COAL INJECTION SYSTEM FOR 2 BLAST FURNACES – NOVEL CONCEPT AND OPERATIONAL PRACTICE[1]

Arno Habermann [2]
Elmar F. Schuster [2]
Christian Bartels von Varnbüler [3]

Abstract
A new concept for coal injection into the two blast furnaces of voestalpine Stahl Donawitz was developed. The concept consists of one single grinding and one single injection plant for the two blast furnaces. For at least one blast furnace is always in operation the availability of the coal injection plant has to be 100 % and the process was designed for permanent operation not influenced by maintenance actions. The safety concept of the grinding and injection process was reinvestigated in a hazard and operability (HAZOP) study, that gave novel solutions to prevent safety issues. After a successful start-up the coal injection rate was gradually increased. Even though low quality iron ore is used, coal injection rates up to 170 kg/t HM were achieved by utilization of low ash coal. The coke replacement ratio and all consumption figures exceeded the projected figures.
Key words: Blast furnace coal injection; Safety concept; Operation.

INJEÇÃO DE CARVÃO EM DOIS ALTOS FORNOS _ NOVO CONCEITO E PRÁTICA OPERACIONAL

Resumo
Para a injeção de carvão nos dois altos fornos da Voestalpine Stahl Donawitz um novo conceito foi desenvolvido. O conceito é composto de uma única planta de moagem e de uma planta de injeção para os dois alto fornos. Como no mínimo sempre um alto forno está em operação a disponibilidade da planta de injeção deve ser 100 % e o processo concebido para operação permanente sem influencia de atividades de manutenção. O aspecto de segurança do processo de moagem e de injeção foi re-investigado em um estudo de risco e operacionalidade (HAZOP), o qual resultou em soluções novas de prevenção de riscos. Após o start up com sucesso a taxa de injeção foi aumentada gradativamente. Mesmo usando minérios de ferro de baixa qualidade as taxas de injeção chegam a 170 kg/tg com o uso de carvão com baixo teor de cinzas. A taxa de substituição de coque e todos os valores de consumos excederam às expectativas.
Palavras-chave: Injeção de carvão no alto forno; Conceito de segurança; Operação.

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[2] Ironmaking Department, voestalpine Stahl Donawitz GmbH&CoKG, Leoben, Austria
[3] Küttner GmbH & Co. KG, Essen, Germany

1 INTRODUCTION

Increasing prices for coking coal and coke led to the necessity for higher auxiliary reductant injection rates. Due to high investment costs the installation of pulverized coal injection systems was not in all cases economically feasible. Especially at small blast furnaces PCI installations lead to a high capital expenditure. Due to the bad quality of raw materials utilized at voestalpine Stahl Donawitz smaller coke savings would be achieved, which would increase the payback period. To overcome these financial difficulties a new, lean concept for coal injection for two blast furnaces was developed.

1.1 Ironmaking Facilities of Voestlpine Stahl Donawitz

Ironmaking in the region around Donawitz, in the middle of the Austrian alpine mountains, dates back to the ancient Romans, since there is a local iron ore mine nearby producing lime rich siderite ($FeCO_3$). The integrated steel works of voestalpine stahl Donawitz started up in 1891, when the first of totally four blast furnaces was blown in.

Figure 1 gives an overview of the production chain as well as some of the key figures from 2007. voestalpine Railway Systems is the long products division of voestalpine Group and voestalpine Stahl Donawitz GmbH is the supplier of blooms and billets for the entire division.

At present there are two blast furnaces and one sinter plant in operation at Donawitz. Since a coke oven plant has never been part of the steel works, from the very first year the need of blast furnace coke had to be covered to 100% by purchasing it in our eastern neighbour countries.

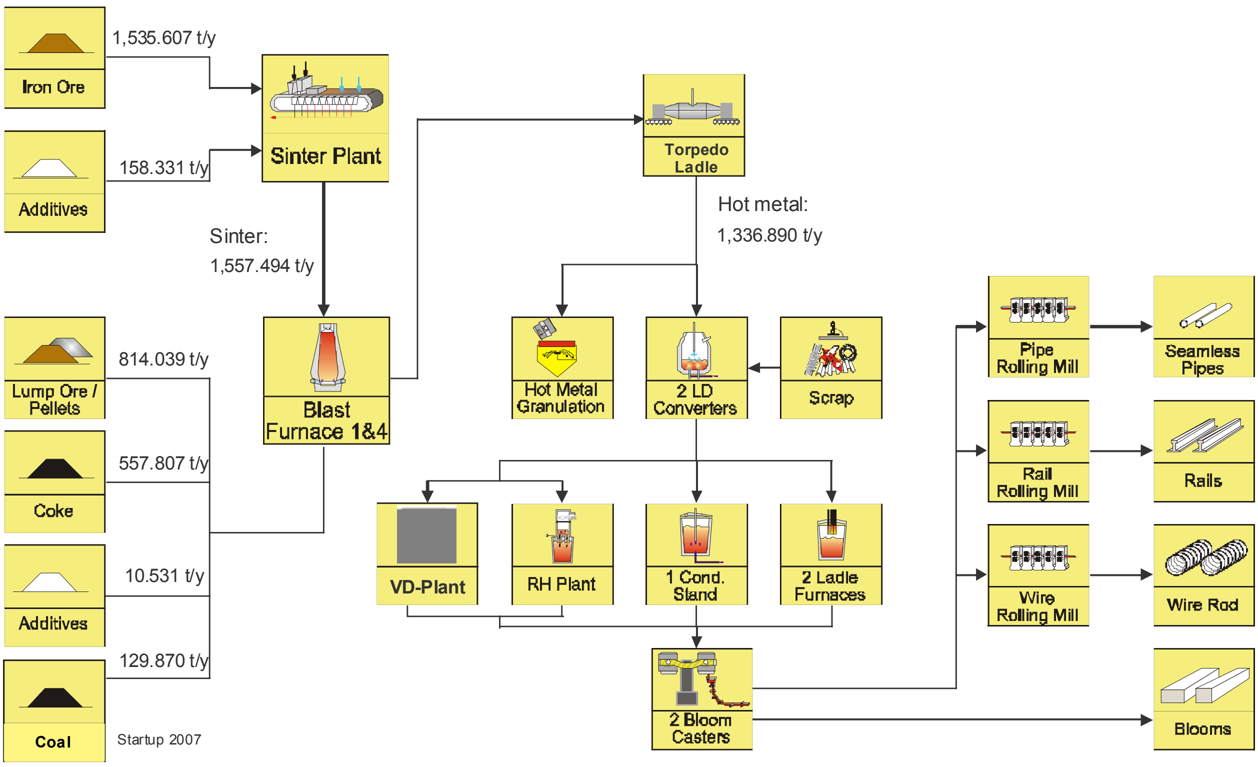

Figure 1. Process chain of voestalpine Division Railway Systems at Donawitz including production figures of 2007.

Due to economic difficulties in the 1980s and early 1990s steel and hot metal production levels were fluctuating. Since 1993 the hot metal production was gradually increased, only limited by blast furnaces relinings and the start-up of the new BOF in 1999 (Figure 2).

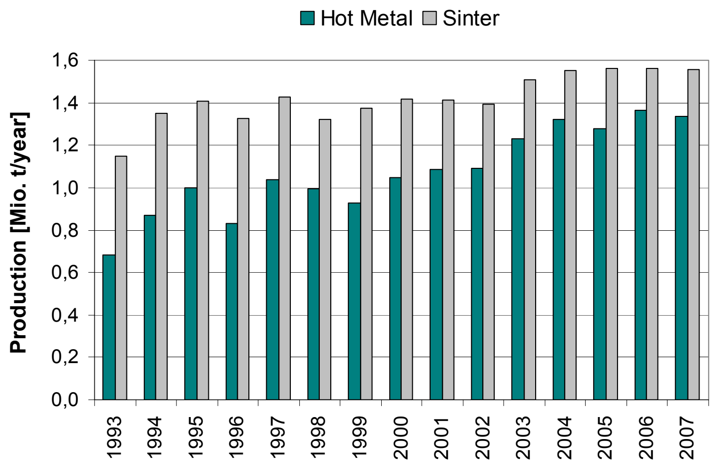

Figure 2. Hot metal and Sinter production at voestalpine Stahl Donawitz 1993 - 2006.

The key figures of the blast furnaces at voestalpine Stahl Donawitz are listed in Table 1. The two blast furnaces are very much the same in technology and geometry, besides higher working volume of blast furnace No. 4. The only significant difference is in hot blast production – state of the art stoves with preheated combustion air at blast furnace No. 1 lead to a maximum hot blast temperature of 1250 °C.

Table 1. Key figures of voestalpine Stahl Donawitz blast furnaces

	Blast furnace No. 1	Blast furnace No. 4
Production (max.)	3080 t/24 h	2441 t/24 h
Hearth diameter	8.0 m	8.0 m
Working volume	1205 m^3	1343 m^3
No. of tuyeres	20	20
Blast (max.)	110 000 m^3/h	120 000 m^3/h
Pressure at bustle pipe (max.)	2.6 bar (abs.)	2.6 bar (abs.)
Hot blast temperature	1200 °C	1050 °C
O_2- enrichment (max.)	5000 m^3/h	5000 m^3/h
Top pressure	40 mbar	40 mbar

1.2 Design Criteria for Coal Injection

The design criteria of a PCI plant in terms of capacity and size depend very much on the specific operational environment of the blast furnaces. One major operational philosophy of ironmaking at voestalpine Stahl Donawitz is the utilization of low grade raw materials.

Low grade seaborne iron ore and the domestic iron ore from the local mine nearby, characterized by a high content of SiO_2 and alkalis, are used for sintering, which leads to high alkali sinter. The specific lump ore rate of 350 kg/t HM also gives a significant share of the total alkali input (Figure 3). It can be seen that the overall alkali input into the blast furnaces exceeds 7 kg/t HM, which is by far the highest level for all the western European blast furnaces.

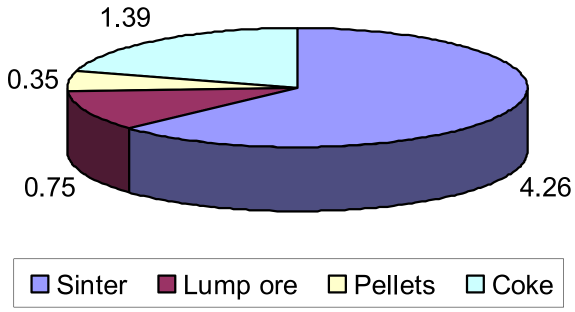

Figure 3. Share of alkali input of BF1 and BF4 in 2004.

Pellets from eastern Europe containing 10,2 % SiO_2 together with the sinter (Fe content approx. 57 %) lead to high slag rates in the range between 250 and 300 kg/t HM.

The other operational practice that affects the design of the PCI plant can be seen in the key figures in table 1: The productivity of the two blast furnaces is comparably low, defined by steel shop demand. This fact makes higher oxygen enrichment and elevated top pressure nonessential. The projected oxygen content of the blast for operation with PCI was therefore defined only by the influence of coal injection on the raceway flame temperature. At the Donawitz blast furnaces the aim is to maintain the raceway flame temperature above 2100 °C, the level of oxygen enrichment is used to keep this level.

The low raw materials quality (high Alkali load, lump ore and slag rates, and bad coke quality) and the low oxygen enrichment of the blast together lead to the design injection rate of 190 kg/t HM at maximum. Given an average production of 2000 t of HM per day and blast furnace, the capacity of the coal injection plant was fixed at 16 t/h for each blast furnace.

For such a small injection rate the economic success of a project depends very much on low investment costs. Plant engineers were requested to design a new, lean concept for coal injection especially suited to the demands of voestalpine Stahl Donawitz.

2 CONCEPT AND DESIGN OF THE PCI PLANT

The concept consists of one single grinding and one single injection plant. Due to the fact that one injection plant serves two blast furnaces and a simultaneous stop of the furnaces does not take place regularly, pneumatic transport of fine coal has to operate permanently. Therefore the dimensions of coal silos and grinding plant were defined to allow maintenance stops of the coal mill. The injection plant was designed for permanent operation, not influenced by equipment failure or any maintenance actions. The design of the whole process was finalized in a a hazard and operability (HAZOP) study, which took both availability and safety issues under consideration.

2.1 General Description of the Plant

Front end loaders discharge the raw coal to a vertical conveyor to transport the coal to the top of the raw coal silo with a holding capacity of 12 hours. A controlled drag chain conveyor feeds the coal to a vertical roller mill. Here the coal grinding and drying takes place at a maximum pulverized coal production rate of 40 t/h and 1 % residual moisture. Blast furnace gas is used as drying energy.

The fine coal is collected in a bag filter and stored in the 1.680 m³ fine coal silo. Before the fine coal is fed into one of three injection hoppers, coarse matter is removed by a screen, which at the same time has a pre-fluidizing effect. Each of the 20 m³ injection hoppers is connected to the main feeding lines to each blast furnace. In order to achieve highest availabilities full operation is also possible using only two injection hoppers. Weighing systems at each injection hopper determine the total injected coal. Coal flow measurement and control systems distribute the coal to both main lines independent of pressure and flow rate at the blast furnaces.

Each main line ends at the compact static distributor, which is located direct at the respective blast furnace. From here 20 separate lines with equal length transport the coal to the injection lance. The total dense phase pneumatic transport is operated at velocities below 8 m/s to prevent any wear.

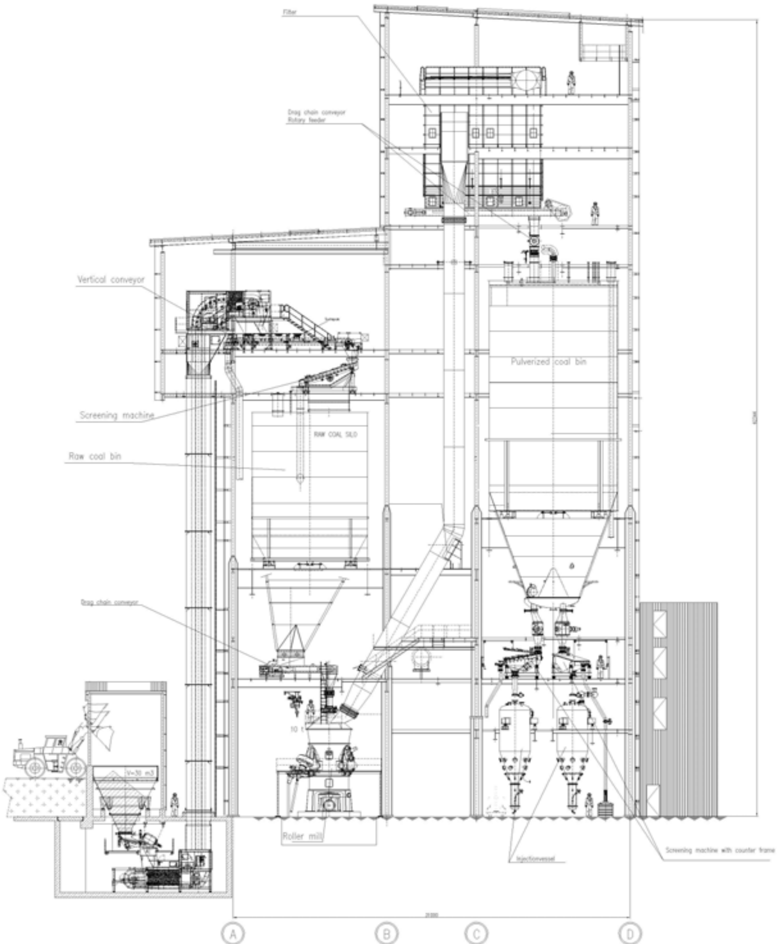

Figure 4. Cross section of Grinding and Injection plant

The process control is divided into injection and grinding process. While the injection plant is controlled and operated from the central blast furnace control room, the grinding plant is as far as possible automated. The grinding plant operates most of the time unmanned, important figures and alarm messages are shown on the user interface of a PDA.

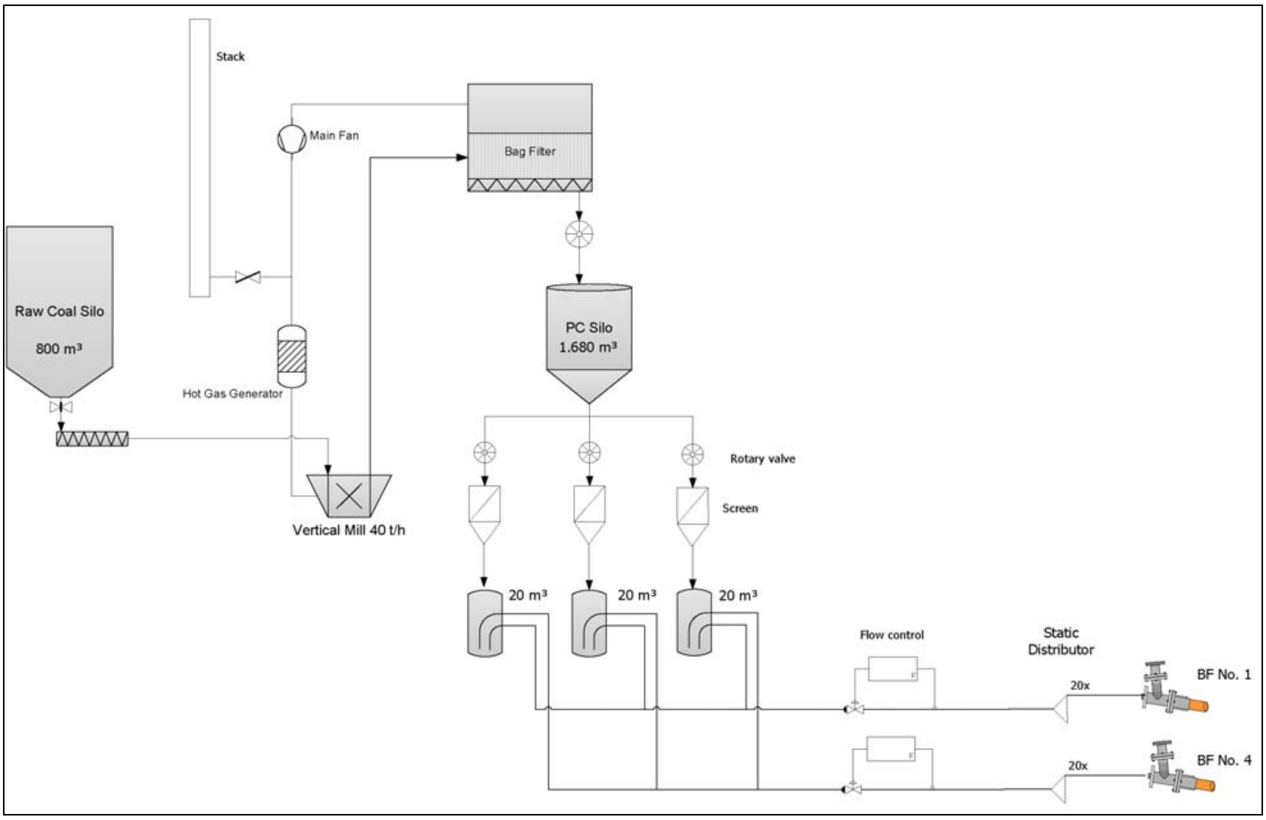

Figure 5. Flow sheet of the plant

2.2 Safety Concept of the Plant

The design of plants for grinding and drying of fine coal has to take place under consideration of various safety aspects as possible failures of the equipment or wrong operation of the plant may cause excessive risks. Especially the prevention of possible explosions and the failsafe monitoring of all important operating conditions is mandatory under all circumstances.

To achieve this Oxygen, CO, Temperature and pressure measurement within the grinding cycle, the filter and also the fine coal silo had to be installed. Sensitive spots were equipped with redundant measurements. All was connected to a fail-safe redundant PLC powered by UPS units in case of blackout. Buffer vessels for Nitrogen were installed to ensure a controlled shut down of the operation and the inertisation of the whole system if the Nitrogen supply would fail. All necessary valves were equipped with spring or emergency tank drives to go in the safety position in such case. By this the operation at Oxygen levels below 10 % and drying temperatures of about 95 °C is possible at optimum conditions without an explosion proof design of the equipment.

In a detailed HAZOP study, executed by an independent institute, every single piece of equipment was screened for the impact of failing. The requirements for all safety related functions regarding health and environmental issues were based on the SIL directive. During this study especially possible and uncontrolled exit of fine coal was looked after. All relevant safety functions were excessively tested before commissioning of the plant. An explosion proof vacuum cleaner is installed to immediately remove remaining fine coal during maintenance services if necessary. For the flexible compensators of the screening units a special leakage detection was developed to minimize the danger of spilled coal in the plant.

2.3 Time Schedule

The execution of the project was realized within only 18 month. Foundation and civil work started already 3 month after signing of the contract. The installation of all mechanical and electrical equipment was completed in only 8 month although the available space for the construction was very limited. After 2 month of cold commissioning, testing and a short start up phase both blast furnaces were online within the scheduled time frame.

3 RESULTS AND DISCUSSION

3.1 Performance of Coal Grinding and Injection Plant

On March 5th 2007 coal injection to blast furnace No. 1 was started, injection to blast furnace No. 4 began 2 days later. For the successful start-up no failures or interruption of coal transport can be reported. Therefore coal rates were ramped up rapidly and up to now coal is continuously injected into the two blast furnaces.

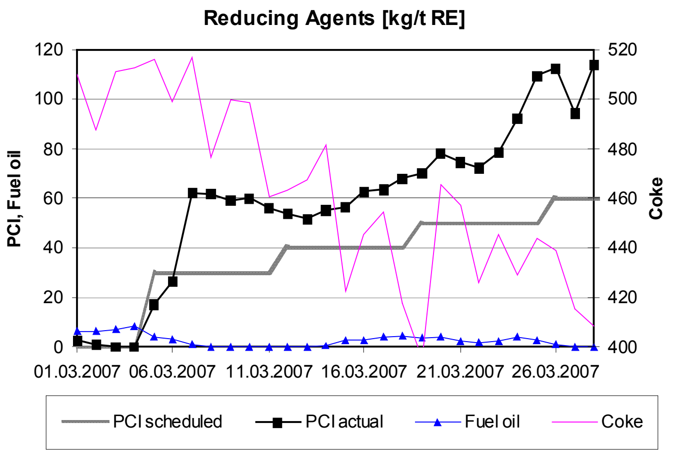

Figure 6. Start-up of coal injection: scheduled vs. actual figures.

The goal of the PCI installation is to deliver coal to the blast furnaces permanently. In the case of one injection plant serving two blast furnaces, planned stoppages of the coal injection plant hardly ever take place. To achieve the desired availability both the coal grinding and the injection plant have to fulfill the specific requirements:

1. At any time the reserve for grinded coal has to be sufficient, to overcome planned and unplanned stoppages of the coal mill. Due to the silo capacity of 850 t even at highest coal rates the operating range exceeds 24 hrs. Up to now the only incident, that stopped coal grinding for a longer period, and forced one blast furnace to change to all coke operation for 4 hrs, was a blockage of a gas supply line prior to the plant.
2. Pneumatic coal transport itself has to operate without failure. During last year only minor adjustments had to be made to increase availability and safety. It turned out, that one bottleneck was the gas analysis of the fine coal silo, which did, in case of a failure, shut down the whole coal injection plant for safety reasons. The way to solve this problem, was to install a third gas analyzer. After the modification a “2 out of 3” check allows to maintain the gas analysis without safety and availability restrictions at any time.

The result of all efforts to achieve highest availability is, that up to now permanent operation without unplanned stoppages longer than 2 hrs was achieved. Changes back to all coke operation due to a failure of coal injection were never needed.

The consumption data for all utilities are below the projected level. The nitrogen consumption for the coal conveying to the tuyeres is of special interest. The dense flow transport technology leads to a specific coal weight above 50 kg per kg N_2. This gives a coal transport velocity in the conveying pipes between 2 and 8 m/s preventing wear of the pipes.

Table 2. Consumption data of coal grinding and injection for May 2008.

Blast Furnace Gas	88 kWh/t coal
Natural Gas	0.25 kWh / t coal
N_2 (overall consumption)	49 Nm3/t coal
Specific coal weight	65 kg/kg N2
Electric Power	23 kWh/t coal

3.2 Blast Furnace Operation with Coal Injection

During the first year of PCI operation it was possible to gain a lot of experience with different grades of coal. To achieve good operational results it was decided to start up PCI with high quality coal, which was already used successfully at other European blast furnaces. Main indicators for high quality coal are a low content of trace elements (such as sulfur, phosphorus, chlorine and alkalis), ash and volatile matter combined with a high carbon content.[1,2]

Due to logistic problems in 2007 the quality of the delivered coal did not meet the expectations. Not until 2008 it was possible to purchase coal according to the specifications. The two grades of coal are denoted as “High Ash Coal” and “Low Ash Coal” respectively, the chemical analysis is given in Table 3.

Table 3. Coal analysis of high and low ash coal grades

		Ash	C	H	N	S	volatile mat.	Na2O	K2O
		[% db]	[% db]	[% db]	[% db]	[% db]	[% daf]	[% db]	[% db]
High Ash Coal	average 09-12.2007	13,86	74,83	5,38	2,08	0,51	23,60	0,07	0,374
Low Ash Coal	average 04-06.2008	5,31	83,00	4,91	2,15	0,37	21,53	0,023	0,064
	std.deviation	0,14	0,32	0,13	0,07	0,03	0,48	0,005	0,009

Figure 7 gives the evolution of coal injection rates at both blast furnaces since the start-up. It can be seen that for several reasons after a fast ramp-up of injection rates between March and May 2007 a further increase was not possible until end of the year.

First of all in July and August there was a reline of blast furnace No. 4 (no coal injection at all in July and limited injection rates in August).

The main influence on achieved coal injection rates was the bad coal quality. The ash content of up to 14 %, leading to increased slag rates, was the major factor. Blast furnace operation was characterized by a high pressure drop, which made further reduction of coke rate impossible. Increased coal rates above 100 kg/t HM had little influence on the thermal state of the furnace, hence the replacement ratio for coke dropped significantly.

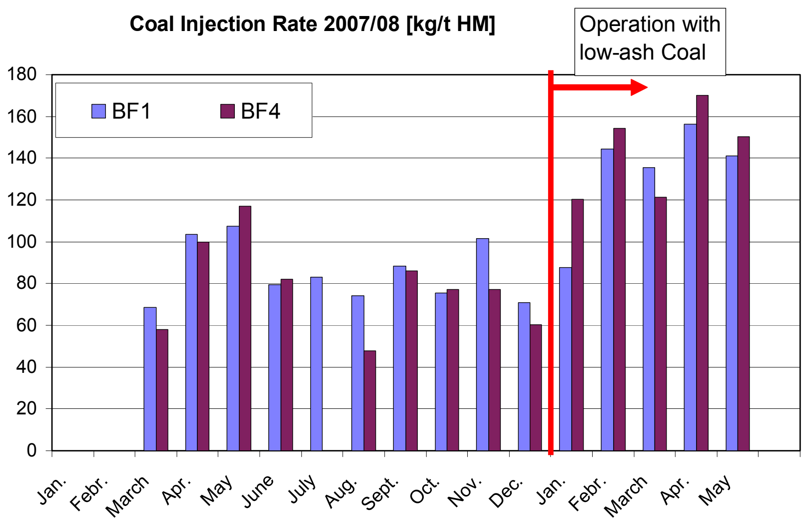

Figure 7. Trend of coal injection rates since start-up in 03.2007.

The utilization of low ash coal since January 2008 led to injection rates between 120 and 170 kg/t HM, sometimes slightly limited by coal logistics. Figure 8 shows the effect of coal injection on the coke rates. Simultaneously with the increase of coal rates in 2008 the coke rate dropped below 300 kg/t HM. For this period no major effect on the reductant rate (sum of coke, small coke and coal) was observed, indicating a good coke replacement ratio.

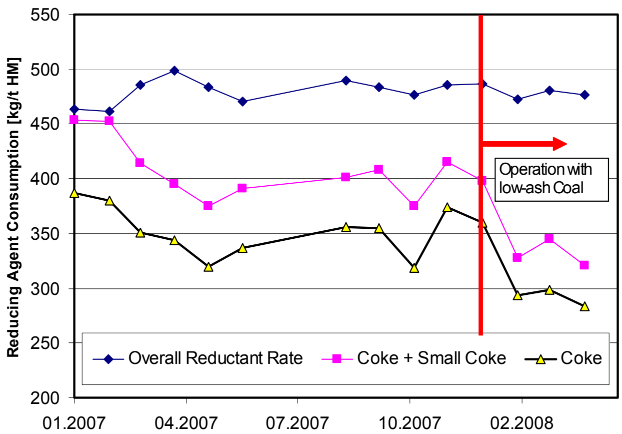

Figure 8. Trend of reducing agent consumption Blast Furnace No. 1 for 2007 and 2008.

3.2 Economic Evaluation

Beside all consumption data the main focus during the economic evaluation of such a project is the coke saving expressed by the coke replacement ratio. The graph (dry) coke rate versus (dry) coal injection rate gives the replacement ratio and is shown for blast furnace No. 1 below (Figure 9). All monthly average data since the start-up of PCI (except for July and August 2007 when the utilization of partly metallic burden materials led to very low reductant rates, that can not be compared) are used for this analysis.

It can be seen that an average replacement ratio above 0.9 was achieved, which is consistent with literature data for low volatile coal. Coal injection rates above 140 kg/t HM led to even higher replacement ratios, which can be explained by the utilization of low ash coal during that period.

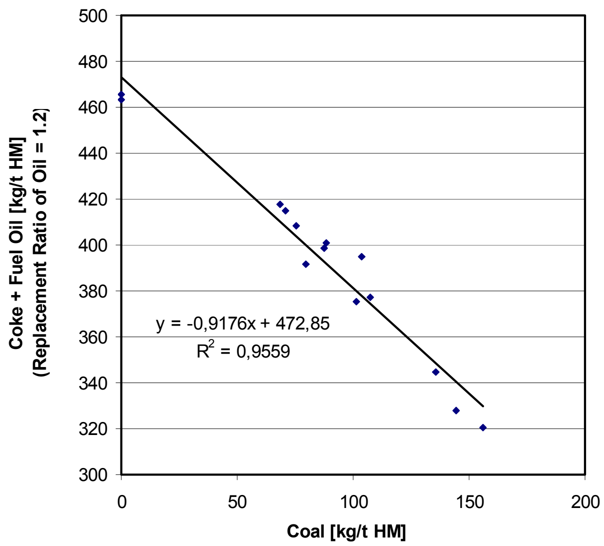

Figure 9. Calculation of Coke Replacement Ratio for Furnace No. 1 on a monthly basis.

According to the investment planning the target average coal injection rate was 143 kg/t HM at a total hot metal production of 3800 t/d, which gives a design injection rate of 11.3 t/h per blast furnace. In the meantime hot metal production rose up to 4290 t/d, which means that the investment pays back even with injection rates of less than 130 kg/t HM.

It was shown, that with low ash coals the forecasted replacement ratio of 0.9 is reached and the projected injection rate is surpassed by 20 %. In both, the technical and economical aspects, the new PCI installation exceeds the expectations.

4 CONCLUSIONS

From signing the contract until the acceptance test the whole project of PCI installation was carried out in 18 months. The start-up of the plant was very successful and since 7th of March 2007 pulverized coal is injected into both blast furnaces permanently. Until now no major unplanned stoppage of the grinding and injection plant occurred. Due to reliable as well as accurate injection equipment and preparation of the blast furnaces to lower coke rates, injection levels higher than 150 kg/t HM and sized coke rates lower than 270 kg/t HM have been achieved.

Considering the boundary conditions of blast furnace operation at voestalpine Stahl Donawitz (e.g. raw materials quality) these results are outstanding, enabled by appropriate designed processes and operational experience.

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