DEVELOPMENT AND CURRENT STATUS OF THE COREX AND FINEX PROCESS[1]

C. Böhm[2]
D. Siuka[2]
J. Schenk[2]
J. KRIECHMAIR[2]
C.O. Kang[3]
H.G. Lee[3]
S. Joo[3]

Abstract

With the contract award for a COREX® C-3000 plant with an annual capacity of 1.5 million t hot metal by Baosteel Pudong ISCO, PR China, a new milestone for the COREX technology could be reached. This module represents the up-scaling and the experiences made with the COREX currently being in operation. Changes in the raw material sector (price of coke, coking coal and steam coal, etc.) and the general increase of energy cost (natural gas, electric power, etc.) in combination with the positive experiences during the operation make it worth today to carefully evaluate the COREX technology in comparison with the blast furnace technology. Another development, the development of the FINEX® technology, is currently carried out by the operation of the FINEX Demonstration plant and by the installation of a FINEX 1.5M Plant having an annual capacity of 1.5 million tons hot metal at POSCO Pohang. One main focus of this presentation is laid on developments of the COREX technology, giving inside views about status of the operating COREX plants, new technological developments and factors endeavoring the COREX technology. Another focus is laid on the FINEX process showing the status and the further steps in process development.

Key words: Hot metal; Iron making; Corex; Finex; Siemens VAI; Posco.

DESENVOLVIMENTO E SITUAÇÃO ATUAL DO PROCESSO COREX E FINEX

Resumo

Com a assinatura do contrato para uma planta COREX® C-3000, planta com capacidade de 1.5 milhões de toneladas de gusa líquido para Baosteel Pudong ISCO, RP China, uma nova etapa para o COREX pôde ser atingido. Este modelo representa um aumento de escala e a entrada em operação das recentes experiências feitas com o COREX. Mudanças nas matérias-primas (preço do coque, carvão coqueificável, finos de carvão, etc) e o aumento geral do custo de energia (gás natural, energia elétrica, etc) em combinação com as experiências positivas durante a operação possibilitam hoje uma avaliação da tecnologia COREX em comparação com o alto-forno. Outro desenvolvimento a ser relatado é a tecnologia FINEX®, atualmente conduzida em operação na planta de demonstração FINEX e pela instalação FINEX 1.5M com capacidade anual de 1,5 milhões de tonelada de gusa líquido em POSCO Pohang. Este trabalho irá apresentar os desenvolvimentos da tecnologia COREX, enfatizando a situação atual das plantas em operação, novas tecnologias desenvolvidas. Será também abordado o processo FINEX, mostrando a atual situação e próximos passos no seu desenvolvimento.

Palavras-chave: Gusa; Redução; Corex; Finex; Siemens VAI; Posco.

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[2] *Siemens VAI Metals Technologies GmbH & Co, Linz, Austria*
[3] *Posco, Pohang, Korea*

1 COREX

1.1 Introduction

The successful operation of the COREX plants in India, South Africa and Korea has confirmed that the COREX Process is a proven economical and environmentally-friendly alternative to the conventional blast furnace technology. With the contract award from Baosteel, China, for a COREX C-3000 plant with an annual capacity of 1.5 million tons of hot metal, a new milestone has been reached for the COREX technology. This up-scaled module represents the experiences made with the COREX plants that are currently in operation. In addition, the two COREX plants that are presently being relocated from Hanbo, Korea, to Essar, India, will further add valuable information to the large COREX experience pool.

Siemens VAI and all COREX plant operators are still continuously working to increase productivity, to introduce alternative low-cost raw materials, to gain operation experience, and to use state-of-the-art concepts for the COREX export gas. The achievements are quite considerable when compared to the matured blast furnace route and will contribute to further boosting this technology.

In addition, changes in the raw material sector (price of coke, coking coal and steam coal, etc.) and the general increase of energy costs (natural gas, electric power, etc.) make it even more worthwhile to carefully evaluate the COREX technology in comparison with blast furnace technology.

1.2 Factors Supporting COREX Technology

Currently, an increased interest in the COREX technology can be seen as a result of a number of factors which have been confirmed during the past years:

- All COREX plants operate above nominal capacity, at high availabilities and produce high-quality hot metal at low consumption rates.
- As a consequence of the improved operation, plant feasibility has also increased considerably.
- The results of production-cost calculations have been verified under operational practice.
- At the FINEX demonstration plant of POSCO, major operational improvements e.g. coal and oxygen consumption reductions have been achieved. These improvements can be fully attributed to the COREX technology.
- In addition to process and technology related improvements, other “external” factors, driven by the global development in the iron and steel industry, support the COREX technology:
- In most countries environmental-protection measures have gained more importance and are now being implemented.
- Due to the lower availability of metallurgical coal and due to higher steel consumption in the booming countries, e.g. China and India, the price of metallurgical coal has increased considerably in comparison with "COREX" coal. As the global reserves of "low-cost-mining metallurgical coal" are being increasingly depleted, a significant price increase is expected for this type of coal in the future.

Another highly important factor is the continuing price increase for energies, especially for natural gas. Since a COREX plant produces high quantities of a clean gas which can be used as a substitute to natural gas, this technology is extremely attractive in areas where a high natural gas price prevails.

The comparable CO_2 emission of a COREX plant/power plant combination in one of the booming countries is considerably lower than the alternative blast furnace route/power plant combination when considering an equal amount of hot metal and electric power.

1.3 Status of Operating COREX Plants

Since the first industrial application of the COREX process; the COREX C-1000 plant of ISCOR Pretoria in South Africa, more than 27 million tons of hot metal has be produced via the COREX route (Figure 1).

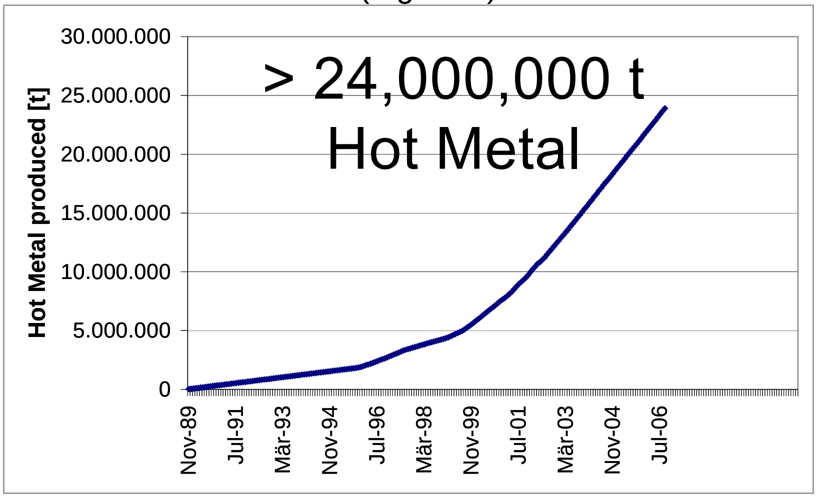

Figure 1: Accumulated COREX hot metal production

1.3.1 Mittal Steel South Africa, Saldanha Steel Works, South Africa (Figure 2)

The highlights of the COREX/combined direct-reduction (DR) plant at Mittal Steel South Africa during the year 2006 are as follows:

- Uninterrupted output of 750,000 tons of hot-metal and 750,000 tons of direct-reduced iron (DRI)
- Installation and successful operation of the gimbal top coal-charging system for a controlled coal distribution in the melter gasifier
- Successful operation of a gimbal top burden-distribution system for a defined burden distribution in the reduction shaft resulting in a better reduction gas distribution and, therefore, a better metallization and lower consumption rates. In the first weeks of operation, a 20% increase in metallization and a 20 kg/t saving of coal per ton of hot metal was achieved.

The reliable production of the COREX plant played a major role in Saldanha Steel’s attainment of their production target goals of 1.25 million tons of hot-rolled coils during the last years.

Figure 2: Mittal Steel South Africa, Saldanha Steel Works

1.3.2 Jindal South West Steel (JSW Steel), Toranagallu Works, India

The highlights of the two COREX plants during the year 2006 can be summarized

- The operation synergies of COREX plants were used with blast furnaces. Especially the combined utilization of COREX coal in the BF route, mainly in the coking plant and in the COREX plants, confirms the synergies achievable when the COREX technology is adopted in integrated steel mills.
- Utilization of most of the metallurgical waste materials, such as coke fines, mill scale, iron ore fines, LD slag, limestone and dolomite fines, etc. as COREX feedstock
- One of the lowest hot metal costs in India

1.4 Status of the COREX Plants Under Construction

1.4.1 World's First COREX C-3000 Plant for Baosteel, China (Figure 3)

Shanghai Baosteel Pudong Iron & Steel Co. (Baosteel), a company of the Shanghai Baosteel Group Corp., the largest steelmaker in China, contracted Siemens VAI for the installation of the world's first industrial COREX C-3000 plant with an annual hot-metal capacity of 1.5 million tons. This will be the basis for a new steel plant currently under construction at Luojing on the western outskirts of Shanghai. Start-up of the COREX plant is expected to be towards the end of 2007.

The major reasons for the decision for the COREX technology as follows:

- Economical production of hot metal
- The production costs of the large blast furnaces at Baosteel’s main works located in the vicinity of the new Luojing site were set by Baosteel as a benchmark.
- Environmentally-friendly production of hot metal
- Luojing site is an environmentally-restricted area, since part of the Shanghai water supply is sourced from this area. Due to the proven environmental advantages of the COREX process, the permission was granted.
- Use of different coals compared to the conventional blast furnace route. The main target of Baosteel is to use 100% Chinese coals in COREX. A set-up for the COREX coals similar to that at Jindal is planned by Baosteel to use all synergies in combination with the existing BF operation main works.
- Lower dependency on the local power and natural-gas supply

- The COREX export gas will be used for a new 150 MWel combined-cycle power plant and for heating purposes within the Luojing Works and in the adjacent main steel works of Baosteel.

Figure 3: Status of the COREX plant for Baosteel as of August 2006

1.4.2 Relocation of two COREX C-2000 Plants to Essar Steel, India

In 1995/1996 Hanbo Steel, Korea started to build a steel plant at Asan Bay, Korea. Siemens VAI supplied two COREX C-2000 units connected to one Midrex DR plant. Before being put in operation, Hanbo Steel went bankrupt in 1996. Recently, the plants have been bought by Essar Hazira Ltd., India, who is now relocating these plants from Asan Bay, Korea to the Hazira steel complex at Gujarat, India. The two COREX plants, the Midrex plant and a new blast furnace will form the ironmaking basis for a new steel mill for the annual production of 1.8 million t of slabs and 2 million t of long products. Siemens VAI will supply an update in engineering and equipment, as well as advisory services for the plant start-up for the two relocated COREX plants.

1.5 COREX Plant Upscaling and Technological Developments

1.5.1 Plant Upscaling and Equipment Improvement

The major changes with respect to plant up-scaling and equipment improvement are:

- A major feedback from the COREX C-2000 plants in operation was that an increased production capacity of the existing core units (i.e. melter gasifier, reduction shaft) is possible. The capacity of these modules could be further increased by minor capacity-related changes to the core units and by adjusting the “auxiliary” equipment such as the raw-material handling system, scrubbing systems, pipe diameters of main gas ducts, etc...
- Change of the profile of the melter gasifier and cooling system. The hearth and "bosh" area of the up-scaled COREX plant is now more or less identical to a modern blast furnace (Figure 4).

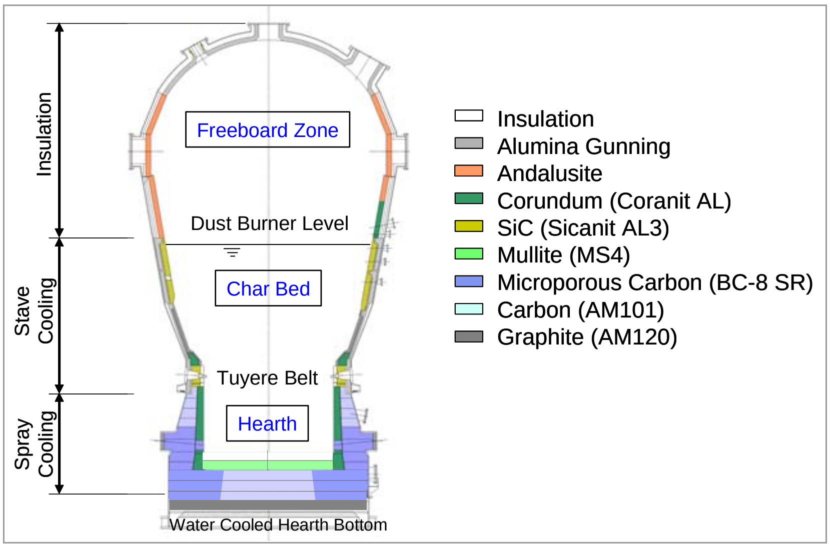

Figure 4: Melter gasifier lining concept

- Application of advanced engineering tools (e.g., CFD models). Their development is strictly based on the operating results of the COREX plants. They support a further optimization of the COREX plants in operation and are a reliable source for up-scaling of the COREX technology.

1.5.2 Changes in Process Design

Investigations in connection with the distribution of the materials charged to the melter gasifier showed that the charging of DRI and coal can be optimized. Based on the results of these investigations, new equipment was designed and applied at the operating plants and will be applied in future COREX plants.

1.5.2.1 Dynamic Coal Distribution System

After the initial start-ups of the COREX plants at SALDANHA and JINDAL, it was found that the charging and distribution of coal into the melter gasifier did not take place as desired. After several correctional measures (deflection plate, static distribution device “riffler”, etc.), a major improvement was obtained with a fully-automated dynamic distribution system, referred to as the gimbal top coal distributor, which is a gimbal-type oscillating chute (Figure 5).

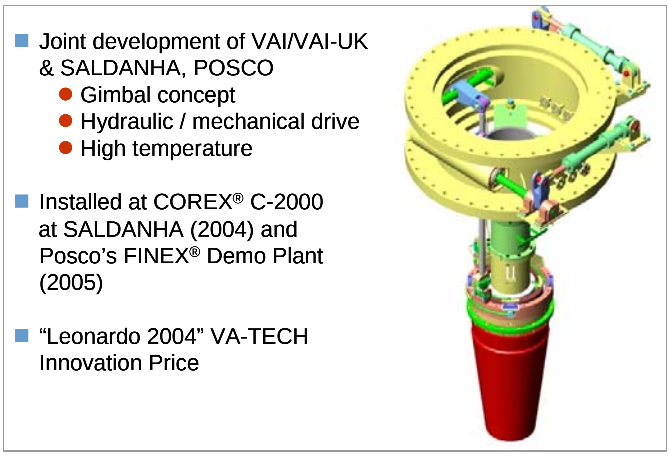

Figure 5: Design of the dynamic coal distribution

This gimbal top coal-distribution system for COREX is a development of Siemens VAI and is already been successfully applied at Saldanha Steel and POSCO. The results in operation are as follows:

- Highly uniform operation of the melter gasifier and total plant, resulting in a more constant product quality (hot metal and export gas)
- More even gas distribution in the melter gasifier, yielding in a higher metallization and lower specific reduction gas consumption enabling a higher melting rate
- Reduced coal consumption (up to 10%)

1.5.2.2 Dynamic Burden Distribution System

After achieving maturity of the gimbal system in the arduous and high temperature atmosphere of the melter gasifier, a similar system was also installed at Saldanha at the top of the COREX reduction shaft. The target was to achieve a defined burden distribution, especially to avoid negative effects of iron-ore segregation during charging. After installation of a gimbal in July this year, positive operational effects were observed immediately after start-up:

A more even gas distribution inside the reduction shaft

- Subsequently a lower pressure drop and 20% higher metallization at equal specific reduction gas volume were achieved during the first weeks of operation.
- Possibility for a higher reduction shaft throughput
- In these first weeks of operation, Saldanha decreased the pellet rate from 19% to 17/18% and decreased the coal consumption by 20 kg per ton of hot metal, which means additional saving of money in operation. However, further optimization is being carried out by Mittal Steel South Africa.

1.5.2.3 DRI Distribution System

This direct reduced iron (DRI) distribution system that is already installed at the Mittal Steel COREX plant since more than two years distributes DRI evenly onto the melter-gasifier char-bed surface (Figure 6). Tests conducted during stable production indicated that the DRI deflection flaps—a component of the DRI distribution system—have a significantly positive impact on melter-gasifier performance in terms of a more stable operation.

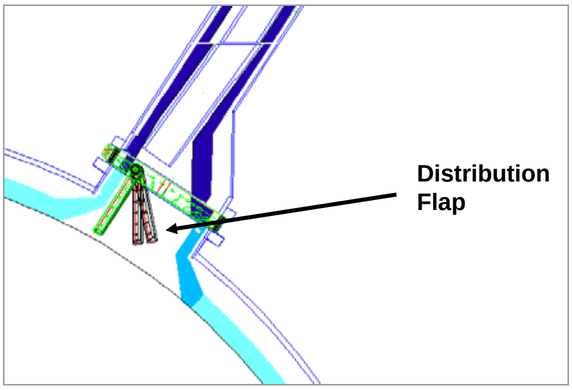

Figure 6: DRI distribution system

On the basis of these sustainable improved operational results, the dynamic coal, burden and DRI distribution systems will be installed in Baosteel's COREX C-3000 plant and in all COREX plants supplied in the future.

2 FINEX

2.1 Introduction

The blast-furnace ironmaking process, which relies on the coking and sintering processes, has been the dominant hot-metal production technology for over a century due to its high productivity, excellent heat efficiency, and long furnace life. However, complex processing requirements, increasingly scarce raw materials, and more demanding environmental standards have created an urgent need for an entirely new ironmaking process.

During the past few decades, steelmakers worldwide have pursued development of innovative new ironmaking technologies to take the place of the blast furnace in response to growing economic and environmental imperatives. The common objective of all these new technologies has been to avoid the drawbacks of sintering and coke making by producing hot metal through the direct use of fine ore and coal. Although many different projects have been initiated over the years, only a handful of technologies have made it to the demonstration scale phase of development. Currently producing 28 million tons of hot metal annually, Posco initiated the FINEX development program in 1992 in cooperation with Austrian engineering and plant-building specialist Siemens VAI. The goal of the program was to create an advanced ironmaking process that would 1) eliminate the coking and sintering processes, 2) operate on low-grade, low-cost raw materials, and 3) be financially competitive with the blast furnace process.

Figure 7: FINEX Demonstration Plant, Pohang Works, Korea

Following successful tests at a 15-tpd model plant starting in 1996 and a 150 tpd pilot plant starting in 1999, a 600,000 t/a FINEX demonstration plant (Figure 7) began operation in June 2003. Based on the excellent results achieved with the demonstration plant, a 1.5-million t/a FINEX plant has been constructed at the Pohang Works. The first hot metal was tapped on April 11, 2007.

2.2 Finex Process Overview

Figure 8 compares the FINEX process with conventional blast-furnace ironmaking. In the blast-furnace process, blended iron-ore fines are agglomerated at a sinter plant, and coking coal is processed at coke-ovens in preparation for use in the blast furnace. The main shortcomings of this conventional process are high raw-material costs and considerable pollutant emissions from the pre-processing plants.

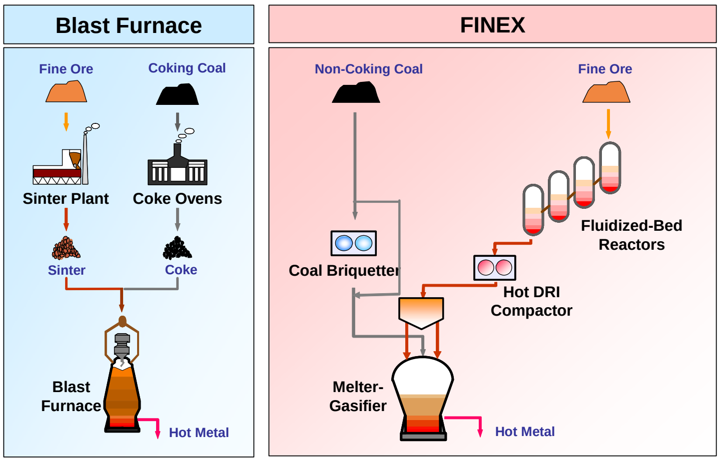

Figure 8: Comparison of the Blast Furnace and FINEX Processes

The FINEX process simplifies ironmaking by eliminating the sintering and coking processes. Its key components include fluidized-bed reactors, a coal briquetting platn, a hot DRI compactor, and a melter-gasifier. Fluidized-bed reactors are capable of directly reducing iron-ore fines. A coal-briquetting technology allows the use of non-coking coal fines. The separation of the iron-ore reduction and melting processes in the reactors and the melter-gasifier, respectively, makes operational control uncomplicated.

Figure 9 shows the process flow of FINEX technology. Fine iron ore is charged into the fluidized-bed reactors together with a flux such as limestone or dolomite. As it passes through the four reactors, it is preheated and reduced. The reduced iron ore or hot DRI is transformed into lump form by the hot DRI compactor, and then charged into the melter-gasifier, where it is smelted into hot metal and molten slag.

Coal is processed by either the briquetter or the pulverized coal injection (PCI) facilities. Briquetted coal is charged into the dome of the melter-gasifier, while pulverized coal is injected through the tuyeres. The reducing gas generated by coal combustion with pure oxygen in the melter-gasifier is channelled to the fluidized-bed reactors to reduce the iron. A portion of the reactor off-gas is recycled back into the reactors after CO_2 removal to achieve higher gas utilization.

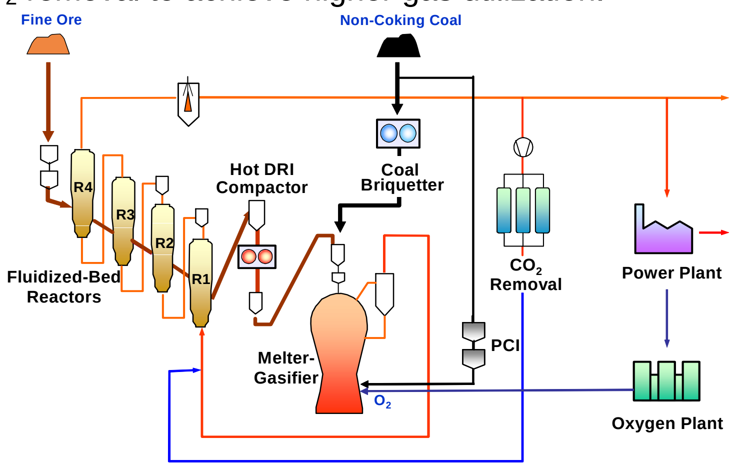

Figure 9: The FINEX Process Flow

2.3 FINEX Demonstration Plant Operational Results

2.3.1 Productivity

In the initial stage of operations after start-up in 2003, intermittent trial campaigns were carried out to verify the performance of newly installed facilities such as the fluidized-bed reactors and HCI equipment, confirm fuel and raw material usage characteristics, and determine optimal operating parameters. As seen in Figure 10, full-scale operation got underway in January 2004 and stabilized over time at a hot-metal production level of 2,400 tons per day. This figure translates into an annual capacity of approximately 900,000 tons, significantly exceeding the plant's 600,000 ton design capacity. The plant is currently operating at around an 800,000 t/a level.

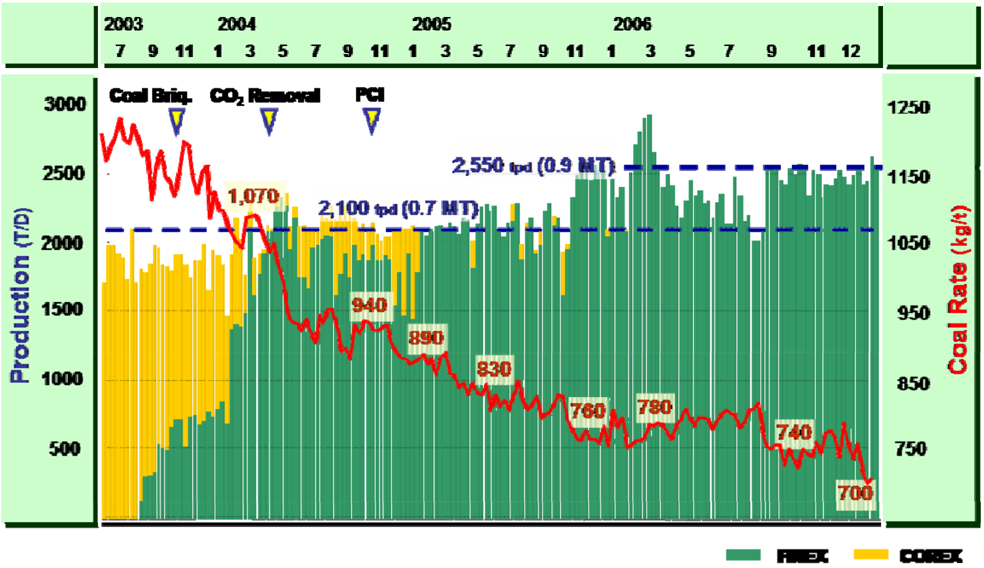

Figure 10: FINEX Demonstration Plant Hot-Metal Production and Coal Consumption

2.3.2 Coal Rate

Significant effort has been paid to reducing the coal rate, the primary indicator of process heat efficiency. An important step in lowering coal consumption rates was the start-up of the CO_2 removal and off-gas recycling systems in June 2004. Following installation of the CO_2 removal system, coal consumption fell from the 1,100 kg/t_{HM} level to the 900 kg/t_{HM} level (Figure 11). This savings was achieved because the recycled off-gas from the fluidized-bed reactors reduced the amount of additional reducing gas needed by the reactors.

The next step in process optimization was the adoption of pulverized coal injection (PCI) on a limited basis in December 2004, expanding to all tuyeres in March 2005. PCI increases the burden retention time in the melter-gasifier and completes decomposition of volatiles, consequently improving heat efficiency. Over time, the PCI rate has been gradually increased to its current 250 kg/t_{HM} level, reducing total coal consumption to the 750 kg/t_{HM} level.

2.3.3 Plant Availability

Operational stability is a key to achieving high plant availability. In the FINEX process, continuous reactor operation, quick maintenance, and tuyeres lifespan are the main factors influencing availability. Among these, continuous reactor operation is the most critical. Over the past few years, the reactor maintenance interval has steadily been extended, most recently reaching nearly seven months of continuous operation (Figure 11). If optimal operating conditions can be maintained, continuous operation of more than a year is very feasible. Having achieved a plant availability of 95% in 2006, it is aimed at to achieve a blast-furnace-level availability of 97%.

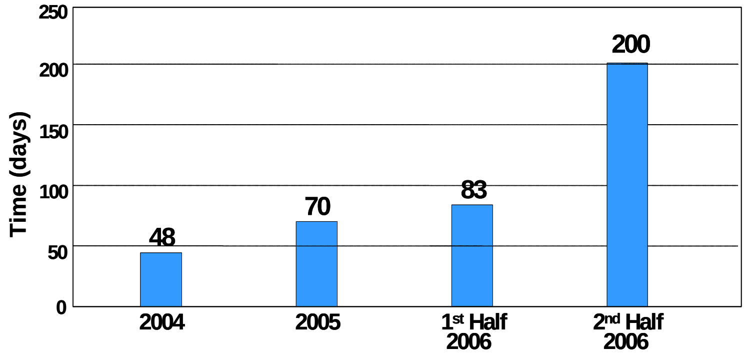

Figure 11: Fluidized-Bed Reactor Operating Performance

2.3.4 Hot-Metal Quality

Table 1 summarizes and compares the operating performance of the FINEX demonstration plant and the Pohang No. 1 blast furnace. The FINEX hot-metal quality is similar to the blast furnace hot metal. Silicon content is virtually identical at around 0.6%, as is slag basicity. The alumina in FINEX slag is higher in 17~18% range due to the use of Australian ore which has a high alumina content. The ability to operate with high-alumina ore is a key benefit FINEX has over blast furnaces.

Table 1: Comparison of FINEX and Blast Furnace Operating Performance (Sept. 2006)

		Pohang BF1	FINEX Demo
Production (t/d)		3,616	2,499
Hot Metal	Temp (°C)	1,509	1,492
	[C] (%)	4.5	4.4
	[Si] (%)	0.58	0.59
	[S] (%)	0.022	0.040
Slag	Basicity	1.21	1.18
	Volume (kg/t_{HM})	282	315
	(Al2O3)(%)	15.36	17.94

2.4 Environment

The environmentally friendly nature of the FINEX process ensures it will be even more competitive in the future. FINEX SO_x, NO_x, and dust emissions are a mere 3%, 1%, and 28%, respectively, of those generated by the blast furnace process (Figure 12), enabling it to easily comply with strict environmental standards and legal regulations. While these ultra-low figures are primarily due to the elimination of coke oven and sinter plants—both major sources of emissions—the FINEX process inherently prevents pollution from being generated. The sulfur contained in coal and ore reacts with limestone into CaS in the reactors, and then smelts into slag, leaving almost no opportunity for SO_x to escape into the air. NO_x emissions are naturally very limited because reactions take place in a reducing atmosphere, unlike the oxidizing atmosphere inherent in the sintering, coke-making and hot-stove processes of the blast-furnace ironmaking route. Dust emissions are low as well, due to simplified processing. It has also been verified that no dioxins are generated in the FINEX process.

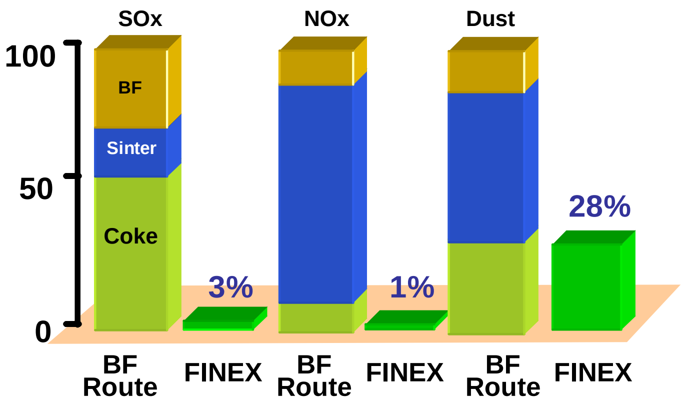

Figure 12: Comparison of Pollutant Emissions

3 Conclusions

Based on the successful experience of the four operating COREX plants, a considerable knowledge base has been accumulated with respect to engineering and operation. This knowledge and subsequent investigations have resulted in a most competitive hot-metal production compared with the blast-furnace route. During the past years, market conditions and “external” factors have also changed in favour of COREX technology, e.g. mandatory environmental legislation, increased costs for metallurgical coal compared with COREX coal and an increased energy price. Baosteel and Essar Steel selected the COREX technology for exactly these reasons: Economical and environmentally-friendly production of hot metal and lower dependency on metallurgical coal or externally sourced energies such as natural gas.

Developments and optimization of COREX are still underway and major additional economical and technological improvements are yet anticipated. Under consideration of the highly flexible plant concepts, well-proven components and systems, new process features and equipment as well as the highly competitive production costs, Siemens VAI is confident that the COREX process will capture an increasing share of the hot-metal production worldwide with its attractive module sizes (Figure 13).

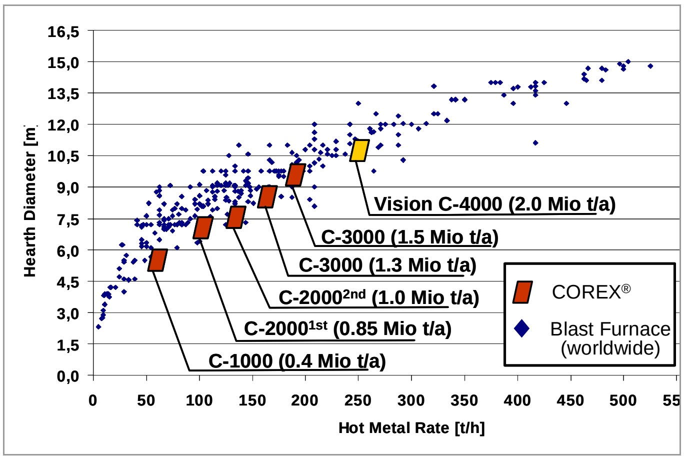

Figure 13: COREX module sizes available

The simple nature of the FINEX process and its ability to use low-cost raw materials means that both capital investment and production costs are much lower than the blast furnace route. A 1.5 million t/a FINEX plant can produce hot metal more cost effectively than a modern 3 million t/a blast furnace. When oxygen and power plants are included in the comparison, the capital and operating costs of a

FINEX plant are roughly 20% and 15% lower, respectively, than the blast furnace route.

Posco and Siemens VAI continue to accelerate development of FINEX technology to enhance its competitiveness by further reducing consumption figures and increasing overall availability. At the present time, all efforts and resources are focused on achieving early nominal operation at the 1.5 million t/a FINEX plant at the Pohang Works that commenced operations on April 11, 2007 (Figure 14). Once this first commercial FINEX plant has achieved a proven operating record, Posco plans to replace the small- and medium-sized blast furnaces at the Pohang Works with FINEX plants as well as make the technology its main ironmaking process for future overseas integrated steel mill projects. The company fully expects this revolutionary process to be adopted in developing countries where integrated steel mills in the 3 to 4 million t/a range are desirable due to limited economic scale, steel demand, or resources.

Figure 14: FINEX 1.5M Plant at the Pohang Works