (24 masters and 2 doctorates), 66 intermediate level technicians, 56 laboratory analists and 17 for administrative support. Specifically in coal and coke: 4 university graduates (2 masters), 6 technicians and 12 analists.
Main Activities:	Absorption and development of new technologies and transfer to other Company departments, providing the necessary training for the proper dissemination of the technical knowledge; Development of Research Projects aiming at evaluation of conventional and potential alternative raw materials, improving process efficiency and developing new processes, upgrading the quality of products and development of new products, developing new analytical methods for better characterization of products and raw materials, process control and energy savings. Rendering of technical support to the different departments and to clients regarding specific problems.
Infra-Structure (Coal and Coke):	1 bench-scale flotation cell, equipments for coal preparation and size distribution analysis, 1 HGI 1 volatile matter furnace, 3 drying ovens for coal and 3 for coke, 1 ash muffle furnace, 1 FSI, 2 Gieseler plastometers, 1 Audibert-Arnu dilatometer 02 polarized-light microscopes, 1 heating stage (1350ºC), 1 movable-wall pilot oven (100 kg), 1 sole-heated oven, 2 ASTM and 1 JIS drums for coke strength, 2 CRI ovens, 1 CSR drum, 1 volumetric surface area analyser, 1 Helium picnometer, 1 mercury porosimeter and 1 TGA apparatus. The Group can count on other laboratories apparatuses such as atomic absorption for ash chemical analysis, elemental analysis, micro-strength and scanning electron microscope.

ANNEX II

USIMINAS RESEARCH CENTRE

Location:	Usina Intendente Câmara P.O. Box 22 - Ipatinga MG Brazil Telex 311334
Area:	10,000 m^2
Personnel:	352 employees of which 81 are university graduates, 132 medium level technicians, 141 analists and administrative support personnel; Specifically in coal and coke: university graduates (1 master), 7 technicians and 12 analists.
Main Activities:	Absorption and development of new technologies; Development of research projects aiming at: - evaluating and metallurgically characterizing new raw materials; - increasing quality level of products and development of new ones; - promoting technical support to clients in the utilization of USIMINAS products; - keeping technical exchange with universities and research institutions and - transfering technology and disseminating technical information to other departments.
Infra-structure (Coal and Coke):	Equipments for coal preparation and size distribution analysis, 2 Gieseler plastometer, 1 Audibert-Arnu dilatometer, 1 Chevenard-joumier dilatometer, 1 caking index apparatus (NSC), 2 polarized light microscopes, 1 CRI oven, 1 CSR drum, 2 pilot ovens (40 kg), 1 movable wall oven (40 kg), 3 sole-heated oven, 1 ASTM, 1 JIS and 1 DIN drum for coke strength, 1 drum for high temperature coke strength and 1 briquetting machine (0.5 tons/hour).