REDUCTION OF BLAST FURNACE COKE-RATE: VISION OF THYSSENKRUPP

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Abstract

ThyssenKrupp Stahl AG (TKS) operates in the Duisburg works near the river Rhine 4 blast furnaces (Schwelgern 1 and 2, Hamborn 4 and 9) with a total hot metal production of about 11.7 mill. t HM per year.

On the basis of extensive development work, at the beginning of the 1980th the decision was taken to optimise hot metal production by the injection of pulverised coal with the following aims:

- to increase productivity
- to minimise the coke consumption

To optimise the coal combustion the blast furnaces of TKS operate with coaxial lances, oxygen enrichment up to 6 %, a coal grain size of 80 % < 90 µm, volatile matter between 18 to 25 % and pneumatic dense flow injection systems. Blast furnaces No. 1, No. 2 and No. 4 have the individual feeding control by mechanical valves.

To inject a constantly rising quantity of pulverised coal it needs continually increasing demands on the quality of coke especially in the hearth of the blast furnace. In particular the coke reactivity and the corresponding coke strength after reaction CSR influence the processes taking place in the lower part of the blast furnace and thus the blast furnace behaviour in general. More lumpy coke and less coke fines in the hearth of the blast furnace have a positive effect on the gas permeability, the drainage of liquid hot metal and slag and leads to a lower reducing agent consumption. Beside that, the coke rate can be reduced and the coal injection increased. Moreover, it is possible to attain a higher furnace productivity.

The aim for all blast furnaces at TKS will be a total reducing agent consumption less than 470 kg/t HM and a coal rate larger than 180 kg/t HM.

Keywords

blast furnace, reducing agents, productivity.

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Introduction

In the past 40 years, the consumption of reducing agents in the blast furnaces has been reduced by over one third. During the 1960's and 1970's the injection of fuel oil was the main feature of furnace operation to attain high productivity levels and low coke rates. From this time onwards, numerous energy and heat recovery measures made it possible to raise blast temperatures, without any additional primary energy input, to more than 1200 °C. However the two oil price crisis led to all coke operation and everyone started thinking over alternative reducing agents. As a consequence pulverised coal injection has been adopted by many plants. In 1984 at blast furnace Hamborn No. 4 coal injection started at Thyssen Stahl. Up to 1993 all the furnaces, which are still in operation at ThyssenKrupp Stahl, got a coal injection facility. The first main topic was to optimise the combustion process in the raceway. Much research work was carried out on plant, pilot plant and laboratory scale. The important factors controlling coal combustion are :

- coal properties (volatile matter, ash content, size distribution)
- lance design
- partial pressure of oxygen
- amount of nitrogen for the pneumatic coal transportation
- additives to the coal

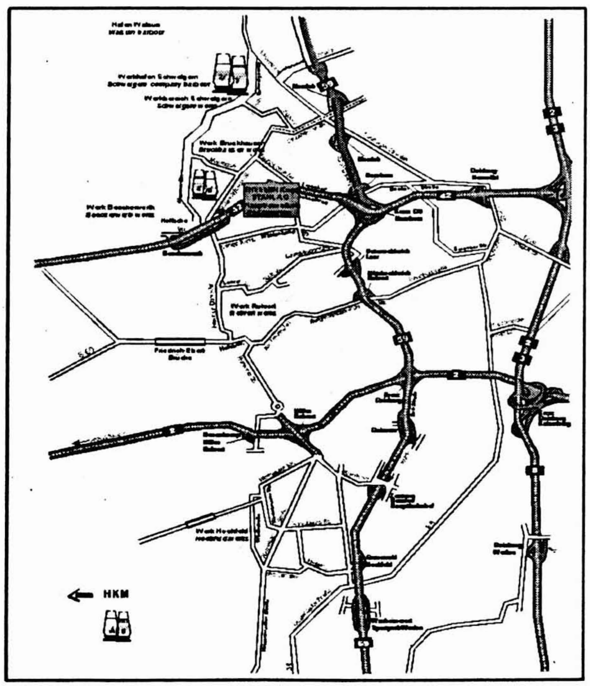

Fig. 1: Location of TKS in Duisburg

At the end the blast furnaces of TKS operate with coaxial lances, total oxygen enrichment up to 6 %, a coal grain size of 80 % < 90 µm, volatile matter between 18 to 25 % and pneumatic dense flow injection systems. Especially blast furnace No. 1, No. 2 and No. 4 have the individual feeding control by mechanical valves.
This report will show, how TKS operates blast furnaces today and what is the aim for the future.

Blast furnaces at ThyssenKrupp Stahl

The main plants of ThyssenKrupp Stahl are favourably located at Duisburg on the Rhine river with optimum logistical conditions for raw materials and finished products (Fig. 1). As a consequence

of the merger of Thyssen Stahl and Krupp Hoesch Stahl the production of hot metal in Dortmund ended after 160 years and a total production of round about 250 million t by the shut down of the last blast furnace on the 28th of April 2001. Since May 2001 TKS operates the two blast furnace plants Hamborn and Schwelgern and a total of four furnaces (**Fig. 2**). The production capacity is about 11.7 million t HM per year.
In the Hamborn plant blast furnaces 4 and 9 with hearth diameters of 10.64 and 10.20 m are in operation. Between 5,000 and 5,500 t HM are produced per day and furnace.

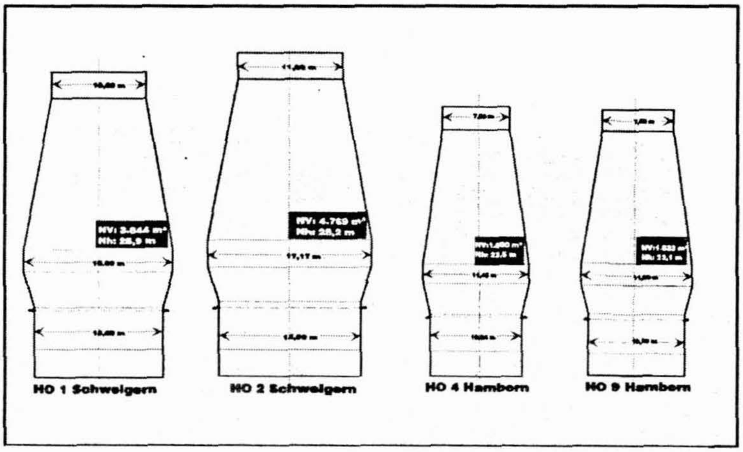

Fig. 2: Dimensions of blast furnace at TKS

Both large-capacity blast furnaces 1 and 2 in the Schwelgern plant with hearth diameters of 13.60 and 14.90 m are capable of producing up to 11,000 and 13,000 t HM a day.
The smallest and oldest blast furnace Hamborn No. 9, relined in 1987, has a working volume of 1833 m³ and produced up to the end of April 2001 more than 22 mill. t of hot metal (**Fig. 3**). The biggest is Schwelgern No. 2 with a working volume of 4,769 m³. He is in operation since 1993 and produced 28 mill. t.

Constructional Features of Blast Furnaces of ThyssenKrupp Stahl Duisburg		Schwelgern 1	Schwelgern 2	Hamborn 4	Hamborn 9
General features					
Year of construction		1973	1993	1974/1964	1987/1962
Manufacturer		GHH	GHH-MDH-TE	GHH	GHH
Date of blow-in after last complete relining		9.96	10.93	01.00	11.87
Hot metal production during the preceding campaign	10^6 t	32.5		11.4	7.5
Dimensions					
Hearth diameter	m	13.60	14.90	10.64	10.20
Working volume	m3	3.844	4.769	2.030	1.833
Inner volume	m3	4.416	5.513	2.323	2.132
Total volume	m3	4.687	6.020	2.475	2.298
Blast and top gas					
Maximum blast output	10^3m3(S.P.T.)/h	520	585	220	220
Maximum blast pressure (absolute)	bar	5.50	6.50	3.75	3.80
Maximum top gas pressure (absolute)	bar	3.30	3.80	2.45	2.50
Auxiliary reducing agents					
Reducing agents injected through tuyeres		coal	coal	coal / oil	coal
Injected quantity at nominal capacity	t/h	77.5	88.0	35.0 / 23.0	40.0
Top					
Type of burdening		conveyor belt	conveyor belt	skip	skip
Top design		P. Wurth	P. Wurth	P.Wurth	P. Wurth
Slag treatment					
Type of slag granulation system		OCP	INBA	no	OCP
Type of dedusting					
Number of cast houses		2	2	2	1
Total volume dedusted	m3(S.P.T.)/h	600.000	1.000.000	500.000	470.000

Fig. 3: Constructional features of TKS blast furnace

At all the furnaces are equipped with bell-less top.
The operation of the blast furnace represents a technical process with a long history. For this reason most of the developments to date have been achieved empirically. In more recent times attempts have been made to describe mathematically the reactions taking place inside the furnace in order to make internal process reactions visible and interpretable. The reactions that influence the metallurgical results in a blast furnace cannot be directly observed, so activities have been made to develop the measuring technology.
Figure 4 shows the complete range of measurement techniques used at Schwelgern No. 1 blast furnace.

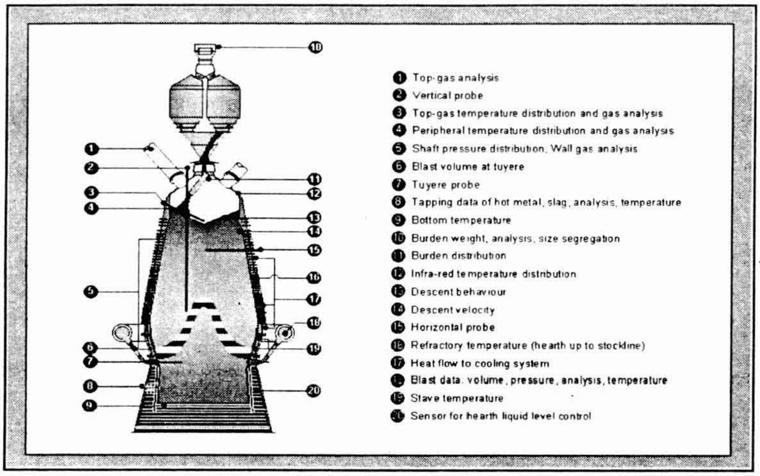

Fig. 4: Measuring technique at TKS

For the blast furnace operation, particular importance is attached to the accuracy of determination of the top gas composition, because this is the basis for any mass and heat balance.
The horizontal inburden probe installed at about 5 m below the burden surface at the wall side has proved to be an invaluable aid for the control of modern blast furnaces. Continuous measurements of the shaft gas pressure at the furnace wall over the furnace height enables conclusions to be reached in regard to the position of the root and the peak of the cohesive zone while changes in the furnace characteristic can also be detected at an early stage.
All these installations are standard equipment at all ThyssenKrupp blast furnaces.
By gathering all the measured data and material flow data the evaluation of mathematical equations and algorithms for the relationship of outside information to inside furnace behaviour is realised with statistical methods. The various models for the individual regions of the blast furnace are supported by comparing theoretical considerations with operating results (**Fig. 5**).
These models are combined in a common framework called THYBAS. The main target of THYBAS is to decrease the fuel rate, to increase the productivity and to make a correct data and process control possible.

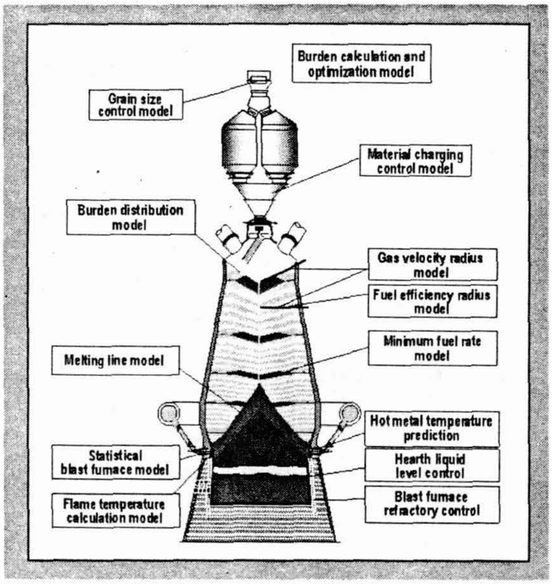

Fig. 5: Application of THYBAS models

Blast furnace operation with pulverised coal injection

When Thyssen Krupp started coal injection the first aim was to maximise the injection rate. Schwelgern No. 1 was the first furnace with a pulverized coal injection rate of more than 200 kg / t HM and a total fuel rate of 507 kg / t HM.
After the research about coal combustion the main feature was to optimise the charging program. So the idea of the centre coke feeding was realised (Fig. 6).
In 1995 the decrease in steel demand led to the shut down of Hamborn No. 4. Following that period an increasing demand for crude steel made it necessary to step up productivity of the other three furnaces. In total it proved possible to increase the hot metal production from about 25,000 t a day in 1994 to more than 30,000 t a day as the monthly average (Fig. 7). Correspondingly the average productivity of blast furnaces 1, 2 and 9 rose to values of about 2.70 t HM per m³ working volume and 24 hours, as shown in the lower part of the diagram.

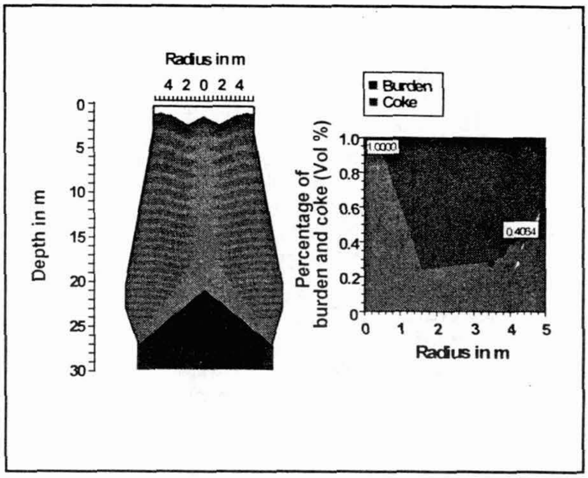

Fig. 6: Inner state of blast furnace and radial burden distribution

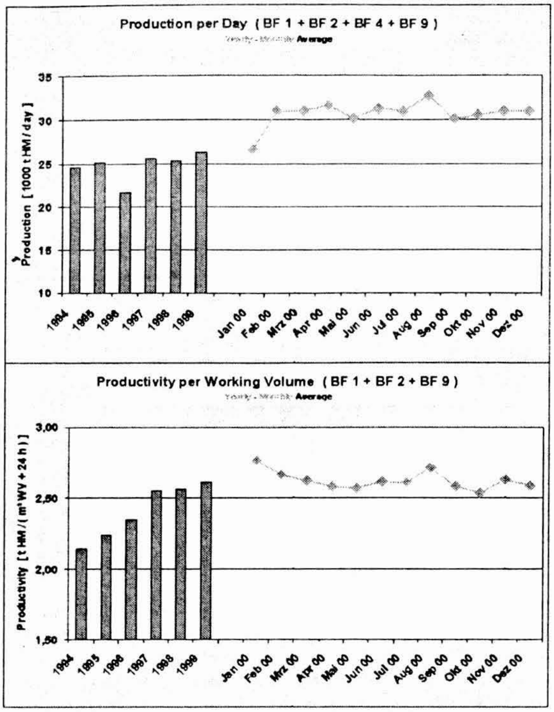

Fig. 7: Productivity (BF 1, 2 and 9)

Figure 8 gives an overview of the ore burden used. The blast furnaces are operated with a high-quality ore burden consisting of

- 900 to 1,100 kg/t HM sinter
- 300 to 400 kg/t HM pellets
- 150 to 250 kg/t HM lump ore.

In addition, about 10 to 50 kg fluxes and recirculated materials are used.

The concentration of steel production in Duisburg has been accompanied by investment measures in the Duisburg works. Accordingly a new continuous casting and rolling plant (CSP) was built and the converter capacity was increased in the Bruckhausen steel shop by changing over to 2 converter operation. Because of the higher hot metal requirement, Hamborn 4 blast furnace was blown in January 2000 after relining.
With constant sinter production, especially after re-commissioning of blast furnace 4 and thus a higher hot metal production, it was necessary to reduce the specific sinter rate to values below 1,000 kg/t HM.

The development of reducing agent consumption since 1994 in the average of blast furnaces 1, 2 and 9 is shown in **figure 9**. It was possible to reduce the use of coke to values of about 325 kg/t HM total coke. This coke rate includes a share of up to 150 kg/t HM small coke calculated at a mean value for the year 2000 of 51 kg/t HM for all furnaces.

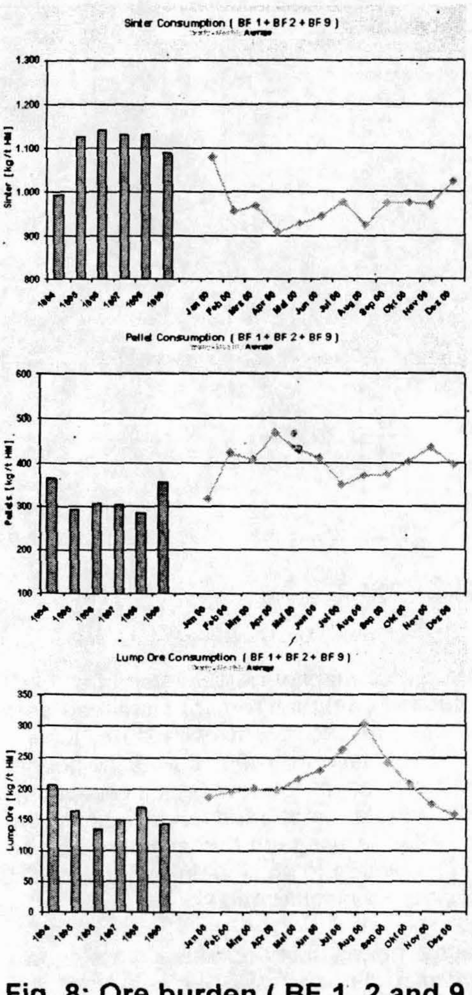

Fig. 8: Ore burden (BF 1, 2 and 9

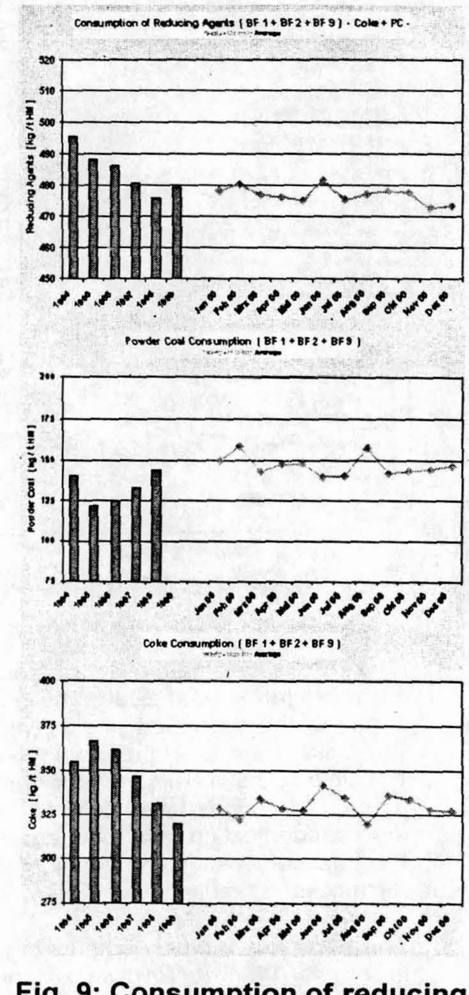

Fig. 9: Consumption of reducing agent at BF1, 2 and 9

In the same period the injection of pulverised coal was stabilised at a level of about 150 kg/t HM. Accordingly, with a
total reducing agent consumption of about 475 kg/t HM, a target is reached that is close to the thermodynamic equilibrium.
The successful results of the year 2000 show the operating data of the TKS blast furnaces in **figure 10**. Accordingly, it was possible, especially in Schwelgern 1 blast furnace, to reduce the annual mean coke rate in the annual average to 314 kg/t HM inclusive of 28 kg/t HM small coke with a pulverised coal injection rate of 164 kg/t HM and to stabilise production at a level of 2.70 t HM per m³ working volume in 24 hours.

Operating Data for 2000 of Blast Furnaces of ThyssenKrupp Stahl Duisburg					
Works		Schwelgern	Schwelgern	Hamborn	Hamborn
Blast Furnace Nb.		1	2	4	9
Hot Metal Production					
Utilization time	h	8.458,9	8.544,1	7.987,5	8.577,5
Operation time	h	8.253,3	8.376,9	7.871,4	8.415,2
Utilization	%	97,6	98,0	98,5	98,1
Hot metal production	1000 t	3.517,7	4.141,3	1.682,5	1.874,2
Average production	t / 24 h	10.229,3	11.864,9	5.130,0	5.345,3
Productivity	t / m2 * 24 h	70.4	68,0	57,7	65,4
Productivity (working volume)	t / m3 * 24 h	2.7	2,5	2,5	2,9
Burden					
Lump Ore	kg / t HM	220.4	210,7	147,1	212,6
Sinter	kg / t HM	965,5	968,7	977,8	978,6
Pellets (CaO+MgO)/SiO2 >0.5	kg / t HM	247,3	296,4	191,0	48,8
Pellets (CaO+MgO)/SiO2 < 0.5	kg / t HM	*158,3*	*107,9*	*276,3*	*320,9*
Scrap and reclaimed iron	kg / t HM	0.0	0,0	0,0	0,0
Others	kg / t HM	2,4	8,5	0,6	25,2
Additions	kg / t HM	14,4	10,1	21,9	30,4
Total	kg / t HM	1.608,2	1.602,3	1.614,7	1.616,6
Reducing agents					
Dry coke rate	kg / t HM	314,0	345,9	343,9	326,0
Small Coke Rate included	kg / t HM	27,4	41,5	69,6	116,8
Oil	kg / t HM	0.0	0,0	0.0	0,0
Others	kg / t HM	0.0	0,0	0,0	0,0
Coal (dry basis)	kg / t HM	164,2	129,0	141,7	153,1
Blast					
Total moisture of blast	g / m3 (S.P.T)	15.9	26,6	13,9	15,5
Pressure in bustle pipe (absolute)	bar	4.7	5,2	3,5	3,6
Volume	1.000 m3 (S.P.T) / h	412.8	449,5	213,3	197,7
Oxygen content of blast	%	24.9	24,8	24,1	25,7
Temperature	°C	1.177,4	1.177,1	1.123,0	1.109,9
Top gas					
Average top pressure (absolute)	bar	3,1	3,5	2,3	2,4
Temperature	°C	120,9	105,6	96,4	108,6
Eta CO	%	49,4	49,9	48,3	49,0

Fig. 10: Opertional data of TKS blast furnace

The results obtained in Schwelgern 1 blast furnace could not be achieved in all blast furnaces in the year 2000. The pulverised injection coal requirement increased as a result of the described rise in capacity in all blast furnaces and because of the re-commissioning of Hamborn 4 blast furnace. Especially in 2000, it was no longer possible to cover this increased requirement because of too low grinding capacity. The construction of an additional mill will allow adaptation of grinding capacity to the increased injection coal requirement in future. After carrying out this measure and on the basis of existing know-how, TKS will be in a position to achieve in the other blast furnaces the results already obtained in Schwelgern 1 blast furnace.

The maximum monthly outputs of all TKS blast furnaces obtained hitherto are shown in **figure 11**. The following records in particular demonstrate the quality of the improvement measures carried out in past years:

- highest productivity per hearth area — 74.99 t HM / m² and 24 h
- highest productivity per useful volume — 3.03 t HM / m³ and 24 h
- minimal coke rate — 287.40 kg / t HM

The minimisation of reducing agent consumption with a simultaneous high and stable coal injection in the presented period was mainly possible by the improvement of coke quality.

Best Results of TKS - Blast Furnaces

01.1990 to 03.2001

(Monthly Average)

			S 1		S 2	
Highest Productivity	[Hearth Area]	t HM / m^2 and 24h	74,98	Nov 99	72,43	Nov 99
	[Useful Volume]	t HM / m^3 and 24h	2,83		2,65	
Minimal Coke Rate incl. Small Coke		kg / t HM	287,40	Sep 99	318,10	Sep 99
Within PC - Rate		kg / t HM	186,10		162,40	
Total Reducing Agents		kg / t HM	473,50		490,50	
			Ha 4		**Ha 9**	
Highest Productivity	[Hearth Area]	t HM / m^2 and 24h	60,86	Sep 00	68,00	Dez 99
	[Useful Volume]	t HM / m^3 and 24h	2,67		3,03	
Minimal Coke Rate incl. Small Coke		kg / t HM	319,50	Nov 00	309,80	Feb 99
Within PC - Rate		kg / t HM	157,70		153,90	
Total Reducing Agents		kg / t HM	477,20		463,70	

Fig. 11: Best results of TKS blast furnace

Improvement of coke quality and the influence of furnace operation

The question of coke properties required for the charged coke into the blast furnace has become more and more important with increasing injection of high coal or oil rates, even though the consumption of coke decreased steadily. Nevertheless the remaining coke in the blast furnace has to fulfil its functions such as maintaining gas distribution, reaction with carbon dioxide, and finally to remain the drainage for the liquid hot metal and slag in the hearth of the blast furnace. It is subjected thereby to a higher mechanical load, as the burden proportion in the blast furnace increases with decreasing coke proportion

Also a higher coke disintegration has to be expected, especially at high alkali input through increased alkali attack as well as longer residence time of the coke at high temperatures. This must lead to a clearly more difficult gas flow in the lower shaft area and finally disturbed liquid flow in the hearth area by decreasing permeability.

The coke quality features of prime interest are the tumbler index I40 and its strength after reaction CSR.
Figure 12 shows the development of the coke CSR-value since 1994. The improvement of CSR-value results from fundamental research followed by the import of special coking coals for the own coking plant on one hand and the requirement of a better coke quality to the coke supplier.

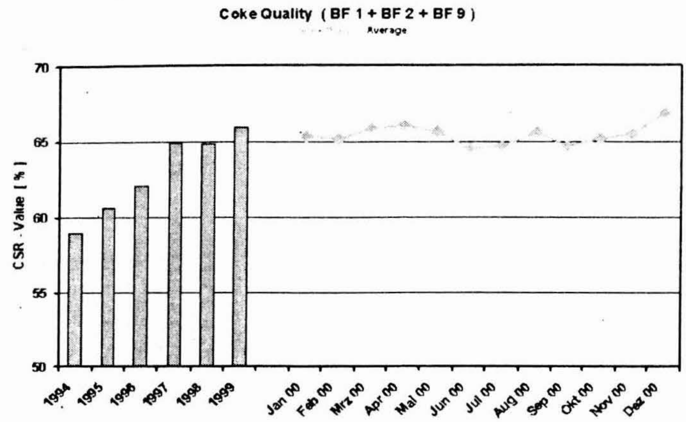

Fig. 12: Coke quality (CSR-value) at BF 1, 2 and 9

This also influenced the alkali input (**Fig. 13**). The German coals have a high alkali content, so the use of imported coking coal by German suppliers and also coal for injection leads to a decrease in alkali input of more than 1.0 kg/t HM to a level of 2.5 kg/t HM.

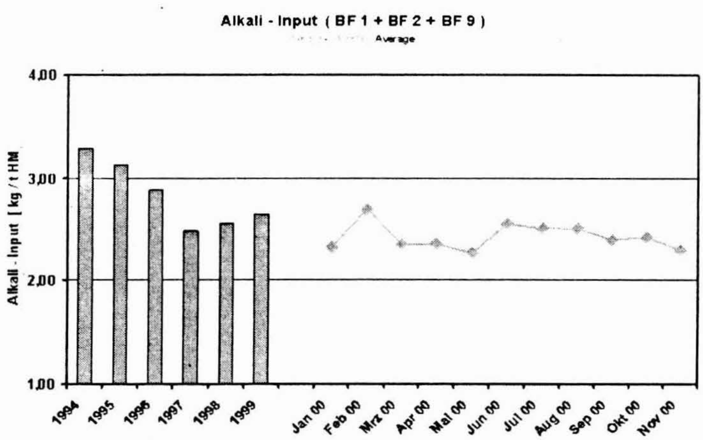

Fig. 13 Alkali input at BF 1, 2 and 9

The effects of this coke quality parameters on blast furnace operation are shown on the example of blast furnace No. 1 of Thyssen KruppStahl in Schwelgern. All points in the **figure 14** correspond to monthly average values.

The upper figure shows a sharp reduction of coke and coal consumption with increasing CSR values. A lower limit seems to be given in the moment at about 470 kg/t HM. For the same period, with rising CSR values the coal injection rate could be clearly increased followed by a considerably improved shaft gas permeability even with higher coal rates of more than 170 kg/t HM and lower coke rates of nearly 300 kg/t HM.

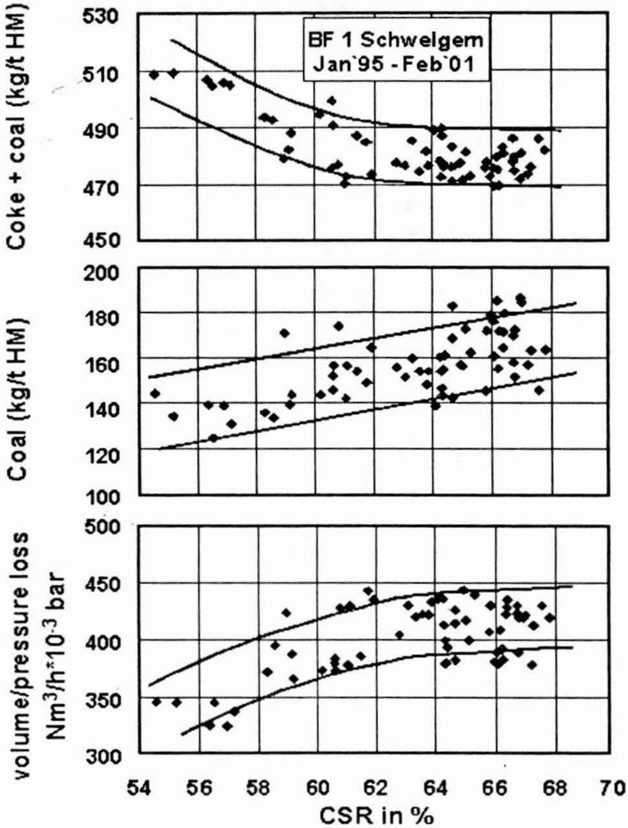

Fig. 14: Influence of CSR on reducing agents and gas permeability at BF 1

In contradistinction to blast furnaces No. 1 where no evidence of an influence of the coke strength I_{40} on reductant rate or on shaft gas permeability could be realised, in blast furnace No. 2, a blast furnace with a hearth diameter of 14.9 m, the coke and coal consumption drops both, with the hot strength CSR and with cold strength I_{40} which can be seen in figure 15. At the same time it was possible to inject much more coal up to 160 kg/t HM. An improvement of the shaft gas permeability could not be found. That follows, that the shaft gas permeability in all blast furnaces seems to be determined mainly by the hot strength of the coke and less by the cold strength.

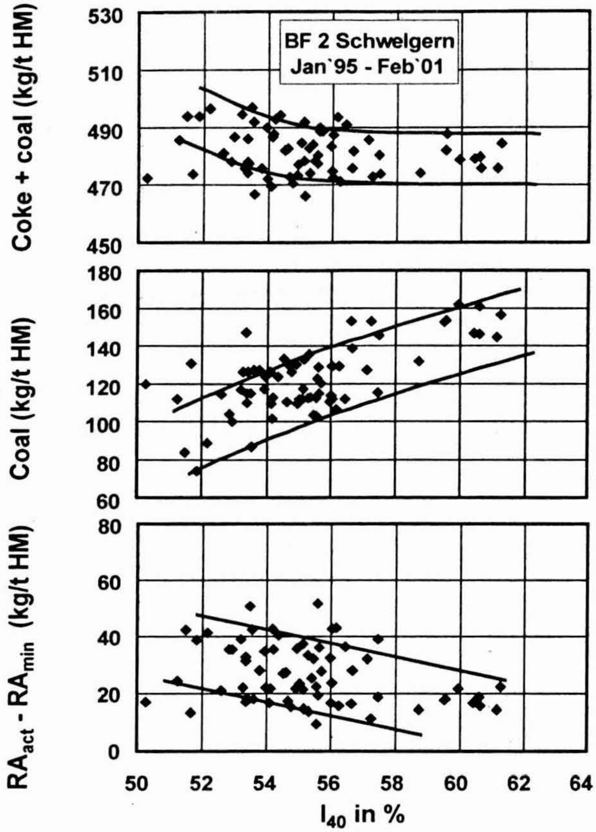

Fig. 15: Influence of I_{40} on reducing agents and gas permeability at BF 2

It has to be mentioned in this context that there was no evidence for a functional correlation between the hot strength CSR and the cold strength I_{40}. Both values are independent of each other.

To get a better understanding of the correlation between the coke properties and the blast furnace operation, numerous tests were carried out in the lower part of the furnace.

In order to check the effect of coke degradation at different coal injection rates, material has been taken by means of tuyere probes at Schwelgern No. 1, and the coke size distribution at the tuyere level across the radius was determined (**Fig. 16**).

It was established that under constant coke quality conditions in case of coal injection the proportion of <6,3 mm coke fines is higher in the transition zone and dead man than in case of all coke operation. Values of 35 % < 6,3 mm are reached already at a distance of about 150 cm.

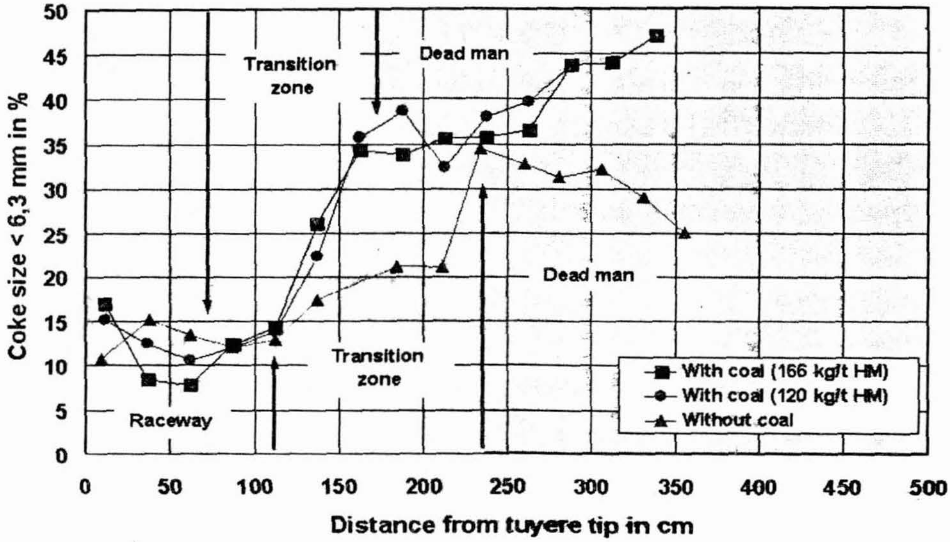

Fig. 16: Change of coke size at tuyere level with and without coal injection at BF 1

The influence of the coke quality on the raceway depth is shown in **figure 17**. The raceway in front of the tuyeres expands, as the CSR values increases. With an increase of the hot strength CSR from about 55 to above 60 %, the raceway length rose to about 1 m, that means it practically doubled. CSR values of more than 60 % lead to a further increase of the raceway length.

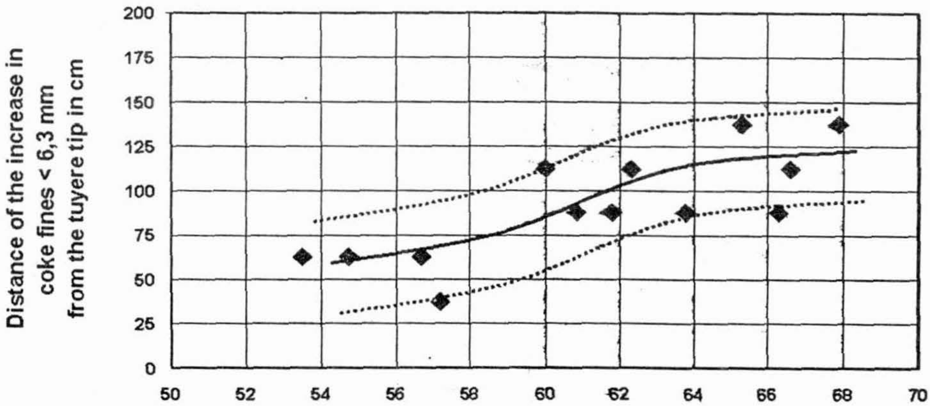

Fig. 17: Influence of CSR on raceway depth

Further on it could be realised, that raising CSR strength and equivalent of course lowering CRI values of the feed coke produces significantly lower fine coke fractions at the tuyere level, especially in the transition zone.

It is sufficiently known that the flow of hot metal and slag from the cohesive zone into the hearth of the blast furnace as well as the gas permeability conditions in the lower part of the blast furnace are, among others, determined by the coke quality in the belly, the bosh and the hearth.

All coke tests which have become known so far, are largely limited to the coke behaviour in the upper part of the blast furnace and at the tuyere level. Now the question of interest is the influence the coke quality in the liquid part of the furnace.

For this purpose, monthly average values of the hot metal temperature and the carbon content in the hot metal were correlated against the hot strength as indication for the processes taking place in the liquid area (**Fig. 18**). As can be seen on the example of Schwelgern No. 1, a good correlation with the hot strength CSR is given. In all the cases, the carbon content in the hot metal follows the carbon saturation curve at the same distance.

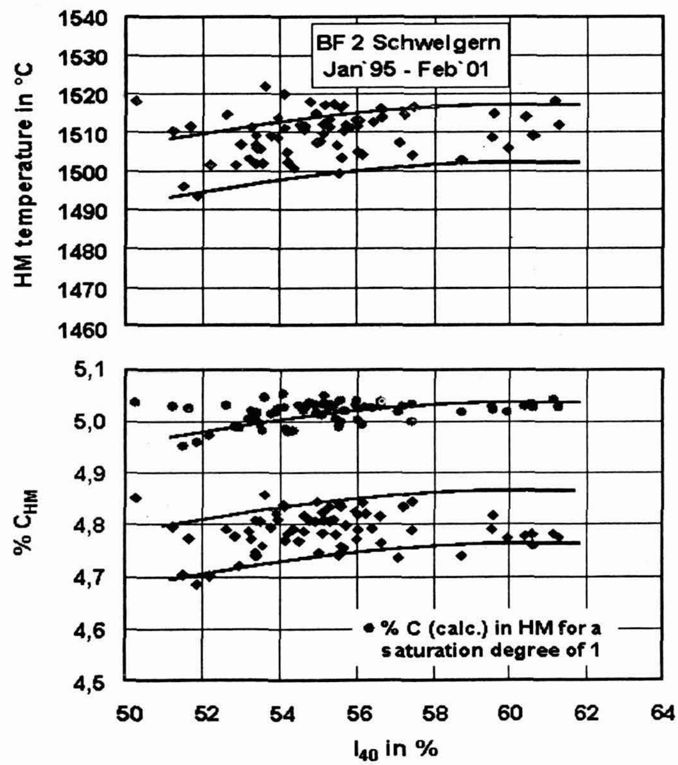

Fig. 18: Influence of CSR on hot metal temperature and carbon content

The increase in the hot metal temperature and the carbon content in the hot metal evidences that the blast furnace operation becomes more steady, which is reflected in a decreased reducing agent consumption and an increased production rate.

To obtaining further information particularly on the exchange behaviour of the coke in the "dead man" zone, before shut down of Schwelgern No. 1 in July 1996 different coke grades, traced with and without ZrO_2 and Cr_2O_3, were produced, charged and finally sampled by means of tuyere probes during operation and after shut down in the hearth of the furnace by selected sampling.

This kind of sampling permitted a continuous monitoring of the coke with additions from the tuyere level down to the hearth bottom and to make a time-dependency diagram which gives rather clear information on the downward movement of the coke in the hearth of the furnace (**Fig. 19**).

- About 4 days after charging, the coke has not or only partially reached the tuyere level
- 5 days after charging, the coke has reached the tuyere level
- 6 days after charging, the coke is about 3 ½ m below the tuyere level
- 8 ½ days after charging, the charged coke has completely passed the tuyere level and is only to be found in the hearth zone ≤ 5 m.
- 11 ½ days after charging, the coke has reached the lower part of the hearth.

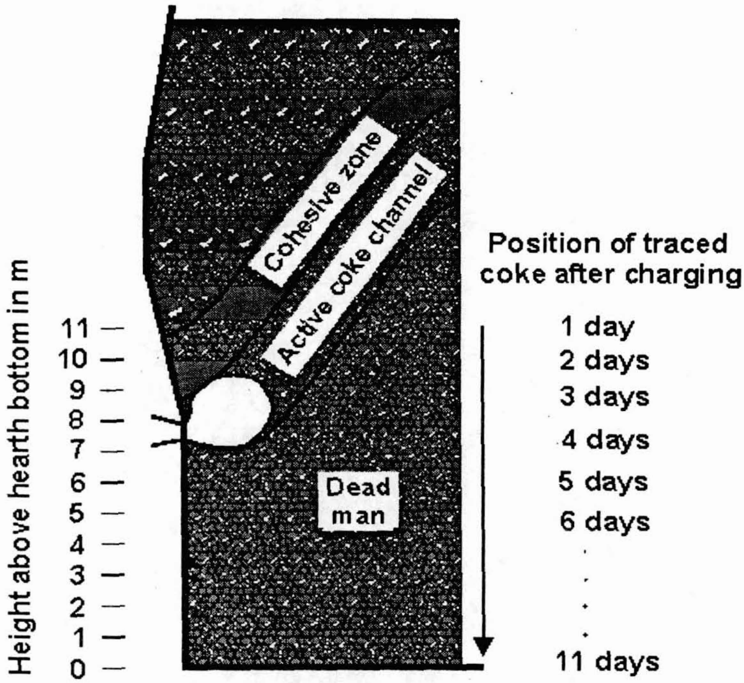

Fig. 19: Exange of coke in the hearth of the blast furnace

It can be concluded from the described movements taking place at the tuyere level and the lower hearth area, that the coke in the "dead man" moves downward by about 1 m per day. However, the downward movement in the lower hearth area is not always time-proportional and in layers. Traced coke was also found in levels which

the coke should have actually been passed. Thus a somewhat longer residence time is to be expected in particular in the lower hearth part and here especially in the furnace centre. During this investigations the coke quality showed CSR values of about 58 % and I_{40} values of about 55 %.
The investigations have shown that the processes in a blast furnace are for a major part determined by the conditions in the lower part of the furnace. In this context, especially the coke and its quality are – besides a good combustion of the injected coal dust – of major importance. In particular the coke reactivity and the corresponding coke strength after reaction CSR influence the processes taking place in the lower part of the blast furnace and thus the blast furnace behaviour in general. More lumpy coke and less coke fines in the hearth of the blast furnace has a positive effect on the gas permeability and leads to a smaller amount of reducing agents. Beside that, the coke consumption can be reduced and the coal dust injection rate be increased. At the same time, the hot metal temperature and the carbon content in the hot metal rise. Moreover, it is possible to attain a higher furnace productivity. For this reason ThyssenKrupp Stahl attaches special attention to the coke quality, the more as good coking coals in the near future are less available from resources in the Federal Republic of Germany, and ThyssenKrupp Stahl has to import coking coals abroad for its own coke production.

Future aspects

The main topic of TKS is to stabilise the total consumption of reducing agents on a level of 470 kg/t HM within pulverised coal rates of 180 kg/t HM.

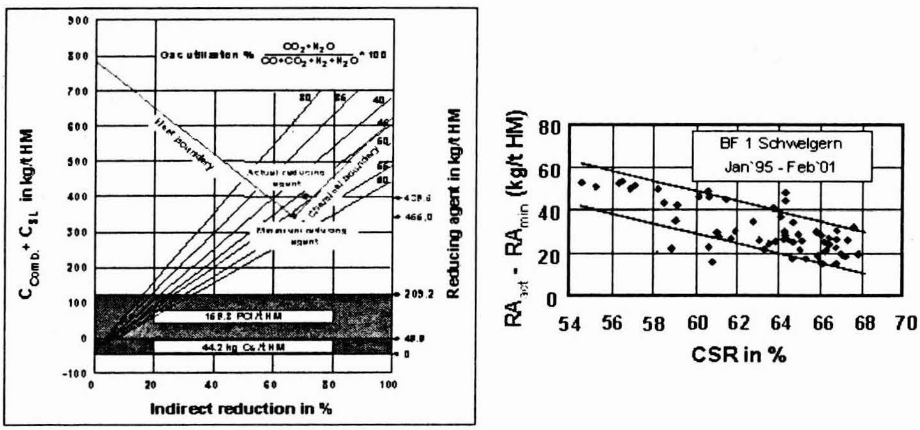

Fig. 20: Influence of CSR on reducing agents (RA) and distance from metallurgical minimum RA

The difference between the actual reducing agent consumption and the metallurgical minimum is still 15 to 20 kg/t HM, so the aim will be to minimise this difference and to maximise the injection rate (**Fig. 20**).
This will be done by optimising the furnace operation with the support of THYBAS and further fundamental research of coke and burden quality.

Schwelgern No. 2 is now on the same way, but coke strength is much more important for this large furnace (**Fig. 21**).

But for the future it is to expect that all the TKS blast furnaces will reach this aim.

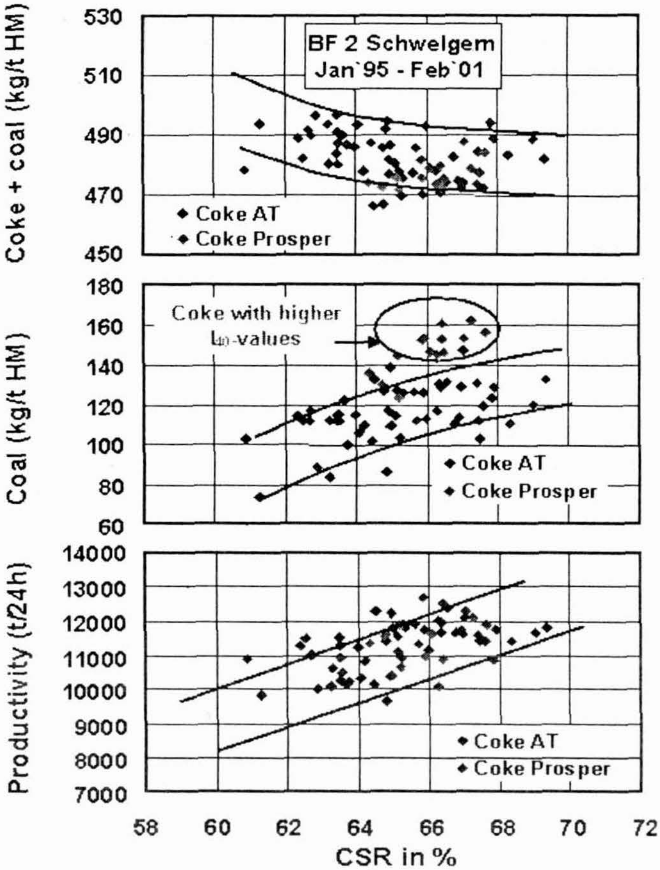

Fig. 21: Influence of CSR on reducing agents and HM productivity

Over recent years operating characteristics have reached a level that is both high in terms of international comparisons and, especially, constant. In this respect an essential criterion for the operating mode of the blast furnaces is not only to achieve an increase in the coal injection rate, but, from the viewpoint of an aggregate consideration of costs, to aim for optimum operating conditions and an overall low consumption of reducing agents. Several procedural improvements have been implemented since the commissioning of coal grinding and injection facilities in the mid-1980th.

Current measures will further improve operating results and extend the know-how available at TKS.

The combination of operational know-how, intensive process monitoring and control using the THYBAS system and the possibility of carrying out reproducible process simulation calculations for operating and strategic decisions form a first-class basis for minimised cost of hot metal production.