REACTIONS OF COKE WITH LIQUID PHASES IN THE LOWER PART OF THE BLAST FURNACE

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The behaviour of coke on the tuyere level of the blast furnace is still not known in depth at present. Different reactions of coke in the blast furnace affect its dissolution ability in hot metal. Experiments at laboratory scale have been performed to distinguish between the different influences. The different reactions of coke with hot metal are discussed as well as its reactions with slags. An emphasis of the work is the influence of alkalis on those reactions.

Key-words: Coke dissolution, hot metal, slag, alkalis

Work performed at the Institute of Ferrous Metallurgy (IEHK) – Aachen University of Technology (RWTH Aachen), Germany from 1997 to 2000

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1 Introduction

During the last decades blast furnace technology has strongly improved. One goal of the research was the reduction of coke rates to decrease costs arising from the expensive coking process. The amount of coke needed to produce one ton of hot metal decreased from 1,200 kg to less than 350 kg in some works /1/. One reason for this, is the substitution of coke by injected pulverised coal.

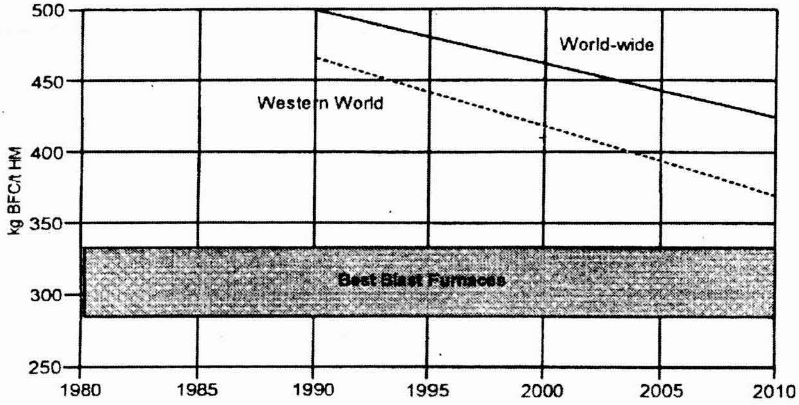


Figure 1: Specific coke rate development /1/.

The trend towards low coke rates caused a change in coke quality requirements, because a smaller amount of coke has to fulfil the newly distributed tasks of the reductants.

1. Heat resource for process heat generation,
2. producer and regenerator of reducing gas,
3. supporting structure to ensure permeability,
4. carburising agent and
5. dust filter /2/.

The first two functions can be partly overtaken by the injected auxiliary fuels. Therefore coke should react less with carbonmonoxide in the shaft, so a low Coke Reactivity Index (CRI) is required. Only coke can work as dust filter and grant for a high permeability for upward gas flow and an easy downward flow of the liquid phases like slag and metal. It needs a sufficient post-reactive strength below the cohesive zone expressed by a high Coke Strength after Reaction (CSR) /3, 4, 5/.

A number of tests have been developed to characterise the coke quality and the concerning conditions to which it is subjected in the blast furnace. The coking plant has to grant for the fulfilment of these qualities. Generally in Germany agreed values are shown in Table 1.

Table 1: Quality requirements for blast furnace coke /according to 6/.

I. Chemical analysis		
Ash	%	<9,0
Sulphur	%	<0,7
Alkalis	%	<0,05
II. Physical characteristics		
Drum strength		
I_{10} (<10 mm)	%	<15
I_{40} (>40 mm)	%	>55
Screening size		
<40 mm	%	<18
<3 mm	%	<3
III. Metallurgical characteristics		
Coke strength after reaction (CSR)	%	>65
Coke reactivity index (CRI)	%	<23 >18

Oil and fine pulverised coal can not be carburised in the hot metal. If coke does not solute fast enough, the carbonaceous refractories in the hearth will be affected. Concerning a prolonged furnace life, wearing in the hearth is the most serious problem /7, 8/. The dissolution and carburisation behaviour of raw cokes produced from different coal blends and coke probes from the tuyere level have been examined and compared /3, 4, 9/ at the Institute of Ferrous Metallurgy.

All German raw cokes in Figure 2 show a similar behaviour, in contrast to the coke from the coking plant in Shijang, China. This coke can not be used exclusively in blast furnace, because of the incomplete carburisation of the hot metal. Industrial experience shows that this Chinese coke can only be used in a mixture with other cokes with high reactivity towards hot metal. A tendency can be observed, that coke from coking plants with a large chamber width (Single Chamber System SCS, Kaiserstuhl) have a better carburisation behaviour than coke produced in smaller conventional chambers.

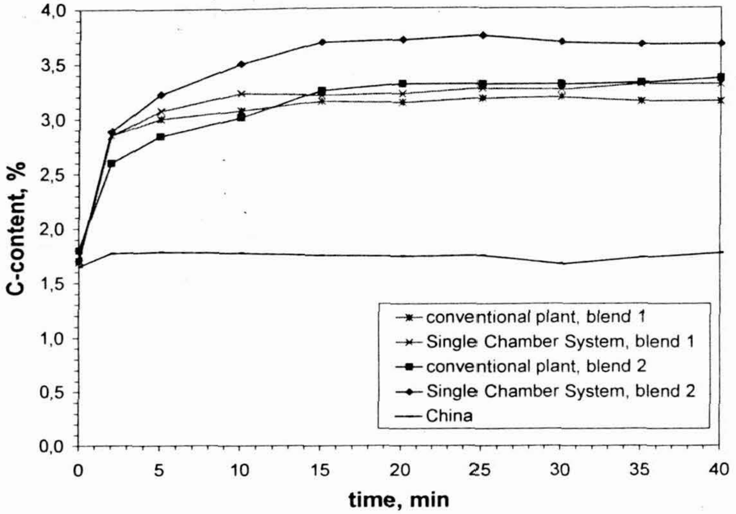


Figure 2: Carburisation and dissolution behaviour of different raw cokes (according to /3/).

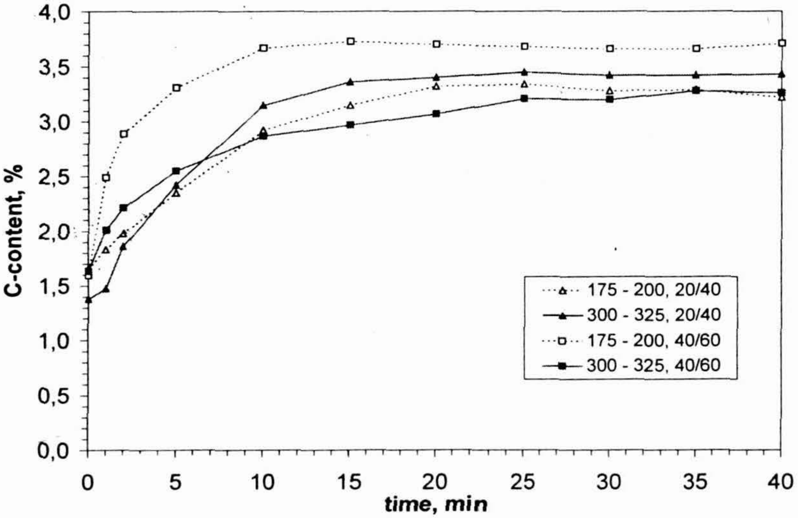
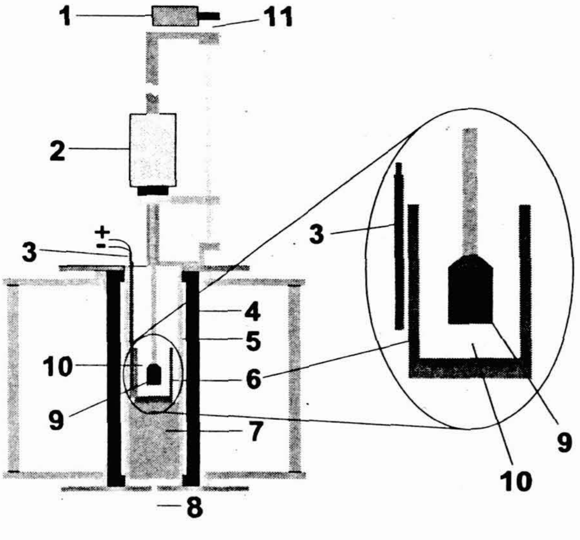


Figure 3: Carburisation behaviour of coke from the tuyere level taken at different distances from the furnace wall (according to /3/, distance to tuyere tip, screening size).

The dissolution velocity depends on surface in contact with hot metal. Figure 3 shows the results of experiments with coke samples from tuyere level. Coke from the deadman (300 – 325 mm distance to tuyere tip) is dissoluted faster if smaller particles are used (20/40 mm screening size vs. 40/60 mm screening size). Contrary to that larger particles from the raceway (175 – 200 mm distance to tuyere tip) dissolute faster than smaller ones. The reason can be found in surface structure of those particles. The surface of small particles from the raceway does not show clear pores if examined via microscope. Even inner parts are highly destroyed whereas coke from the deadman appears like coke before charging /3, 4/.

2 Experiments

At the Institute of Ferrous Metallurgy an experimental apparatus exists to investigate the carburisation of coke in a hot metal bath (Figure 4). The vertical electrical furnace can reach up to 1600°C with a defined gas atmosphere in the reactor. The coke specimen is fixed to a specimen holder. At 1500°C the specimen is stirred in the hot metal bath for 40 min. Metal probes are taken at certain intervals and analysed for their C-content. The C-content of the bath as a function of time is a possibility to describe the dissolution of coke in the bath.



1	**spindle drive assembly**
2	**specimen driving motor**
3	**thermo couple**
4	**graphite tube**
5	**corundum tube**
6	**corundum crucible**
7	**crucible holder**
8	**inert gas supply**
9	**coke specimen**
10	**hot metal bath**
11	**thread spindle**

Figure 4: Schematic view of the experimental apparatus.

Cokes produced from different coal blends and in different coking plants are used. From the large lumps of coke containing petroleum coke, cylindrical specimen with a diameter of 37 mm and a height of 40 mm are prepared. The other cokes are used in their natural size, because the lumps are to small. All specimen have a mass of about 40 g. The amount of metal is adjusted to the weight of the coke specimen to grant for the same relative amount of carbon in every experiment.

In the blast furnace coke has to stand different stresses before it comes into contact with liquid iron. To determine the influence of the reactions with the gaseous phases, coke has been gasified under similar conditions like the test for CRI. Cylindrical specimen have been partly gasified by carbon-dioxide at 1100°C for 120 min. To distinguish between the influence of alkalis in the tuyere samples and other influences on dissolution, raw coke has been impregnated with K_2CO_3-lye under vacuum.

3 Results

Different percentages of petroleum coke (PC) have been added to the coal blend of a coking plant. Petroleum coke is a derivative from mineral oil refineries. Low additions of petroleum coke caused nearly no change in the carburisation behaviour of coke (Figure 5). With PC-contents at about 15%, the final C-content of the hot metal bath is the lowest, whereas coke with 25% petroleum coke reaches a higher final C-content than the conventional coal blend. The dissolution velocity does not change.

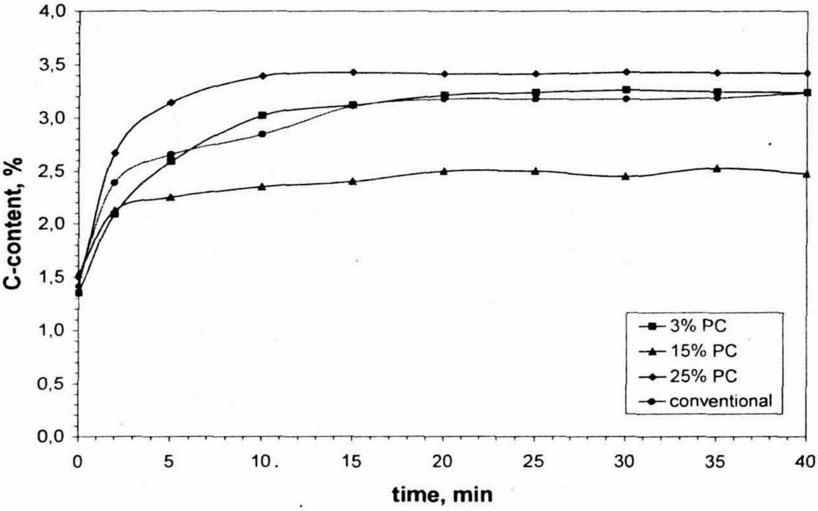


Figure 5: Coke produced from coal blends with different contents of petroleum coke.

Figure 6 shows that differences in the carburisation behaviour of cokes with different PC-contents are diminished by gaseous reaction.

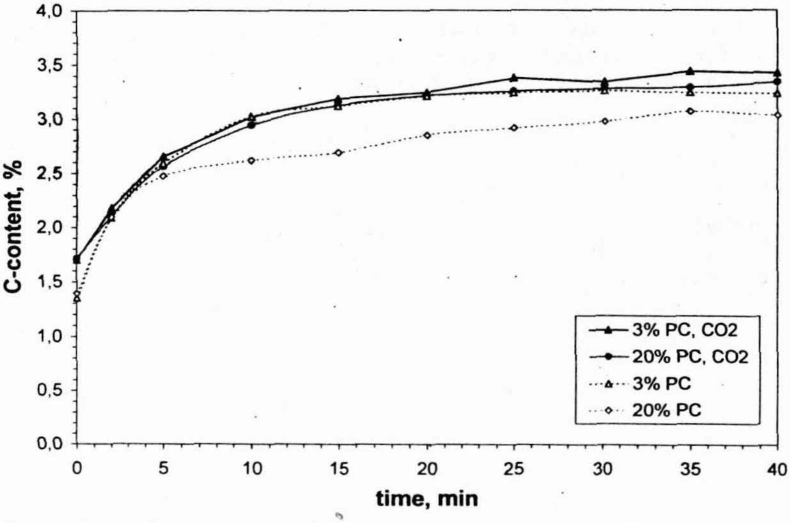


Figure 6: Comparison of dissolution of cokes of different PC-content after partly combustion.

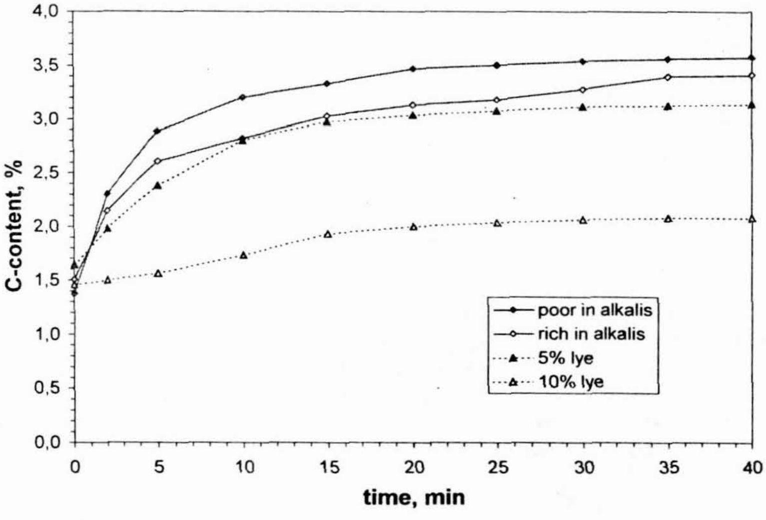


Figure 7: Coke samples from the tuyere level with different alkali contents and coke impregnated with K_2CO_3-lye.

Coke sampled from the tuyere level is used in the dissolution experiments. Both blast furnace cokes in Figure 7 (low alkali-content and high alkali-content) have been sampled at the same tuyere. The coke which is rich in alkalis carburises the metal slower and leads to a lower final C-content. An impregnation with 10%-K_2CO_3-lye caused the worst diminution of dissolution.

Coke has been subjected to slags containing alkali in the experimental furnace. Those slags have been mixed based on granulated blast furnace slag with defined additions of K_2CO_3. Basicity has been adjusted by adding SiO_2. The alkali content of cokes at the end of the experiment was higher if it was subjected to slags with higher *initial contents of alkalis.*

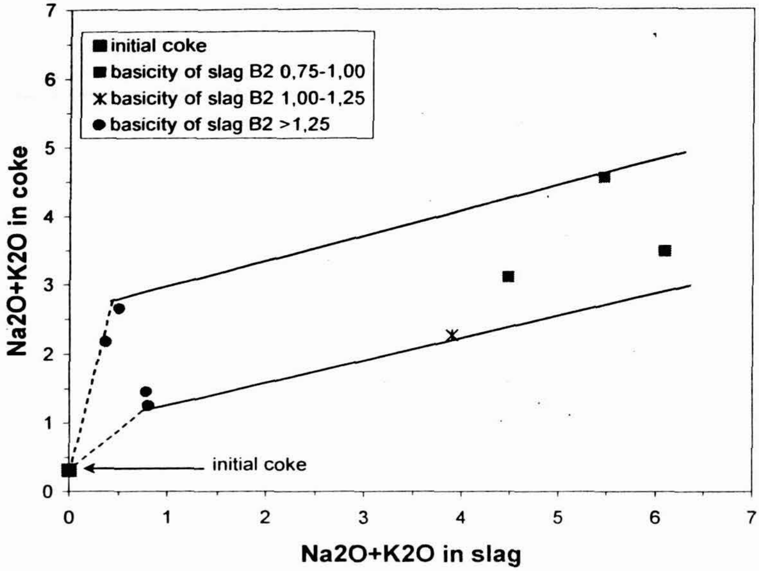


Figure 8: Alkali-content of coke at the end of the experiment depending on the initial content of slag.

4 Conclusion

A diminution of prize for coke is a possibility to decrease costs in hot metal production /5/. This can be reached by the use of cheaper raw materials in the coal blend. Petroleum coke is used in German coking plants as a measure to minimise swelling. Anyway coke quality must be sufficient for the blast-furnace process. The addition of petroleum coke changes the dissolution and carburisation behaviour of coke depending on the amount added. High percentages increase the final C-content of the metal.

After the reaction of cokes with carbon-dioxide the carburisation behaviour of different cokes is adapted. Observations of the partly gasified specimen via raster electron microscopy show a coarse area near the surface. In this area are more fissures than in the inner parts of the specimen and ash particles can be detected. Dissolution of coke in the experiments depends on the surface coke/bath. Small particles are broken from a coarse and weak surface by abrasion in the bath. In the blast furnace the phenomenon will be even more severe. The small particles in the metal bath lead to a better dissolution and therefore a more similar behaviour of the cokes due to large relative surfaces.

Another aspect of the research conducted was the influence of time of residence in the blast furnace on coke. It was observed, that coke with high alkali loads dissolutes slower and leads to lower final C-contents. This behaviour can be fortified by experiments with impregnated coke. The reason for the behaviour is seen in a layer of $NaAl_{11}O_{17}$, $KAl_{11}O_{17}$, $AlSiO_4$ and pure Al_2O_3 surrounding the specimen after the experiment, which has been observed in experiments with impregnated coke. The layer is solid at temperatures reached in most areas of the blast furnace and isolates the surface of the coke from the melt. The layer is weak after taking the specimen out of the experimental furnace. It could be partly destroyed in the blast furnace which would diminish the effect.

The reactions between slags containing alkali and coke have been examined. Higher initial alkali contents of slag led to higher final contents of the coke. The difference in the calculated alkali amount picked up by coke is higher than the loss of the slag. So a part of the alkalis seems to be taken up by the gaseous atmosphere. A phase analysis of the coke after the reaction detected $KAlSiO_2$, which has been found in probes from a nitrogen quenched blast furnace, too /10/.

Analyses of different areas of coke in a radial direction of the specimen showed a similar alkali content depending on the local position. No slag particles have been found via stereomicroscopy. Therefore reaction between alkalis and coke has to be a solid/gaseous reaction. The gaseous alkalis penetrate the coke lump through open pores and fissures and react at the inner surfaces /11/.

Acknowledgement

The authors are grateful to the "European Coal Steel Community" (ECSC), Thyssen Krupp Stahl AG (TKS) and Hüttenwerke Krupp Mannesmann GmbH (HKM) for their financial aid of this work. We would like to thank Dr. Beppler and Dr. Janhsen from TKS for their practical and internal support. Also we want to express our thanks to Dr. Eisen from HKM for his kindly help and the discussions about the results.

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