Evolution of Blast Furnace Productivity and Reductant Rates in Western Europe[1]

By Luc Bonte, Philippe Lacroix, Hans Bodo Lüngen and Kurt Peter Stricker

Summary

The paper gives a 10 years overview of the efforts of the steel industry in Western Europe (EU) to enhance its efficiency by improving blast furnace productivity and reductant rates as major factors to reduce costs. As a result of steel industry's commitment to improve its international competitiveness, restructuring of iron and steel industry has been going on. Concentration in large production units at only a few sites is therefore a logic consequence.

The European story for high productivity went along with a steep increase of oxygen enrichment even if new large blast furnaces were taken into operation. Oxygen enrichment and injection technology are inseparably linked together, giving the chance to match operational conditions for low gas volume, favourable coke replacement ratio, high hydrogen input and optimal flame temperature.

Productivities of nearly 83 t/m².d, total reductant consumption of 422 kg/t HM, coke rates of 265 kg/t HM only and coal injection rates of 211 kg/t HM are not reached at random. Moreover, these encouraging results point out the potential for consistent operation. The global approach for such targets is asking to meet a lot of requirements including burden and coke quality, as well as burden distribution, process or hearth conditions control and high plant availability.

---

[1] 1st International Meeting on Ironmaking, September 24th to 26th, 2001, Belo Horizonte/MG, Brazil

Dr.-Ing. Luc Bonte, General Manager Ironmaking, Sidmar NV, Gent, Belgium; Philippe Lacroix, Process Manager Ironmaking Dep., Sollac Méditerranée, Fos-sur-Mer, France; Dr.-Ing. Hans Bodo Lüngen, Senior Manager Metallurgy, German Iron and Steel Institute (VDEh), Düsseldorf, Germany; Dipl.-Ing. Kurt Peter Stricker, Senior Division Manager Quality and Industrial Engineering, Hüttenwerke Krupp Mannesmann GmbH, Duisburg, Germany.

Introduction

The search for a greater international competitiveness goes along with the personal challenge of ironmaking plant operators to continuously improve the blast furnace technology and its performances. The paper gives a 10 years overview of the efforts of the steel industry in Western Europe (EU) to enhance its efficiency by improving productivity and reductant rates as major factors to reduce costs.

1. Evolution of blast furnace productivity in the period 1990-2000

As a result of steel industry's commitment to improve its international competitiveness, restructuring of iron and steel industry has been going on in the last 10 years. Concentration in large production units at only a few sites is therefore a logic consequence.

Figure 1 illustrates the continuous reduction of number of blast furnaces operated in Western Europe in this period. In 1990 about 94 million t HM where produced in 92 blast furnaces, in 2000 nearly the same amount of hot metal was produced in 66 blast furnaces only. The mean specific production per blast furnace has steadily increased by 40%, from 1.04 to 1.45 million tpy. The productivity of all blast furnaces correlatively progressed in this time in average from 51.7 to 58.4 t/m².d (**figure 2**). The yearly individual best performances of a blast furnace rised up from 65.6 to 75.6 t/m².d. **Figure 3** shows that the number of blast furnaces operated with productivity higher than 60 t/m².d increased from nearly 8% in 1990 to 36% in 2000; 6% - that is 4 blast furnaces - were operated in 2000 with more than 70 t/m².d.

2. Oxygen enrichment and reductant rate figures

Fundamental prerequisites to achieve high blast furnace production rates are not a secret. Raising productivity requires either to decrease gas volume, which basically means to enhance oxygen enrichment and to decrease the specific reductant rate and/or to improve furnace permeability.

The European story for high productivity went along with a steep increase of oxygen enrichment even if new large blast furnaces were taken into operation. In 1990 about 37% of blast furnaces were still operated without oxygen enrichment and other 49% with rather moderate rates up to 23% O_2 in the blast (**figure 4**). The year 2000 survey reports about only 8% blast furnaces operating without oxygen enrichment, 40% with enrichment rates between 23 and 25% and in the last nearly 11% with enrichment rates of 27% O_2 and more.

Oxygen enrichment and injection technology are inseparably linked together, giving the chance to match operational conditions for low gas volume, favourable coke replacement ratio, high hydrogen input and optimal flame temperature. **Figure 5** shows the evolution of reductant rates in the period 1990-2000. Consistent is the reduction in dependence on coke by increased injection rates. The share of alternative injectants in the European reductant mix increased in this time from 81 to 123 kg/t HM, which is from 17 to 25% of the total consumption.

Remarkable are individual best performances such that of Sidmar A, with a consistent operation over five years with coke rates nearly 300 kg/t HM and a record of 286 kg/t HM obtained as yearly average in 1998 in conjunction with coal injection rates of 197 kg/t HM (**figure 6**). In 2000 about 22% of European blast furnaces were operated with less than 340 kg coke/t HM, ten years before - in 1990 - only 3% (**figure 7**). In the same period the share of blast furnaces performing coal injection rates of 150 kg/t HM and more rised from 3 to 33% (**figure 8**).

During the past furnace specific coke consumption was continuously reduced by improving ferrous burden material and coke quality, reducing slag rates, as well as optimising burden distribution and last but not least by substituting coke by injectants. The improved process control, necessary to reach high injection and productivity levels resulted finally in a coke rate reduction more significant than expected before by the simple effect of carbon replacement. **Figures 9 and 10** give an overview of the replacement ratios for coal and oil in the European hot metal production. The slope of the linear regression of the monthly average for individual optimised conditions is nearly 1 kg coke/kg coal for Sidmar's coal injection and 1.17 kg coke/kg oil for HKM's oil injection practice.

In the light of this arguments **figure 11** is a comprehensive evidence for the link between low coke rate and high productivity operation.

3. European highlight performances

The overview given for the last 10 years is based on annual average data. Furthermore, a certain number of blast furnace plants were operated during significant periods of time – at least one month - with highlight performances ranking far beyond that limits (**figure 12**). Productivities of nearly 83 $t/m^2.d$, total reductant consumption of 422 kg/t HM, coke rates of 265 kg/t HM only and coal injection rates of 211 kg/t HM are not reached at random. Moreover, these encouraging results point out the potential for consistent operation. The global approach for such targets is asking to meet a lot of requirements including burden and coke quality, as well as burden distribution, process or hearth conditions control and high plant availability.

4. Burden quality for high productivity operation

The increase of the gas throughput in the blast furnace and burden permeability improvement are inseparably linked together. That is why the majority of blast furnaces operating at high productivity have ratios of prepared burden – that is sinter or pellets – close to or even higher than 90%. **Figure 13** shows furthermore that the share of prepared burden is higher in the case of blast furnaces operating simultaneously at high productivity and low coke rate (i.e. high injection rates).

When the aforementioned key issues for high productivity operation are considered, the main requirements for burden quality have to be focused on:

- High permeability and homogeneity going along all furnace temperature and reaction zones,
- high reducibility to match with short throughput times and

- low tramp element contents such as zinc, lead and alkalis to avoid process disturbances.

Figure 14 shows a comprehensive presentation of the productivity improvement of HKM's BF-B, going along with both: low reductant rates and permeability increase despite substantial savings in coke, which is known for its significant contribution to stabilise the burden permeability. These results suggest that the permeability improvement by more than 10% in the period 1995-1998 was highly supported by improved ferrous burden quality.

Size distribution of burden materials is of particular importance to control the permeability in the upper part of the burden column: main target is to limit the amount of fines. **Figure15** illustrates the influence of the sinter grain size fraction –5 mm on the permeability. For the same reason the sinter coarse fraction + 40 mm is generally limited too, searching for a narrow grain size range.

The extend of low temperature degradation is responsible for flow disturbances in the 500° C zone. Particular importance should be attached to sinter degradation, which is generally higher compared with pellets. In **Figure 16** an increase in the frequency of tuyere failure is experienced when sinter low temperature degradation increased. In this case poor shaft permeability seems to affect the position of cohesive zone and consequently the meltdown behaviour. A lot of research work was done to deepen the knowledge and to assess the influence of tramp elements on the degradation. The catalytic effect of alkalis on iron oxide reduction seems to enhance the degradation tendency, whereas sulphur and chlorine components in the gas phase should have an inhibiting effect. A reason more to limit the alkali input in the furnace.

The specific pressure loss in the cohesive zone is almost five times higher than in the dry shaft zone. High softening and melting temperatures, a narrow softening-melting interval and a low primary slag melting point may improve the permeability in this area.

The final assessment of blast furnace burden configuration however relies on both: technological and economical factors, strongly affected by local conditions. As sinter plant productivity is increased in order to raise the sinter share in burden, sinter marginal costs steadily rise because of raising burnt lime and energy consumption. In this case sinter becomes less attractive compared with pellets and lump ore, which are purchased for fixed prices.

At first sight it seems to be of interest to include cheap ore in the blast furnace burden. But operational results confirm previous findings suggesting that lump ore affects shaft permeability and locally impede sinter reduction. **Figure 17** illustrates the impact of higher lump ore ratios on indirect reduction; this is asking for more coke. That is why consistent high productivity operation with high lump ore ratios was not yet practiced in Western Europe.

5. Coke quality for high productivity operation

Coke quality plays as well a significant role for the permeability control and in particular in the lower part of the blast furnace. The gas flow in this area is to a great extend influenced by the hot metal and slag flow, dripping out of the cohesive zone via the "dead man", into the hearth. The final grain size of the coke in the hearth is decisive for these conditions as well as for hearth drainage and liquid evacuation. Samplings in the nitrogen quenched BF-5 at former Mannesmann Works assessed a decrease of coke layer voidage from 0.45 at the stockline to 0.3 at tuyere level. The general approach to improve bosh coke size is to optimise feed coke size and strength while minimising coke breakdown inside the blast furnace during reduction. **Figure 18** shows the influence of coke grain size distribution on productivity performance of BF-2 at Rautaruukki Steel.

The need for excellent coke quality is even stronger when the targets for productivity and injection rates are high. Different investigations mention enhanced coke fines in the raceway area with high-pulverised coal injection. This could be explained by longer residence time of coke in the furnace, in particular in the zone where its gasification occurs (**figure 19**). Consequently the coke is exposed to greater mechanical and chemical attack. Moreover the coke is burnt proportionately less at tuyeres, whereas more coke is consumed for direct reduction. For this reason it seems to be advisable to increase the share of nut coke charged with the ferrous burden.

Coke reactivity, assessed by the CSR index is supposed to give a good approach for the coke degradation by gasification. That is why CSR values of at least 60% and recently 65 % are at present considered to be necessary to support a stable blast furnace operation, especially for large furnaces as illustrated in **figure 20** for BF-Schwelgern 1. By appropriate selection of coal mixtures and coking process control coke with CSR of 65-to70% as yearly average can be produced nowadays (**figure 21**). **Figure 22** shows the worsening of furnace permeability with decreasing CSR values with a time lag of many days experienced at Sidmar. Even if afterwards the CSR increases again, it takes time before permeability recovers. Investigations with marked coke at BF-Schwelgern 1 of TKS indicated that coke substitution in the hearth would take several weeks. That is why coke regularity and homogeneity are of utmost importance.

6. Hearth wear and extension of campaign life

Hearth conditions are significantly influenced during high productivity operation. Statistical studies made by Sidmar show a strong correlation between hearth wall, hearth bottom temperatures and productivity variations. As mentioned before, high injection rates may impair the permeability of the dead man. Consequently enhanced peripheral flow of hot metal and slag occurs resulting in a pronounced refractory wear. That is why a good liquid evacuation with controlled tapping speed as well as liquid and wall temperature monitoring are essential prerequisites for stable operation. **Figure 23** demonstrate the effect of stronger peripheral flow going along with the productivity increase on the tap hole length at BF-A of HKM, despite optimised tapping practice with shorter times between taps and improved clay quality. A new type softly operating drill machine equipped with a high speed hydraulic hammer supported by nitrogen and water cooling - installed during the rebuild 1998 - was a major contribution to stabilise the tap hole area.

Nevertheless one question has to be discussed at the end: Does productivity impair the blast furnace life? Specialist's opinions vary on this point. In **figure 24** specific hot metal production during a campaign has been plotted versus productivity for completed campaigns of blast furnaces blown in the period 1975-1990. Obviously, blast furnace campaign life was not negatively affected by increased productivity, mostly even the opposite occurs. This finding is valid at least up to productivity of around 2.2 t/m^3 inner volume and 24 h, corresponding to about 2.6 t/m^3 working volume and 24 h according to European reference parameters.

This result is not unexpected because long furnace life requires apart from constructional prerequisites a consistent process operation, high quality burden materials and sophisticated tapping technology. These are not only prerequisites for long campaigns, but also essential conditions for high productivity operation.

References

1. Dauwels, G.; Dufresne, P.; Godijn, R.; Lacroix, Ph.; Perini, P.G.; Stricker, K.P.; Virtala, J.: High blast furnaces productivity operations with low coke rates in European Union. 4th European Coke and Ironmaking Congress, Paris, June 2000.

2. Hartig, W.; Langner, K.; Lüngen, H.B.; Stricker, K.P.: Measures for increasing the productivity of blast furnace. 59th Ironmaking Conference, Pittsburgh, USA, March 2000.

3. Bekaert, R.; Bonte, L.; Danloy, G.; Stas, F.; Vervenne, R.: Processcontrol technigues for the realisation of high hot metal quality, high productivity and high pulverezed coal injection at the Sidmar blast furnaces. 2nd International Congress on the Science and Technology of Ironmaking, Toronto, Canada, March 1998.

4. Beckmann, B.; Eisen, P.; Hüsig, K.R.; Stricker, K.P.: Burden composition for high productivity blast furnace operation at HKM. IISI-Seminar on Sinter and Pellets, Brussels, Belgium, June 1999.

5. Großpietsch, K.H.; Lüngen, H.B.: Coke quality requirements by European blast furnace operators. Cokemaking International 1/2001, pp. 54/60.

6. Didelon, F.; Eibes, C.; Eymond, JL.; Negro, P.: French experience about coke quality at high coal injection rate. European blast furnace committee, Koverhar/Finnland, September 1997.

7. Fliermann, G.A.; Langner, K.; Leonard, D.C.; Libralesso, J.M.; Massin, J.P.; Palomba, R.: Operation with high coal injection and low coke rates in Europe. 3rd European Ironmaking Congress, Gent, Belgium, September 1996.

8. Bennington, C.R.; Beppler, E.; Jahnsen, U.; Negro, P.; Steiler, J.M.; Wilmers, R.R.: Assessment of coke degradation in the blast furnace from tuyere probing

investigations. 3rd European Ironmaking Congress, Gent, Belgium, September 1996.

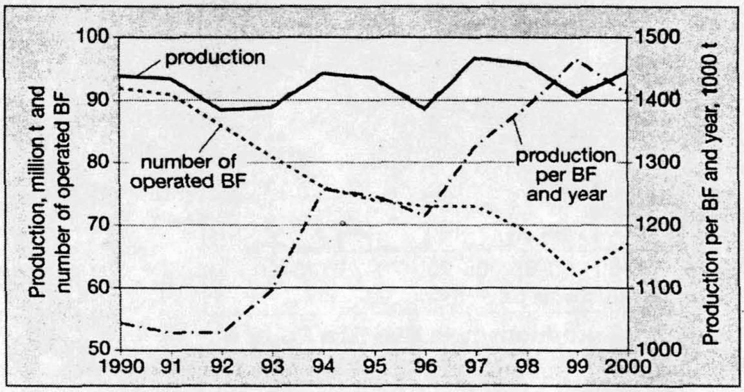


Fig. 1 Evolution of hot metal production in Western Europe, number of operated blast furnaces (BF) and production per BF and year

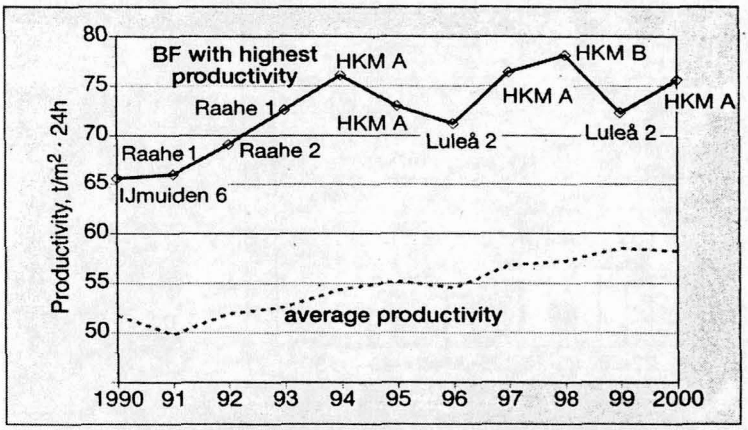


Fig. 2 Evolution of BF productivity in Western Europe

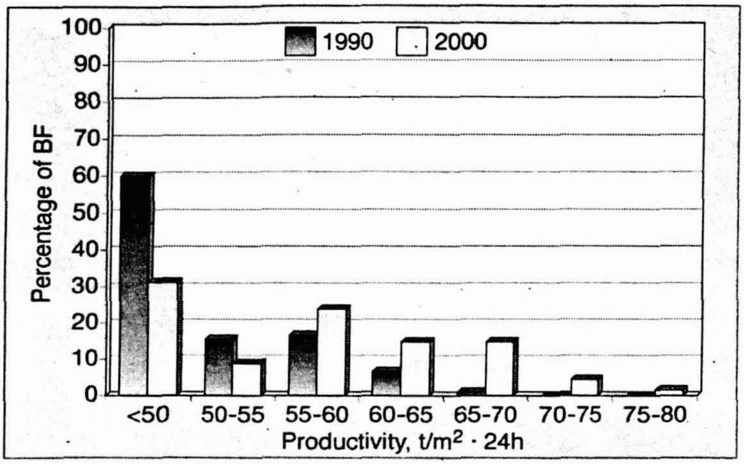


Fig. 3 Comparison of BF productivity in Western Europe in 1990 and 2000

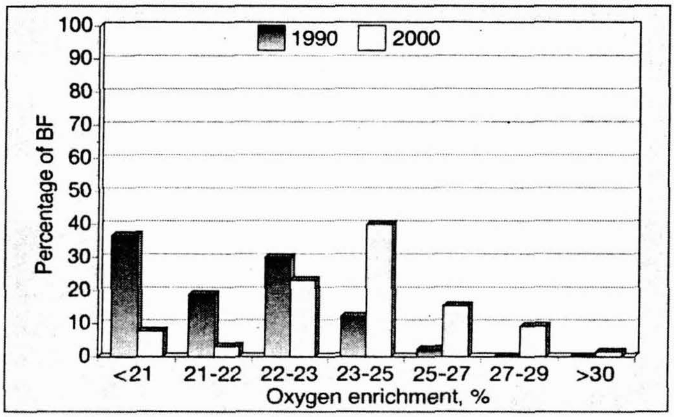


Fig. 4 Comparison of oxygen enrichment in Western European BF in 1990 and 2000

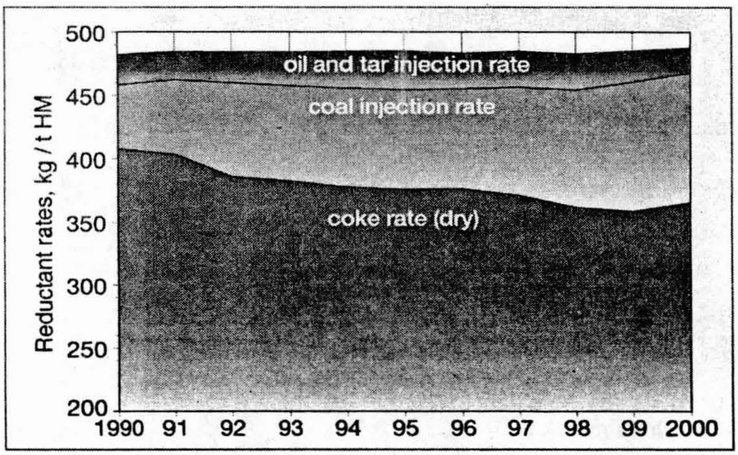


Fig. 5 Evolution of BF reductant rates in Western Europe

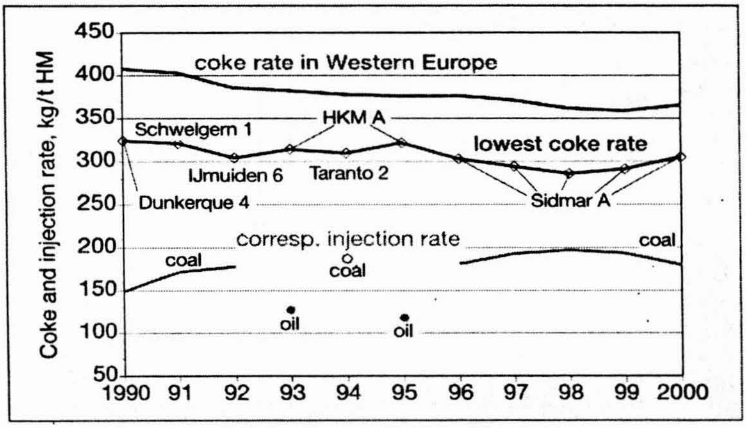


Fig. 6 Evolution of BF coke rates in Western Europe and BF with lowest rates

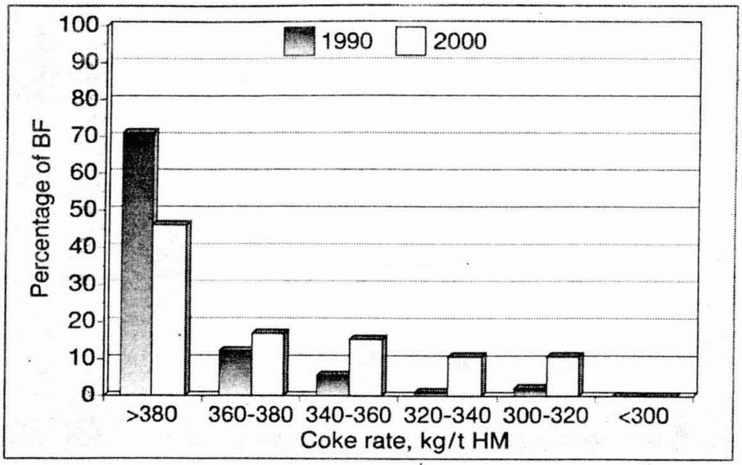


Fig. 7 Comparison of BF coke rates in Western Europe in 1990 and 2000

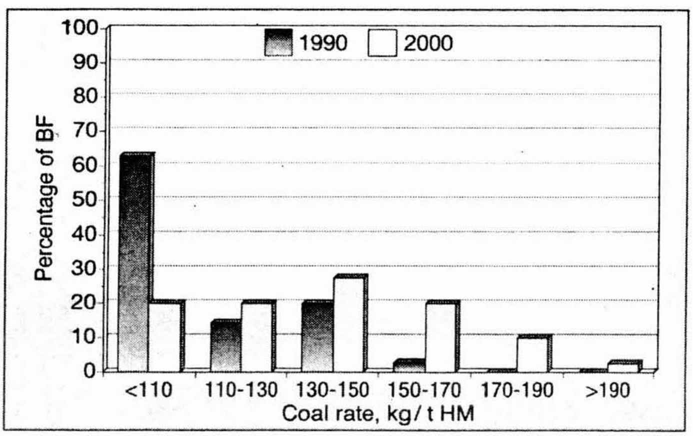


Fig. 8 Comparison of BF coal injection rates in Western Europe in 1990 and 2000

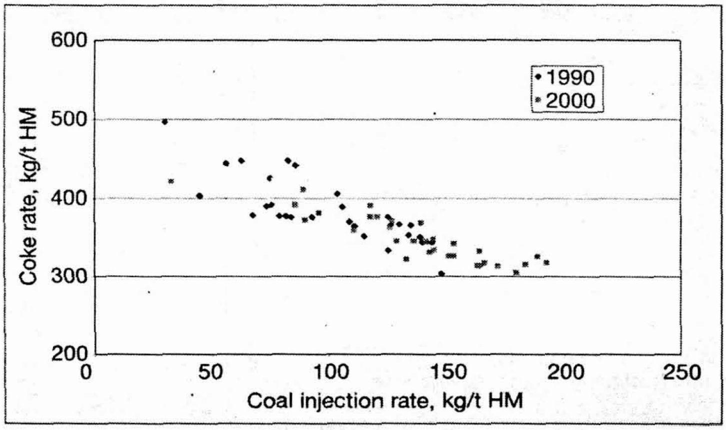


Fig. 9 Coke rate versus coal rate for W. European blast furnaces

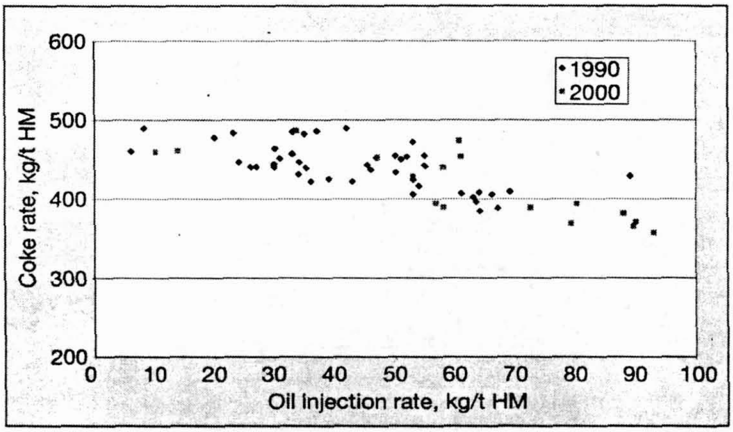


Fig. 10 Coke rate versus oil rate for W. European blast furnaces

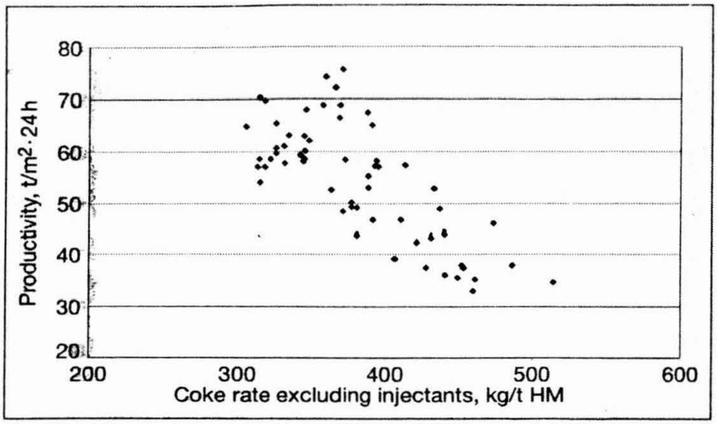


Fig. 11 Coke rate versus productivity for W. European blast furnaces in 2000

Blast furnace	HKM BF-B	HKM BF-A	SSAB Luleå BF-2	Corus IJmuiden BF-6	Sidmar BF-A	Corus UK Q.Victoria	TKS BF-S1	Salzgitter BF-B
Period	06-08 1998	04-06 1994	04 2000	10 1999	11 1998	01-02 1992	09 1999	03 1997
Productivity, $t/m^2 \cdot 24h$	82.7	79.7	78.6	77.7	66.1		71.8	
Reductant rate, kg/t HM								
Bell coke	266	269		277	232	269	272	275
Nut coke	44	32		35	33	20	15	52
Total coke	310	301		312	265	289	287	327
Oil	127	146		3				95
Coal				208	211	207	186	
Total reductant	436	447		523	475	496	474	422

Fig. 12 Blast furnaces in Western Europe with highest productivity, lowest coke rates and lowest total reductant rates

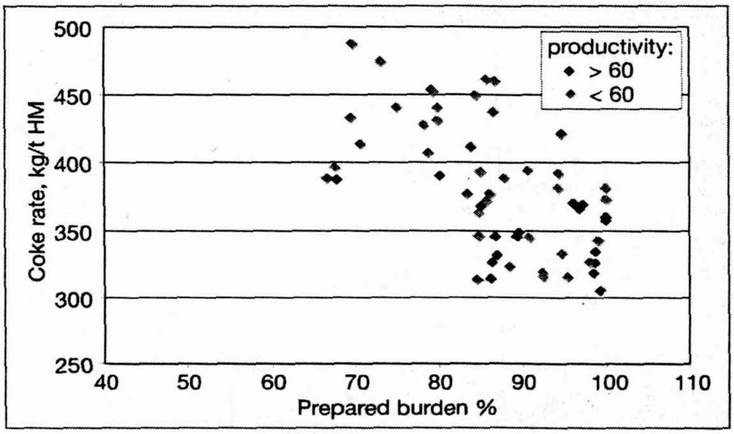


Fig. 13 Coke rate versus oil rate for W. European blast furnaces

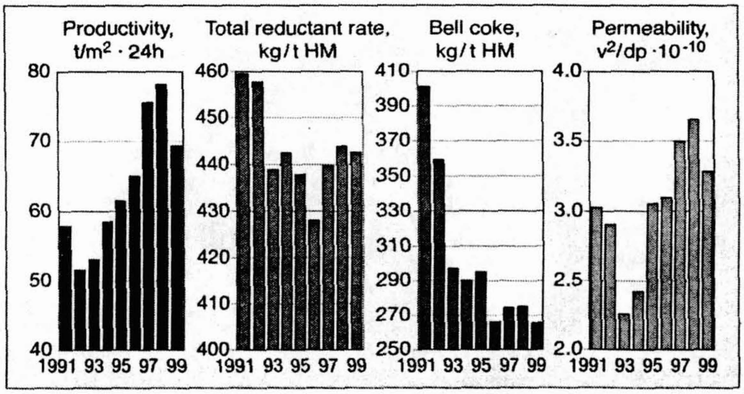


Fig. 14 Evolution of productivity, reductant rate and permeability at HKM BF-B

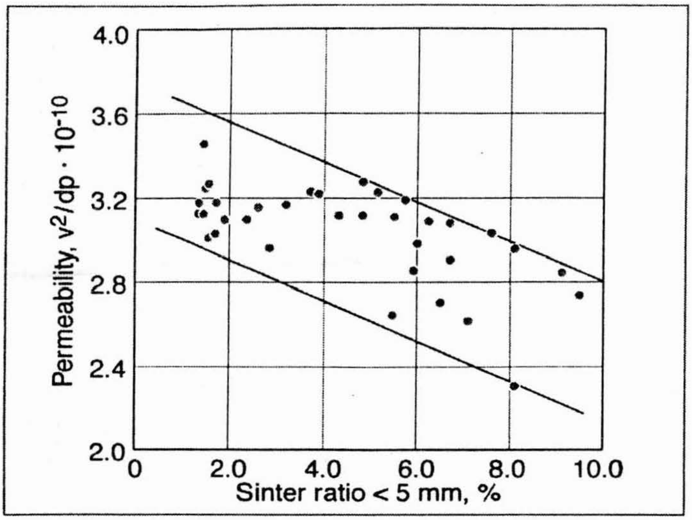


Fig. 15 Influence of sinter fines on the permeability, HKM BF-B

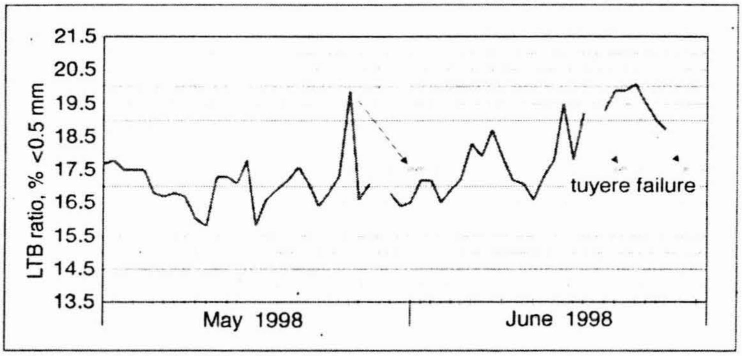


Fig. 16 Influence of sinter low temperature degradation on tuyere failures, Sidmar BF-B

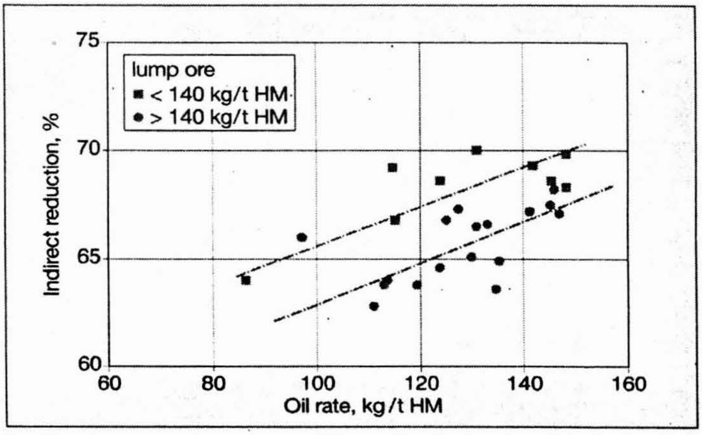


Fig. 17 Influence of lump ore ratio on the indirect reduction at HKM

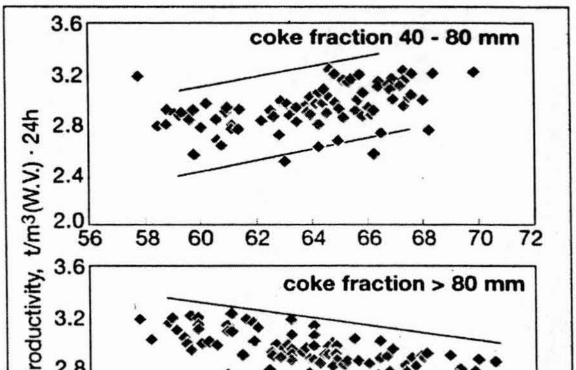


Fig. 18 The effect of coke properties on BF-2 performance at Rautaruukki Steel (1996 - 1998)

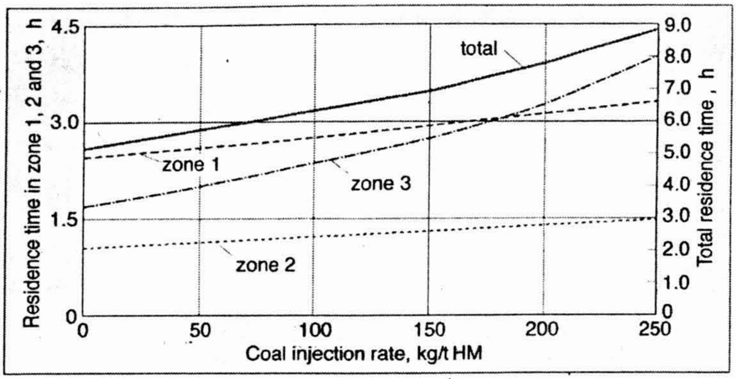
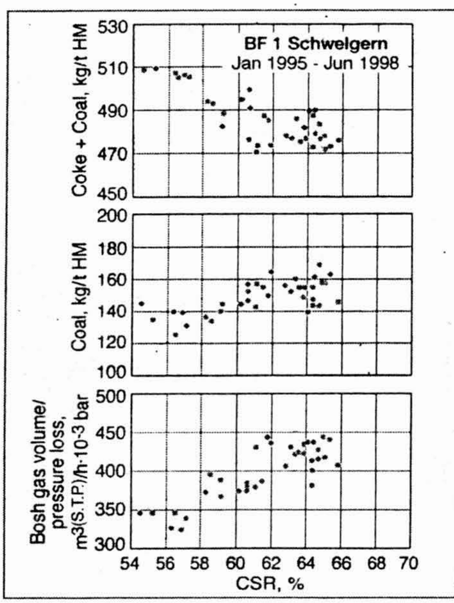


Fig. 19 Influence of coal injection on burden residence time in the BF
(Zone 1: < 950°C temperature zone, Zone 2: zone between 950°C and the end of the cohesive zone, Zone 3: zone under the cohesive zone)

Fig. 20
Influence of CSR on reductant rates and permeability



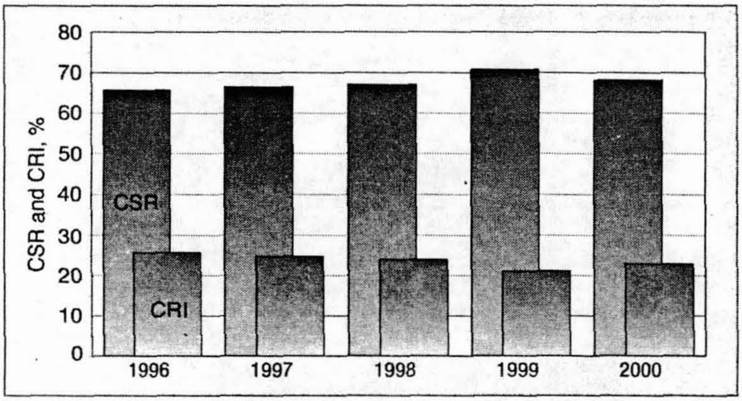


Fig. 21 Evolution of coke CSR and CRI at HKM

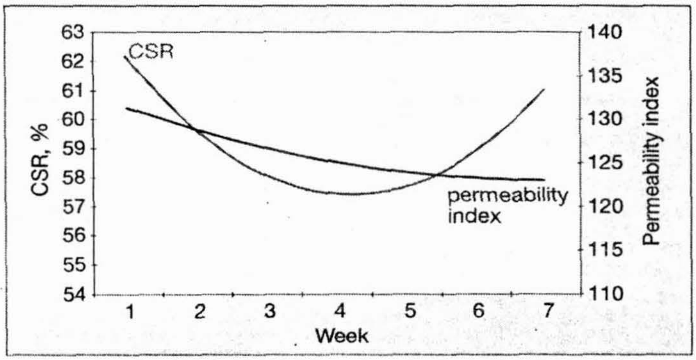


Fig. 22 Evolution of CSR (weekly values) and blast furnace permeability

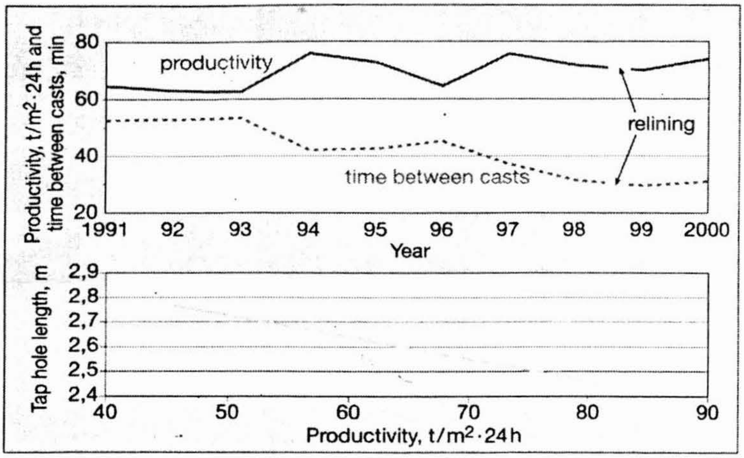


Fig. 23 Influence of productivity on tapping conditions at HKM

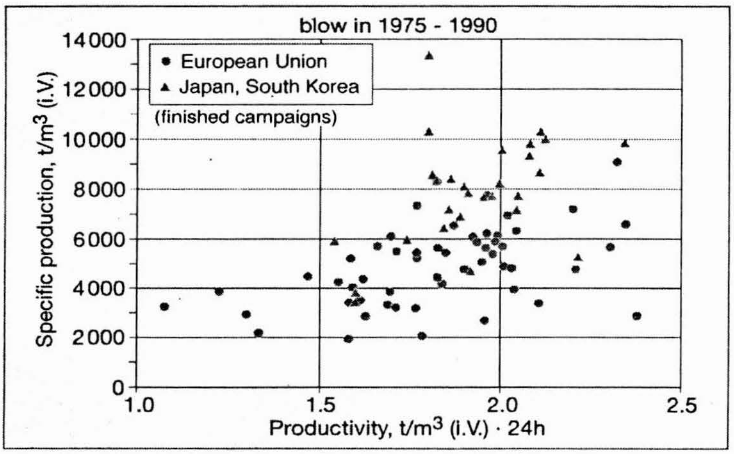


Fig. 24 Effect of productivity on specific production during a campaign