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CAMPAIGN LIVE EXTENSION AT ROGESA BLAST FURNACES BY COINJECTION OF PCI AND TITANIUM DIOXIDE[1]

Walter Hartig[2]
Djamschid Amirzadeh-Asl[3]
Dieter Fünders[4]

Abstract

The blast furnace no. 4 Rogesa Dillinger Hütte, located in Dillingen's plant, Germany, began its 4th campaign in 2003 and was restarted after enlargement of volume and hearth diameter. Until the end of 2011, the campaign's cumulative production has reached 17 million tons of hot metal. In order to protect the hearth wear and to prolong the campaign life a mixture of pulverized coal and synthetic titanium dioxide (Rutilit NF) is injected in blast furnace simultaneously. This new technique is applied since May 2008 by using the PCI grinding and injection equipment. The fine particle synthetic source of titanium dioxide is premixed with raw coal up to 0.9 kg TiO_2/t HM. The mixture is ground und dried, which can be coinjected together into in the blast furnace via the tuyeres. The coinjection of pulverized Rutilit NF and coal with a flow-rate of 190 kg/t HM does not show any negative influence onto the reductants consumption of the hot metal production. The wear of the hearth is controlled by this technique. This paper is a common report from AG der Dillinger Hüttenwerke (Rogesa) and Sachtleben Chemie GmbH, Duisburg and will show the long term evaluation of blast furnace hearth temperature in order to protect the hearth from premature erosion.

Key words: Blast furnace; Titanium dioxide; Hearth protection; Repair; Rutilit.

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2 *General Manager Ironmaking, Rogesa Sachtleben Chemie , walter.hartig@dillinger.biz.*

3 *Metallurgical engineer, R&D of Sachtleben Chemie, Duisburg, Germany; d.amirzadeh-asl@sachtleben.de.*

4 *Metallurgical engineer, Gesellschaft für Synthetische Rohstoffe, Moers, Germany; synthetische.rohstoffe@web.de.*

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1 ROGESA – IRONMAKING FACILITIES

The company Roheisengesellschaft Saar (Rogesa), with a yearly production capacity of 4.6 million t of hot metal (HM), is a joint venture of the AG der Dillinger Huettenwerke, the major European heavy plate producer, and Saarstahl AG, one of the most important manufacturers of long products in the world. It is located at the site of Dillingen in the south west of Germany.
In the following table the characteristic data of the two operating furnaces are shown.

Table 1: BF no.4 and no. 5 most significant parameters

	BF no. 4	**BF no. 5**
Year of construction	1974/2003	1985/1997
Restart after relining	Oct.2003	Oct. 2010
Reason of revamping	BF relining and enlarging	BF relining and new hearth
Daily production	6200 t (metric)	7200 t
Number of tap holes	2	2
Working volume	2356 m³	2893 m³
Hearth diameter	11,2 m	12 m
Number of tuyeres	30	32

Blast furnace no. 4 was restarted after enlargement from 10 to 11.2 m of hearth diameter in October 2003. The bf no. 5 was relined and simultaneously enlarged from 11 m to 12 m of hearth diameter in May 1997.The last relining was carried out in 2010 with the construction of a new hearth.
Both furnaces are high performance furnaces equipped with the latest technology. PCI injection is made on both furnaces via coaxial oxygen lances at a maximum level of 230 kg / t HM.

2 PRESENTATION OF BLAST FURNACE NO. 4 AND HEARTH MONITORING

Blast Furnace no. 4 was restarted in 2003, after a relining with enlargement of its hearth diameter from 10 m to 11.2 m and an enlargement of the working volume from 1790 to 2356 m^3. The charging system of bf no. 4 is equipped with a bell-less top (Paul Wurth System). The hearth of the furnace is cooled by means of external channel cooling system. The tuyère level up to the mid shaft zone is cooled by copper staves. The upper shaft until the throat armour is cooled by cast iron staves.
Blast furnace no. 4 operates on a high productivity level with a burden composition of about 69.2% sinter, 17.1% pellets and 13.7% lump ore. The nominal coke rate varies between 300 – 370 kg/t HM. The reducing agents used are coke and pulverized coal, injected via thirty coaxial lances with oxygen. The injection quantity of PCI is up to 200 kg/t HM. This furnace disposes of two tap - holes at an angle of 90°. The normal daily capacity of HM is 6200 t with a slag volume of about 260 kg/t HM.
The following table 2 shows a summary of data from the campaigns until today.

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Table 2: Summary of campaigns of blast furnace no. 4 until today

Blast furnace no. 4		**First campaign**	**Second campaign**	**Third campaign**	**Forth campaign**
Start campaign		15.10.1974	26.05.1986	28.07.1995	25.09.2003
End of campaign		22.12.1985	29.04.1995	27.06.2003	still in service
Interim repair					28.04.2009
Life time	Years	11.2	8.9	7.9	8.4
Hot metal production	Mio. T	12.0	11.6	11.9	16.5
Specific production	t/m³ w.v.	6.704	6.480	6.648	6.833
Hearth diameter	m	10	10	10	11.2
Hearth area	m²	78.53	78.53	78.53	98.52
Working height	m	23.64	23.64	23.64	23.64
Working volume	m³	1.790	1.790	1.790	2.356
Inner volume	m³	2.065	2.065	2.065	2.705
Number of tuyeres	m³	28	28	28	30
Daily production	t/24h	3030	3779	4247	5.335
Productivity of hearth area	t/m² 24h	38.6	48.1	54.1	54.1
Productivity of working volume	t/m² 24h	1.69	2.11	2.37	2.26
Burden sinter:	kg/tHM	1.498	1.265	1.227	1.082
Pellets	kg/tHM	18.4	215	178	268
lump ore	kg/tHM	102	130	184	214
Consumption of reductants	kg/tHM	460	476	480	475
Coke	kg/tHM	460	378	366	354
Inclusive small coke	kg/tHM	0	0	29	30
Coal injection (PCI)	kg/tHM	0	102	114	170

3 CONTROL OF HEARTH TEMPERATURE USING TITANIUM BEARING PRODUCTS

This purpose of the addition of titanium bearing products is based on the generation of high-temperature- and high-wear-resistant Ti(C,N) compounds, which exhibit temperature-dependent solubility in the hot metal. When the solubility limit is reached due to temperature decrease, which is the case at areas of damage in the hearth as a result of higher heat flux and loss of heat to the outside, the respective Ti(C,N) compounds are precipitated out of the hot metal and deposited in the more severely damaged zones of the masonry, with an intrinsic "hot-repair effect".[(1-4)]

Rogesa Dillinger Huettenwerke does not use natural TiO_2 sources like lump ilmenite in the burden in order to reduce hearth wear, since the feeding of lump ilmenite inevitably results in rising TiO_2 contents in the slag. This, for its part, produces problems in marketing of the blast furnace sand. The injection of synthetic fine-particulate TiO_2 sources (Rutilit products) via the tuyeres directly in the wall of the hearth zone is a more effective method of importing TiO_2 into the BF.[(3-5)]

The industrial use of the synthetic source of titanium dioxide (Rutilit products) indicates a significant reduction in temperature upon systematic injection in to critical BF hearth zones. Precision injection of Rutilit permits rapid repair of the damaged point if a "hot spot" occurs.[(6-9)]

Specific consumption of synthetic titanium dioxide containing products for elimination of hearth damage is significantly lower than when natural ilmenite ore is used.

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In addition, due to the lower specific input and lower migration into the slag compared to ilmenite, the use of RUTILIT also achieves the desirable low titanium dioxide levels in the slag.(10,11)
By this technique of Rutilit coinjection is combined with more advantages. First of all, the TiO_2 load can be evenly distributed throughout the hearth diameter because of simultaneous injection through all 30 tuyeres. Next, the TiO_2 load is brought directly into the reactive zone of hearth wall, in avoidance of the way through the shaft. Furthermore, there is a higher mass transfer of Ti into the hot metal, thus also the kinetically conditions are improved.
The analysis of the injected material is shown in table 3. Rutilit F 50 and Rutilit NF are synthetic produced material, which contain mainly titanium dioxide. The main grain size of the Rutilit products is in a range between 5 and 70 µm with an average particle size of 20 to 30 µm The various Rutilit products are suitable for a range of different uses, varying from preventive application (Rutilit NF) up to including high-speed reactions to "hot spots" (Rutilit F50).(7-10)

Table 3: Chemical analysis of RUTILIT NF and RUTILIT F 50

	TiO_2	**Fe_2O_3**	**SiO_2**	**Al_2O_3**	**CaO , MgO**	**Moisture content**	**Input**
	%	%	%	%	%	%	
RUTILIT NF	50-60	max. 10	max. 25	max. 5	max. 8	22 - 28	Coinjection with PCI
RUTILIT F50	45-55	max. 40	max. 20	max. 6	max. 6	< 2	Separate injection system

The use of Rutilit products for the reduction of wear in the blast-furnace hearth has been jointly tested and optimized by Rogesa Dillinger Huettenwerke and Sachtleben during the past 7 years. The results discussed here also suggest the use of Rutilit for long-term preventive measurements, a subject which is also being studied in currently ongoing projects.

4 COAL - INJECTION (PCI) INSTALLATIONS AND PREPARATION OF MIXTURE WITH RUTILIT NF

The PCI plant at Rogesa Dillinger Huettenwerke offers the opportunity to blend TiO_2 containing materials into the raw coal, so that a mixture with a defined TiO_2 content can be injected into both blast furnaces.
The plant for preparation of the pulverized coal consists of two bedding yards of raw coal with a capacity of 20.000 t each. The addition of Rutilit NF is made from a truck unloading bin on the belt conveyor during the raw coal train unloading. On the bedding yard a homogenization takes place. This results in a constant concentration of RUTILIT NF in the fed raw coal. After the transportation of the mixture to the raw coal bin, a simultaneous grinding, drying and further mixing of the two components occurs in a vertical Loesche mill (Figure 1). The ground mixture is separated in a bag house filter and fed into storage bins by sending vessels. The injection into the blast furnaces takes place by single line controlled quantity for each tuyère with a Paul Wurth injection plant:

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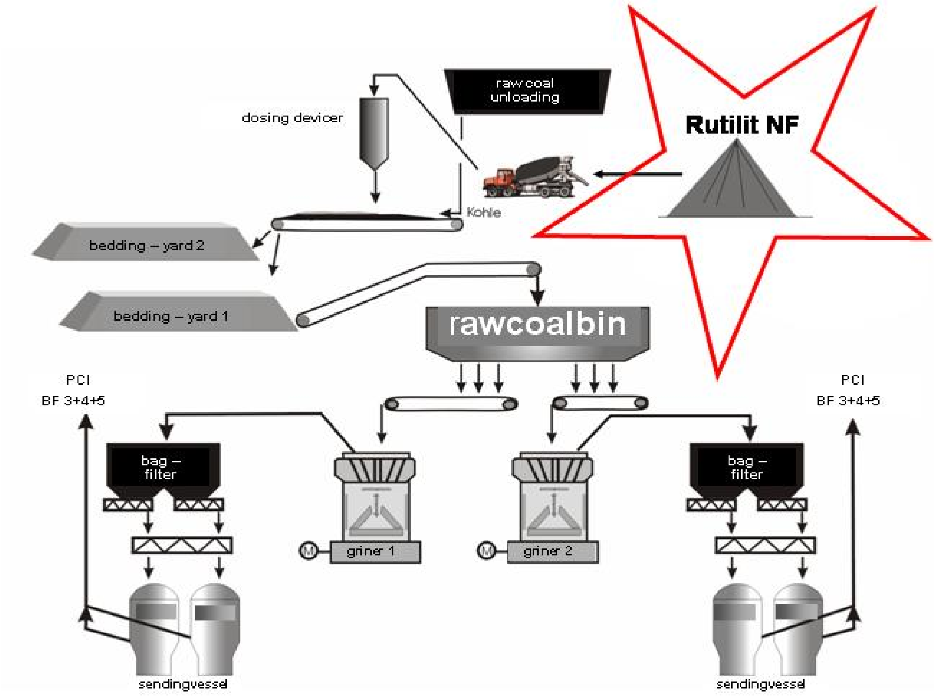

Figure 1: Addition of RUTILIT NF to raw coal.

5 COINJECTION CONDITIONS OF RUTILIT NF AND PCI

5.1 Description of Trial Phases

As a new approach to wear reduction of the hearth, three field tests were carried out to evaluate the suitability of the coinjection of TiO_2 materials and PCI coal. Table 4 shows the time interval of the pilot test phase.

Table 4: Time interval of coinjection Rutilit NF with PCI

Pilot test	Time interval	Coinjection time	Addition Rutilit NF referred to raw coal %	Coinjection rate PCI/ t HM Kg / t HM	TiO2 addition rate Kg / t HM
Phase 1	3th to March. 14th 2007	10 days	0.5	170	0.3
Phase 2	July 15th to Oct. 14th 2007	80 days	0.8 – 1.35	170	0.5 – 0.8
Phase 3	July 20th 2008 to ongoing 2012	4 years	0.8 - 1.5	170	0.5 – 0.9

5.2 Pilot Test Phase 1

This field test was carried out during March 2007 with a total batch of 100 t of Rutilit NF and a duration of ten days. Aim of this test was to evaluate the conveyability of the mixture from truck unloading and blending to the raw coal BF as well as the grindability in the vertical mills. The total amount of 10000 tons of PCI containing TiO2 was injected. The daily production of hot metal was 6200 tons.

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5.3 Pilot Test Phase 2

The second field test was started middle of July 2007 with a duration of 80 days. The mixing ratio was varied in the range of 0.8 to 1.35% referred to raw coal. Aim was to observe the homogeneity of TiO_2 in the PCI coal blend, the impact on the hearth wall temperatures and the long term behaviour of both, PCI plant and BF. Additionally, the Ti-distribution between hot metal and slag and thus the mass transfer between both phases was estimated.

5.4 Pilot Test Phase 3

It was decided to stop the coinjection of Rutilit NF beginning of October 2007 to assess the results and to observe the BF hearth wall and bosh temperature. After a time of constancy the hearth wall and bosh temperature started to rise again beginning of March 2008. In May 2008 Rogesa decided for prevention protection of hearth wall and bosh to start the coinjection with Rutilit NF for a long-term period. Depending on the hearth wall temperature the addition of Rutilit NF to raw coal varied between 0.8 and 1.5% (0.5 – 0.9 kg TiO2 / t HM). Since September 2008 Rutilit NF is injected constantly together with the pulverized coal. Because of low demand for hot metal during the crisis in 2009 the furnace was stopped for five months. During this time an intermediate repair was made by replacing the staves at tuyère level and one row in the upper shaft. The trial had to be interrupted during this time. Specific consumption for elimination of hearth damage is significantly lower than when natural ilmenite ore is used. In addition, due to the lower specific input and lower migration into the slag compared to ilmenite, the use of Rutilit also achieves the desirable low titanium levels in the slag.
The object of this operational was to test operation using only Rutilit product by coinjection of pulverised synthetic titanium dioxide (Rutilit NF) and coal through the tuyeres. The test targets were therefore that of checking the effects of Rutilit in the hearth, the influence on reduction of temperature and, in particular, metallurgical effects on furnace operation.

6 HEARTH CONSTRUCTION AND WEAR

Figure 2 shows the refractories of the hearth of the preceding campaign. The hearth wall consisted of supermicroporous carbon blocks with low heat conductivity. The cooling of the hearth was made with cast iron staves inside the blast furnace shell and a bottom cooling by water pipes. The two lower layers of the hearth were constructed with a high grade chamotte.
Figure 3 shows the refractories in the hearth wall of the running campaign which consist of supermicroporous carbon blocks with medium heat conductivity and a protection layer of a ceramic cup of nitride bonded high alumina bricks with 300 mm thickness. The bottom consists now of only three layers of refractory, two layers of carbon blocks and one layer of chamotte in the upper part in order to get a higher sump depth from the beginning.

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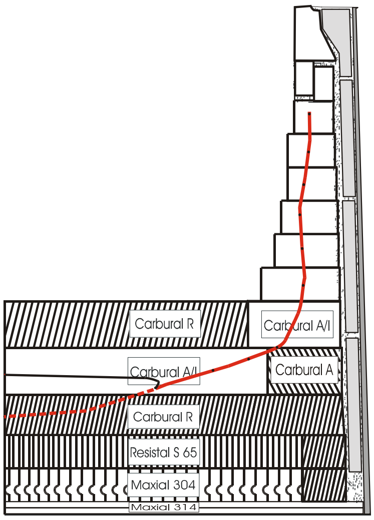

Figure 2: BF no. 4 (10 m)
third campaign 07/95-06/03

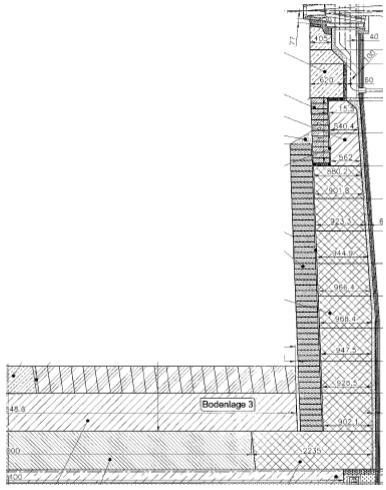

Figure 3: BF no. 4 (11.2 m)
forth campaign since Sept. 2003

7 ACTIONS TO REDUCE THE TEMPERATURE OF THE HEARTH REFRACTORY

To enable correct furnace operation and to reduce the temperature in the affected areas, a protective layer has to be formed and preserved.
This layer is located in front of the hearth carbon blocks and it is basically composed of titaniumcarbonitride (Ti(C,N)). Its role is to protect the carbon blocks from wear and chemical attack. The main actions used at blast furnace no. 4 to control wear to the hearth carbon block are the following:

- improved quality of the coke (CSR-value > 60%, mean size > 50mm). In the years before 2006 the coke quality was poor because of the use of domestic coking coals in the blend for coke making
- constant hearth cooling water temperature (temperature fluctuations lead to uncontrolled strains and movements and lead to the opening of joints and cracks)
- avoiding of longer stops of the furnace
- injection of synthetic titanium products with the pulverized coal

8 MONITORING HEARTH TEMPERATURES AND MODELING OF THE WEAR PROFILE

The hearth is equipped with totally 140 thermocouples which are arranged in 12 vertical sectional planes around the circumference for monitoring the temperatures and for modeling the hearth wear. Figure 4 shows the temperatures of sectional plane 5 in the hearth wall since the commissioning in September 2003. There is a constant increasing of the temperatures until 2008. The water temperature of the cooling system has also an increasing effect on the refractory temperatures as can be seen during the summer months. Since 2008 the inlet temperatures of the system are controlled to constantly 40°C which has a positive effect on the entire hearth.
Since July 2008 the coinjection is made continuously. At the end of 2008 the economical disturbances urged the frequent stopping of the furnace with consequently falling temperatures.

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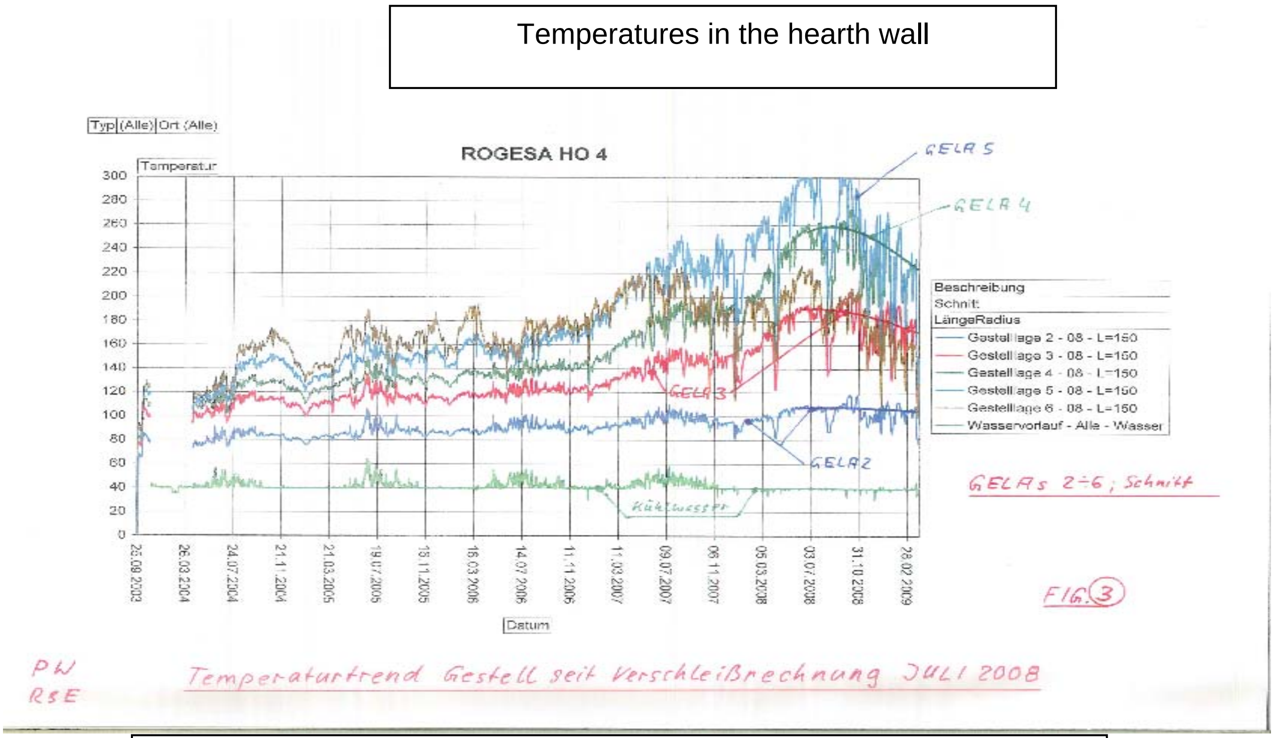

Figure 4: ROGESA BF 4 hearth wall temperatures and cooling water

The modeling of the state of wear is made from the temperature readings (Figure 4). The calculations show a modeling from 2011, that after eight years of operation the ceramic cup has mostly disappeared in the upper part of the hearth and the wear is now attacking the carbon blocks in row (Figure 5). In the lower part of the hearth the ceramic cup still exists.

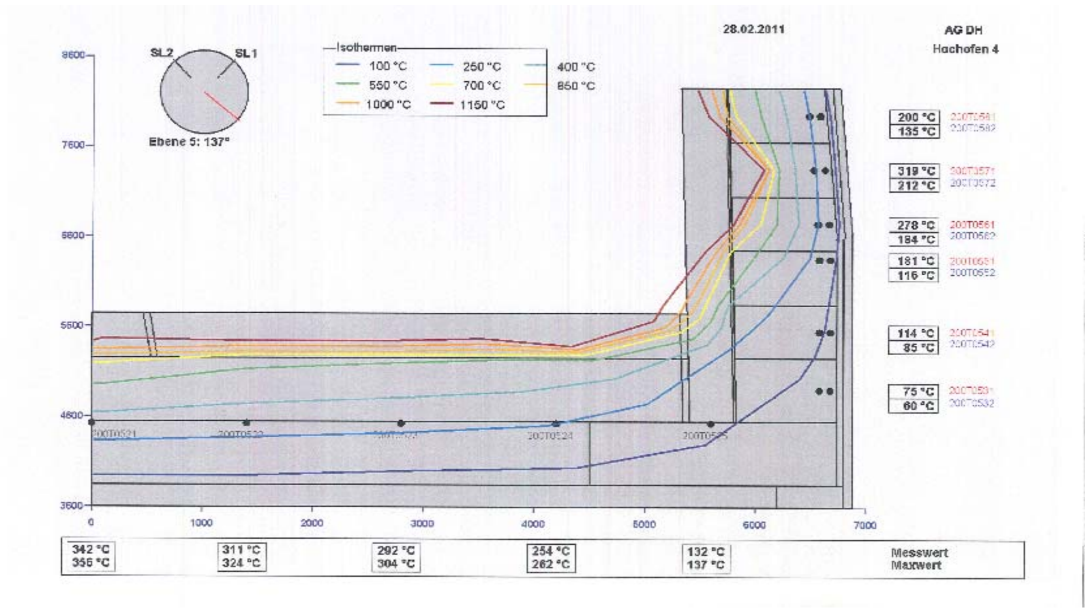

Figure 5: Isotherm and wear line of sectional plane 5 in 2011.

From May to October 2009 the furnace had to be stopped for five months because of the economic disturbances. During this period an interim repair was made with the

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changing of the worn cast iron staves at the tuyere level into copper. In the mid shaft one row of cast iron staves was also changed because of the failure of the fixation of this row.

9 RESULTS

The first two trials lead to the conclusion, that the co-injection of TiO_2 containing materials together with PCI coal in the existing plant is possible and not subject to major problems at conveying or in the drying, grinding and injecting process. Also the BF process was not influenced negatively by the increased ash respectively TiO_2 load in the PCI coal. Because of these facts from former trials, the main results from the long term trial will be subject here and be given with the help of the results of BF no. 4.
Figure. 6, 7 and 8 show the hearth wall temperatures until the present date.
In the first half of the year 2008 there was no Rutilit NF input, the temperatures remained stable or increased only slightly.
In the second half of the year 2008 Rutilit NF input was at approximately 1 kg/t HM, temperatures remained constant or decreased a little at the end of 2008 in section 5, in section 6 occurred a definitive decrease of the temperatures; coke quality was stable all the year 2008 with CSR over 60%.
In the first half of the year 2009 because of the economic crisis the frequent stoppages of the furnace leaded to a decrease of the temperatures, but in the second half of 2009 the coke quality became worse; consequently, the temperatures rose.
In 2010 the wear of the hearth proceeded; an interruption of the Rutilit NF injection in January 2010 caused an increase of the temperatures.
Coke quality problems continued and frequent short stoppages were also not favourable for the hearth.

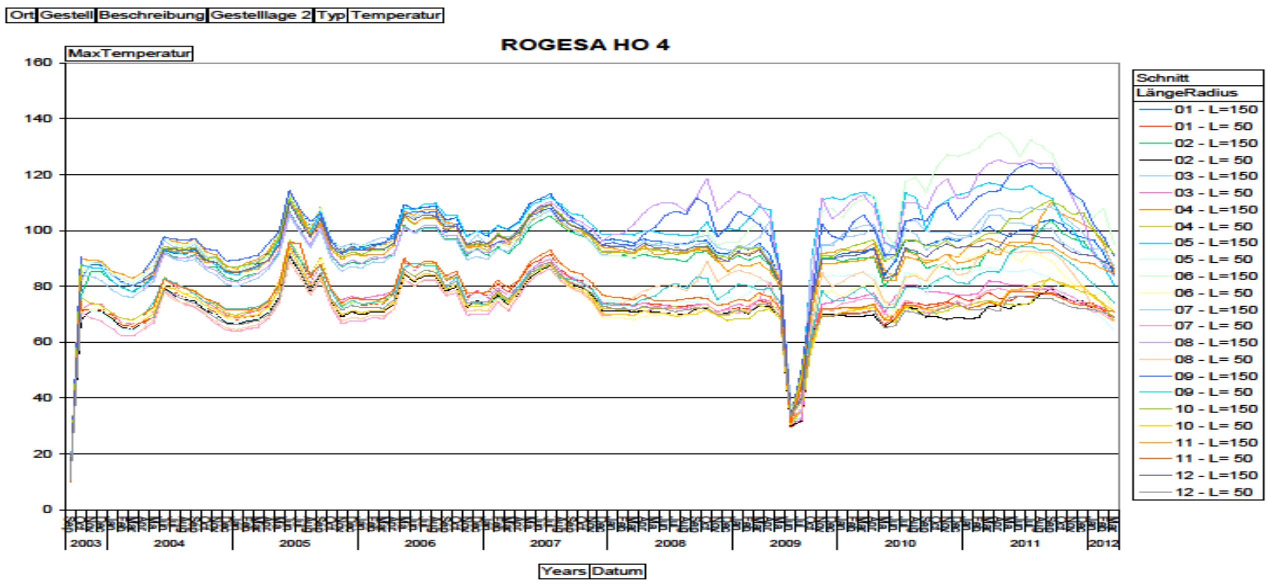

Figure 6: Trends of the hearth temperatures layer no. 2 from 2003 to 2012.

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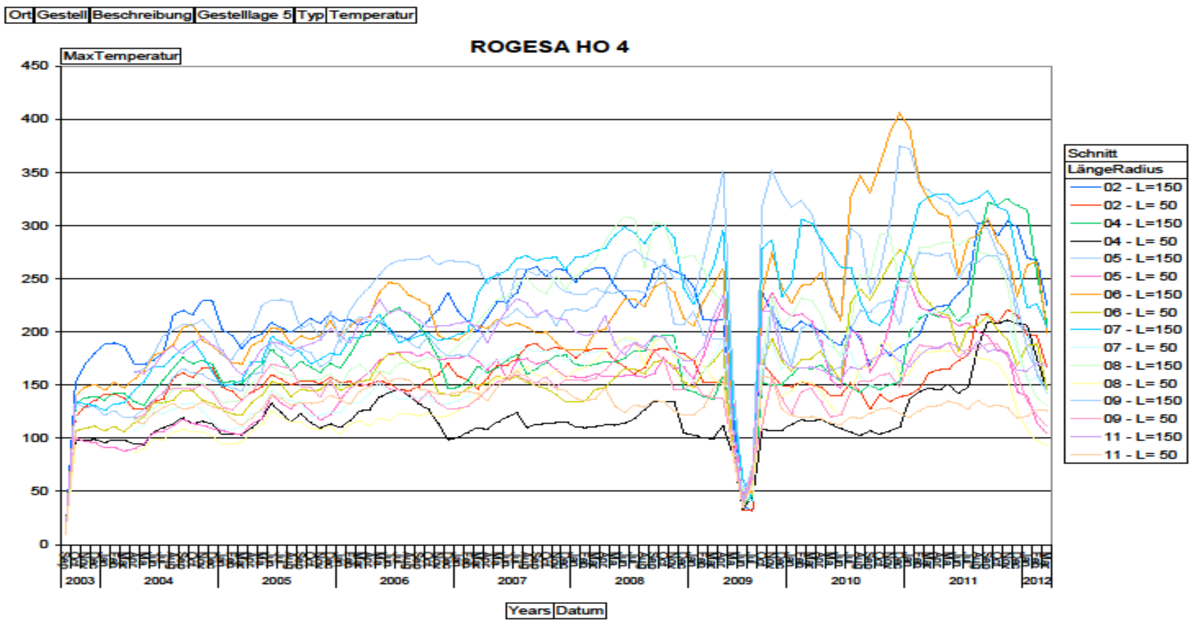

Figure 7: Trends of the hearth temperatures layer no. 5 from 2003 to 2012

Highest temperatures are just at the upper level of the hearth walls level 5 (Figure 7). In this region the ceramic cup is already worn out. At the hearth wall temperatures decrease during the coinjection period.

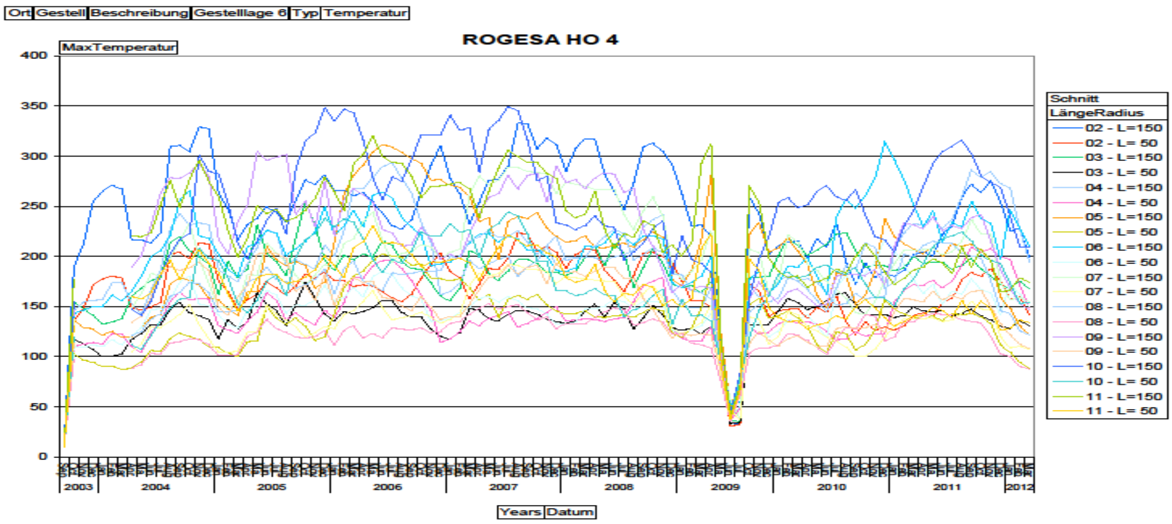

Figure 8: The hearth temperatures layer no. 6 from 2003 to 2012

Before the coinjection, temperatures remain static at about 300 to 350°C in the time of 2004 to 2008. The downward slope begins to increase slightly only short time after begin of the coinjection of Rutilit NF and PCI. The temperature in this region could be kept in the range of 200 to 250°C in the time 2008 to 2012.

Additionally, the inclination between most temperatures is reduced. The temperatures stay on a lower level of about 100 to 300°C. This stagnation on a lower level for at least 4 years indicates to have a long term effect on a lasting temperature reduction.

It can be shown that the temperatures and the wear on the hearth wall can be kept under control with the coinjection of Rutilit NF and PCI.

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The coinjection of pulverized Rutilit NF and coal with a flow-rate of 170 kg/t HM, and i. e. 0.8 - 1.6 kg Rutilit NF / t HM did not show also any negative influence onto the reductants consumption of the hot metal production. The HM temperature has a constant level of 1465 – 1485°C (2669 – 2705 F). The slight fluctuation of the Ti content in the hot metal, which has been in the range of 0.02 – 0.08%, has been caused both by the thermal state of the blast furnace and by the Rutilit NF coinjection. The TiO_2 content in the slag during Rutilit NF coinjection was at any time maintained below 0.9%, which is a significant quality criterion for processing and sale of the granulated slag as an additive for cement products .
The calculation of the residual thickness of the hearth in 2011 is shown in Figure 9. The levels 1 and 2 are in the bottom region. The measuring levels 3 to 8 are in the hearth wall.
The calculated wear of the ceramic cup is also shown in Figure 9. After a campaign life of 8 years the ceramic cup has dissappeared but it has fulfilled its task to protect the carbon lining during this time.
The maximum wear is at section 6 that means on the opposite side of the tap holes and is now 250 mm inside the carbon. This signifies that 700 mm of carbon thickness is still remaining.

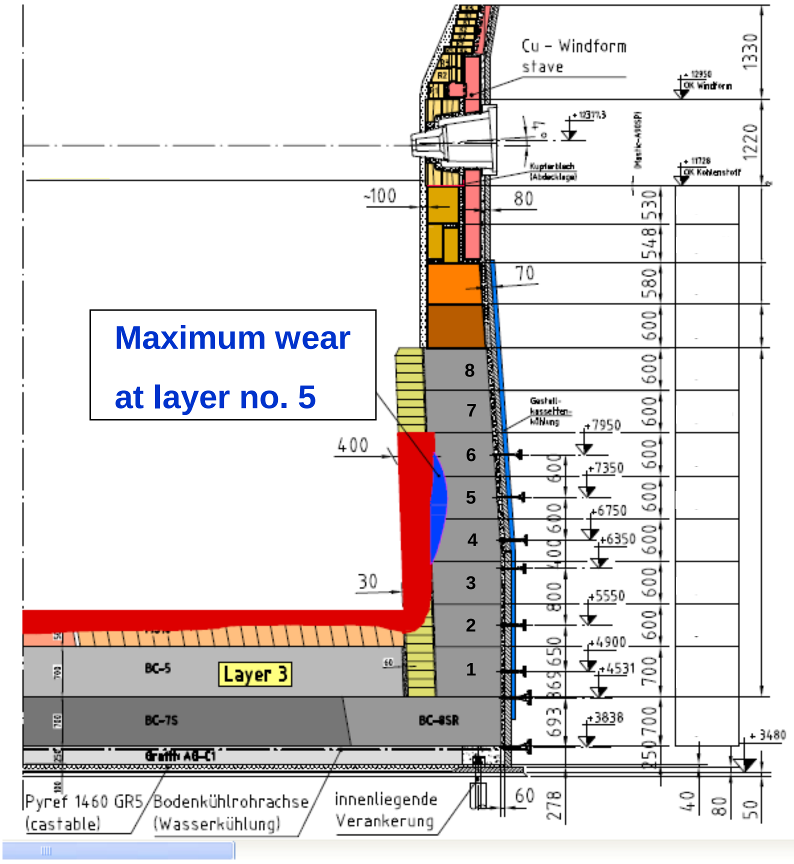

Figure 9: Hearth design layer 1 to 11 at section 5 of blast furnace No. 4 calculated in 2011

The levels 1 and 2 are in the bottom region. The measuring levels 3 to 8 are in the hearth wall. The calculated wear of the ceramic cup is also shown.

10 CONCLUSION

The 4th campaign of ROGESA blast furnace no. 4 began after enlargement of volume and hearth diameter in October 2003.
In order to protect the wear of the hearth wall and bottom the coinjection of pulverized coal and Rutilit NF was developed. The temperature patterns of the hearth walls show the effectiveness of this procedure.
After learning about and mastering the new technology of Rutilit NF coinjection, it was possible to control the temperatures in the hearth wall, with slow losses in the ceramic cup and carbon refractory.
It can be shown that the temperatures and the wear of the hearth wall can be kept under control with this new technique. The decrease of the temperatures at constant productivity utilisation indicates very likely the formation of Titaniumcarbonitride layers on the hearth wall refractories and thus a repair of worn areas. A big advantage of the coinjection technique is the opportunity to decrease significantly TiO_2 contents in the slag, while the Ti content in the hot metal maintains at saturation and thus the formation of Ti(C,N) layers out of the liquid phase. Continuous use of Rutilit NF and PCI coinjection showed the need to prevent the wear of the protective layer of the hearth carbon block.
This new method allows a rapid repair of the affected areas of the hearth and allows reaching 15 years for the campaign of Rogesa blast furnaces.

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