# FUNDAMENTAL ASPECTS OF BF HEARTH DESIGN AND HEARTH LININGS[1]

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**Abstract**

Hot metal produced in blast furnaces today is still by far the most important charging material for the production of crude steel worldwide. During the last decades technological advances have made a substantial increase of the average size and production capacity of the single blast furnace possible. As a consequence the dependence of the operator on the production of the single furnace has increased. This development steadily created more pressure to prolong the campaign life of the blast furnaces substantially. The hearth remains as the area determining the furnace campaign life. The presentation outlines the different hearth lining philosophies and gives an assessment of their advantages and disadvantages, respectively. The Paul Wurth philosophy of thermally low conducting, highly erosion and abrasion resistant carboceramic grades will be described against this background. The hearth has to be regarded as an integrated system of lining and cooling, which both have strong interdependencies. The capabilities of the hearth wall cooling systems mainly used will be illustrated. We focus mainly on design questions, as we think that design is of paramount importance. If the design of the furnace hearth and cooling system is wrong, even the best material grades are not able to reach the target desired. Based on the measurements of thermocouples we are able to calculate wear profiles, which provide the lifetime related information to the operator. Paul Wurth is confident to be able to offer controlled integrated lining and cooling systems able to fulfill the lifetime expectations for blast furnaces of today.

**Keywords:** Blast furnace; Hearth; Lining; Cooling.

## ASPECTOS FUNDAMENTAIS DO PROJETO E DO REVESTIMENTO DE CADINHOS DE ALTOS FORNOS

**Resumo**

O metal líquido produzido via Alto Forno é ainda hoje o principal provedor de material para produção de aço cru em todo o mundo. Durante as últimas décadas os avanços tecnológicos possibilitaram um substancial crescimento do tamanho médio e da capacidade de produção de um único Alto Forno. Como conseqüência a dependência do operador na produção de um dado Alto Forno cresceu. Esse desenvolvimento aumentou substancialmente a pressão para o prolongamento do tempo de campanha dos Altos Fornos. A região do cadinho é caracterizada como a área determinante da campanha do Alto Forno. Essa apresentação esboça as diferentes filosofias de revestimento de cadinho e fornece uma avaliação de suas vantagens e desvantagens respectivamente. A filosofia da Paul Wurth de baixa condutibilidade térmica, alta resistência à abrasão e erosão e utilização de classes carbo-cerâmicas será descrita nesse contexto. O cadinho deve ser visto como um sistema integrado de revestimento e refrigeração, onde ambos possuem grande interdependência. As potencialidades dos sistemas de refrigeração de paredes de cadinhos largamente utilizados serão ilustradas. Focamos-nos basicamente nas questões de projeto, pois acreditamos que o projeto é de vital importância. Uma vez que o projeto do cadinho e do seu sistema de refrigeração sejam errados, nem mesmo as melhores classes de materiais serão capazes de atingir a meta desejada. Baseado em medições de termopares somos capazes de calcular perfis de desgaste, que fornecem ao operador informações sobre o tempo de campanha do Alto Forno.A Paul Wurth tem confiança em oferecer sistemas controlados e integrados de revestimento e refrigeração capazes de atender as expectativas de campanha dos Altos Fornos atuais.

**Palavras-chave:** Alto forno; Cadinho; Revestimento; Refrigeração

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## INTRODUCTION

Hot metal produced in blast furnaces today is still by far the most important charging material for the production of crude steel worldwide, as it has been in the past.
Due to the reliability, maturity and scalability of the process we believe that the blast furnace will defend its leading position also in the future, thus motivating further work for increasing efficiency and lifetime.
During the last decades technological advances in the fields of process technology and control systems have made a substantial increase of the average size, productivity and hence the production capacity of the single blast furnace possible.

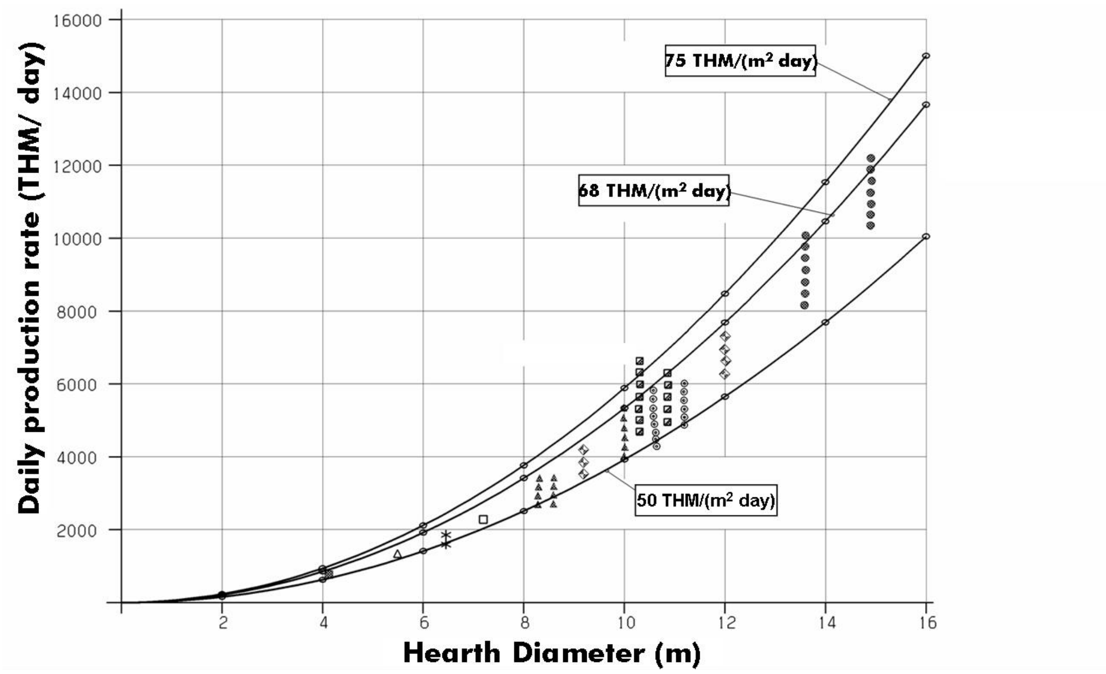


**Figure 1:** Specific production rates of selected German blast furnaces

Figure 1 shows this development for Germany, where today only 17 blast furnaces remained in operation of previously more than 60 in the 1960s, with total hot metal production nearly unchanged. The production rates of German blast furnaces range between 50 THM / (m² 24 h) and 75 THM / (m² 24 h).
As a consequence the dependence of the operator on the production of the single furnace has increased.
This development steadily created more pressure to prolong the campaign life of the blast furnaces substantially, which could be prolonged from an average of 5 years to more than 10 years during the past decades.
The target today is often set to a minimum of 15 years, which requires innovative measures and is a great challenge both for blast furnace engineering companies and operators.
Apart from the hearth, in the past the wear relevant zones have been upper tuyere level, bosh, belly and lower shaft.
Due to the introduction of improved cooling techniques, such as narrow-spaced cooling boxes with sandwich lining and especially after the successful worldwide introduction of copper staves during the 1990s the problems in the mentioned zones of the blast furnace are mainly solved and significant campaign life prolongations

could be achieved. It has been proven that a life time of 15 years and more can be achieved in these zones.
Additionally, the development of refractory grades with increased hot metal and erosion resistance has been another important step for campaign life prolongation during the last decades.
At the moment this development is still carried on further. It is, however, not yet completed, because even today only a few long-term references of campaign lives of 15 years and more are available.

## HEARTH LINING: THE APPROACH OF PW R&E

Since several decades we examine and analyze wear and blow-out profiles with the intention to contribute to an improved lining technology.
We succeeded for example in correlating thermal design features, such as distribution of isothermal lines, and wear or blow-out profiles. These studies gave us a key understanding for the design of the internal and external hearth geometry.

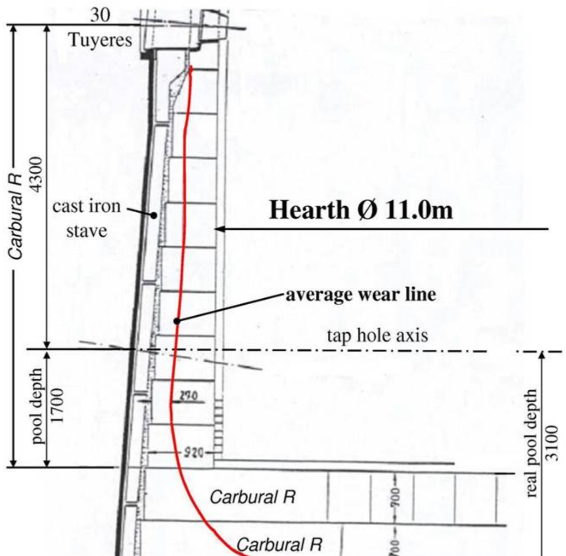


**Figure 2:** Average wear profile, Example 1

Figure 2 shows a nearly ideal blow-out profile of a blast furnace with a total production of 20 million tons of hot metal and a campaign life of 11.5 years.
In this case accelerated wear could not be observed in the lower hearth area. In addition, the calculated position of the freezing line of hot metal is nearly congruent with the measured blow-out profile. The significant characteristic hearth coefficients for the inner hearth geometry show uncritical values.
The blow-out survey showed an average refractory wear rate of 56.5 mm/year in the middle hearth wall area.

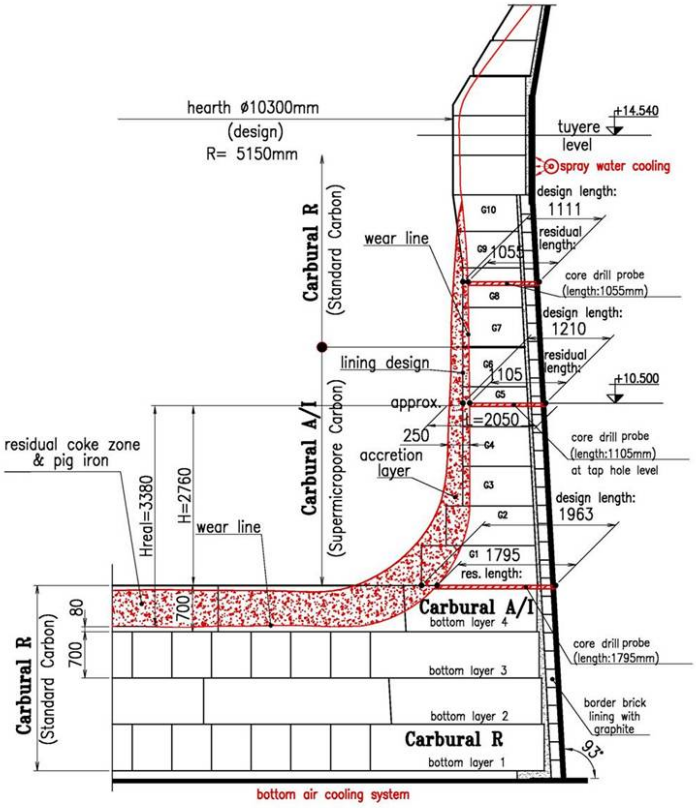


**Figure 3:** Average wear profile, Example 2

Figure 3 shows a blow-out profile of a blast furnace with a total production of 16 million tons of hot metal and a campaign of nearly 9 years. The lower hearth of this blast furnace had been lined with a microporous, carbo-ceramic carbon grade applied for the first time here. With a design of the hearth lining, comparable to the one shown in Figure 3, an average wear profile of 30 mm/year has been measured. We are sure that the improved average wear rate mainly has to be attributed to the use of corrosion and erosion resistant carbo-ceramic carbon grades for the lining of the lower hearth.

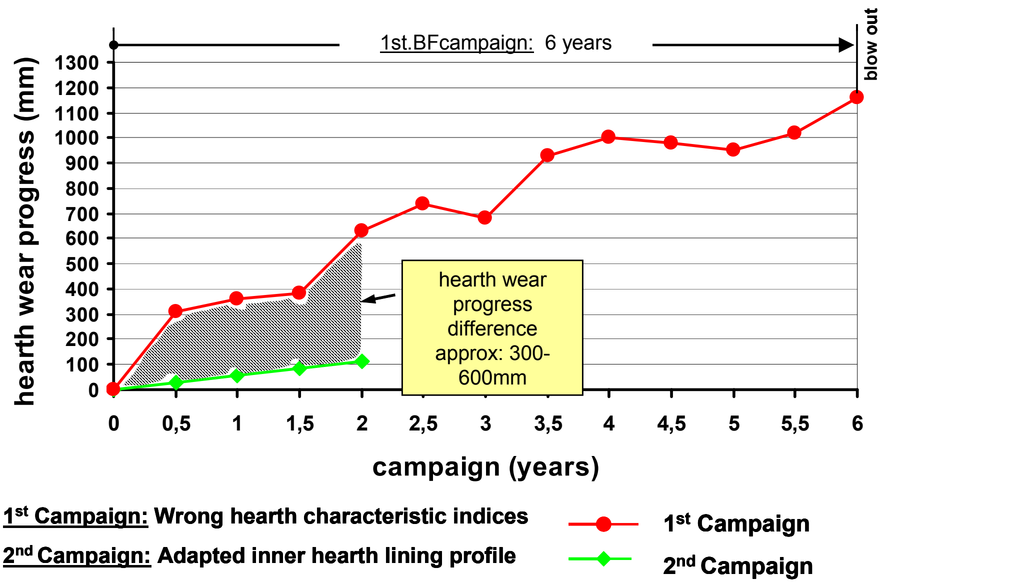


**Figure 4:** Wear progress comparison of two lining concepts for the same blast furnace

Both curves of Figure 4 are for the same blast furnace. The upper curve was measured for a lining where a ceramic cup had been incorporated in an incorrect geometry. The lower curve has been measured for a modified interim lining for the same blast furnace, the major difference being the removal of the ceramic cup for improvement of the geometry.
Already after a short period of operation a considerably longer life expectation could be given for the "modified lining".

| | Characteristic Indices: | | | |
|---|---|---|---|---|
| | H/R | $H_{real}$ / R | L/R | A/R |
| existing | 0,53 | 0,629 | 0,395 | 0,813 |
| critical | ≤ 0,574 | ≤ 0,574 | ≤ 0,333 | ≤ 0,680 |
| remark | defective | good | good | good |

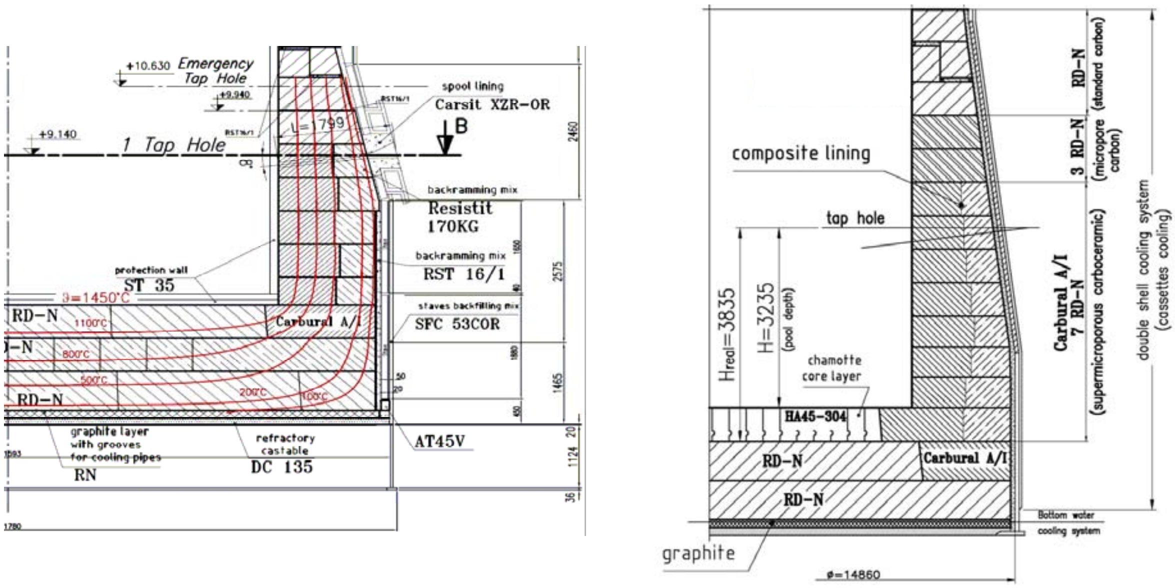

**Figure 5:** Two blast furnace linings relized in 2005

Figure 5 shows two examples of blast furnaces realized in 2005, which have been built according to PW R&E dimensional concepts as well as according to our proven carbo-ceramic, low heat-conducting material philosophy. Using a composite lining, the occurrence of lifetime reducing brittle zones will be avoided.
Being dimensionally and materialwise correct, we expect a lifetime of clearly above 10 years for these blast furnaces.

## REMARKS ON OTHER HEARTH LINING CONCEPTS

Classical hearth linings can be categorized in thermal and ceramic linings.
Figure 6 shows thermal hearth linings with different carbon grades and semi-graphite grades of increased thermal conductivity. The examples comprise big blocks, small bricks as well as combined solutions.
Figure 7 shows so-called ceramic hearth linings using carbon grades of low thermal conductivity and mainly large-sized blocks.
Linings with a reinforced ceramic hearth protection wall and an improved ceramic cup are also shown.

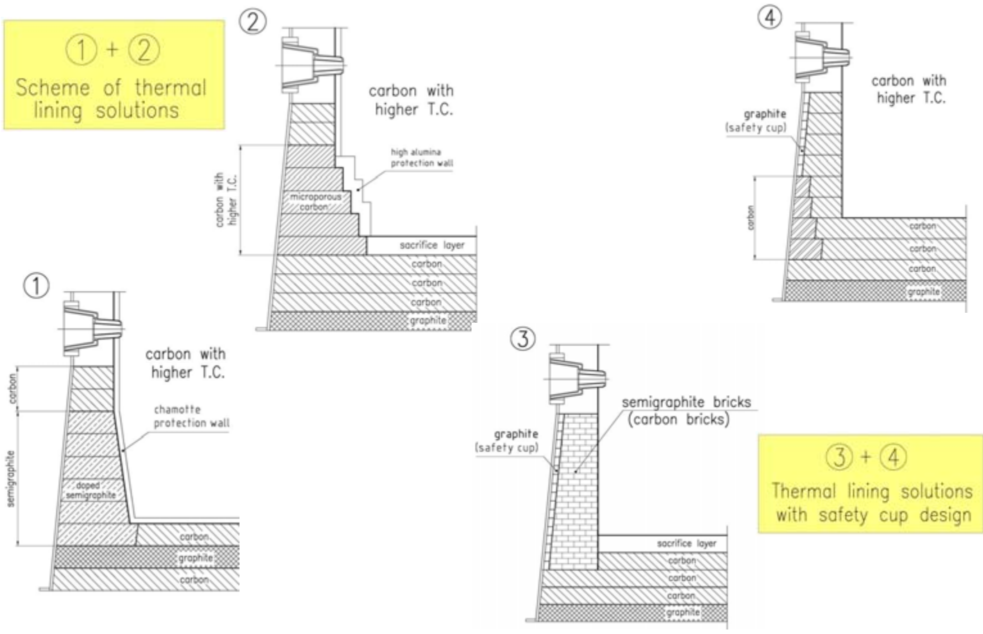


**Figure 6:** Thermal hearth lining solutions

Due to the more favourable energy consumption (due to lower wall heat losses) ceramic hearth linings are enjoying a renaissance compared with thermal linings since the costs, which currently have to be paid for raw materials and fuel, increased considerably. Based on practical examples it has been proven that during a campaign of a middle-sized blast furnace a two-digit million sum of Euros may be saved in case a ceramic hearth lining instead of a thermal hearth lining is preferred.

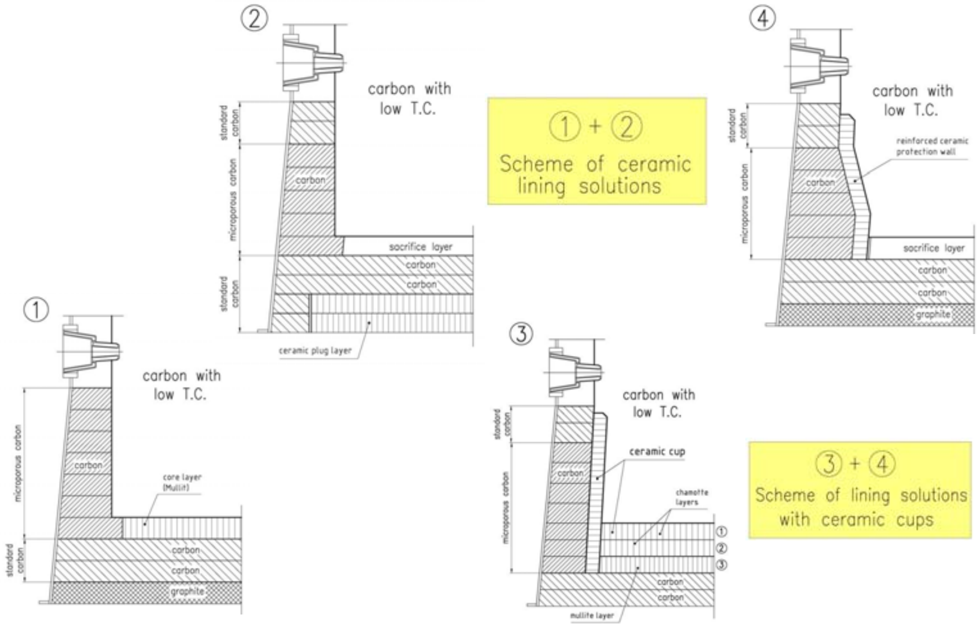


**Figure 7:** Ceramic hearth lining solutions

Figure 8 shows the evaluation of some selected blown-out blast furnaces with respect to campaign life and actually measured hearth wear rates. It has to be noticed that increased wear rates occur, wherever the pool depth is too low compared to those blast furnaces in which the hearth characteristic coefficients are correct. Here it does not matter which carbon grades have been selected or whether a thermal or a ceramic lining has been used.

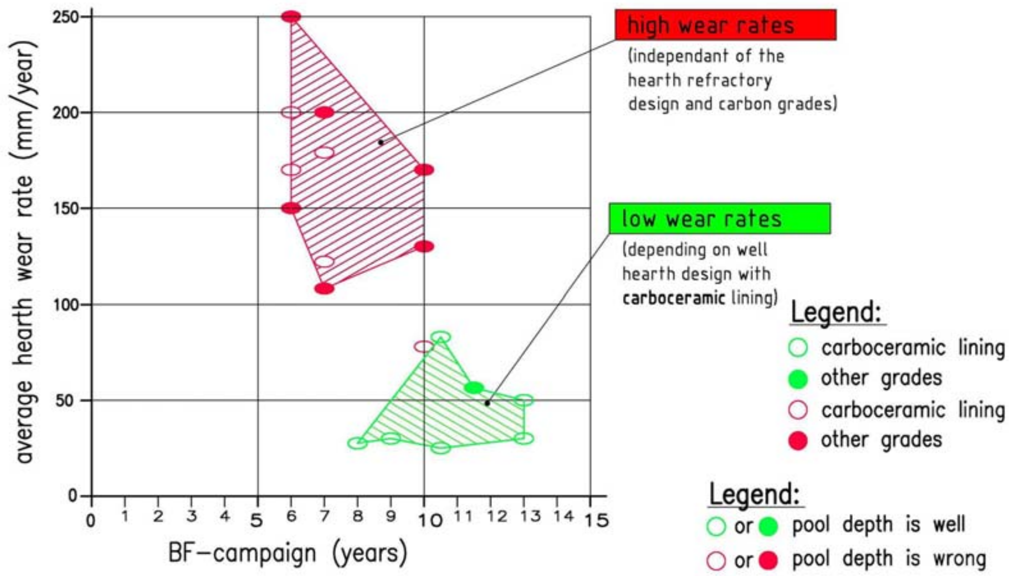


**Figure 8:** The importance of hearth geometry

This proves that

- the best carbon grades in a wrong hearth design have no chance to achieve a long campaign life
- campaign lives exceeding 15 years can only be achieved using a well designed internal and external hearth profile.

Reaching campaign lives of 15 years and more is not yet state-of-the-art technology for all operators. In future, however, the above may be achieved with the assistance of experienced engineering companies.

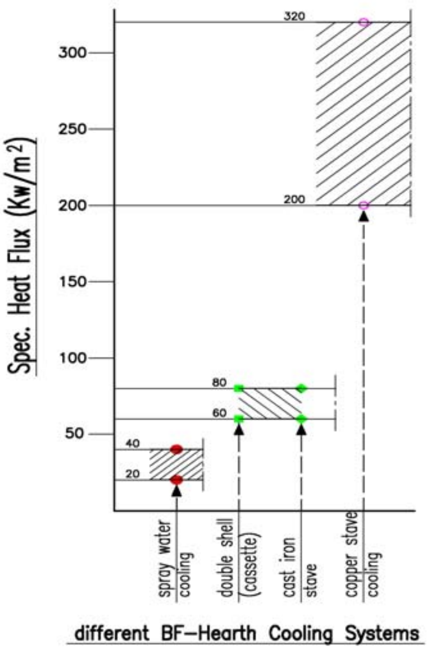


table 1: Different BF-hearth Cooling Systems

| item No.: | Denomination (-) | max.heat flux (KW/m2) | remark |
|---|---|---|---|
| 1 | water spray cooling | **30** | lowest investment |
| 2 | double shell cooling (cassette cooling) | **70** | tolerable investment |
| 3 | cast iron stave cooling | **70** | higher investment |
| 4 | copper stave cooling | **320** | highest investment |

**Figure 9:** Hearth cooling concepts

## HEARTH COOLING TECHNOLOGY

Figure 9 shows cooling technologies used in the BF hearth. With respect to possible heat transfer the water spray cooling with max. 30 to 40 kW/m² ranks in the last place. The double shell or cassette cooling with a heat transfer of max.
70 to 80 kW/m² ranks in the midfield and is equal to cast iron stave cooling.
Copper stave cooling of the hearth is the unbeatable number one of all hearth cooling technologies.

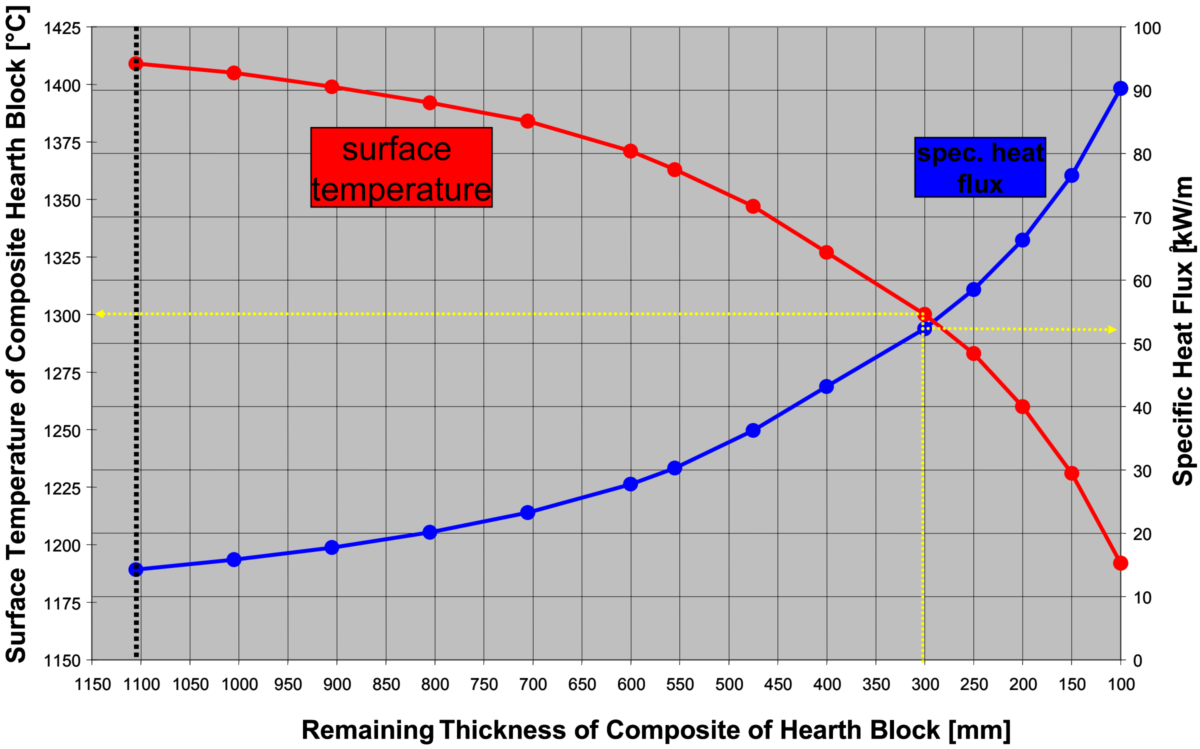


**Figure 10:** Surface temperature and heat fluxes for different lining thicknesses

Figure 10 shows the required hearth side wall heat transfer with decreasing hearth side wall thickness, which means increasing wear. This curve is plotted together with the internal surface temperature of the hearth block.
It may be recognized that the surface temperature of the hearth block is still 1300 °C and that the heat flow density of bigger than 50 kW/m² to be transferred is too much for the water spray cooling in case the residual hearth side wall thickness is only 300 mm.
In addition, it can be observed that hot metal solidifies only when a residual hearth side wall thickness of approx.100 mm has been reached in front of the carbon material. A theoretical heat flow density of 90 kW/m² is required for solidification of hot metal. Transfer of 90 kW/m² is also too much for double shell and/or cast iron stave cooling of the hearth.
The above makes clear that break-outs in the hearth area can only be avoided using copper stave cooling.
Due to commercial disadvantages we want to point out that we do not recommend to use a copper stave cooling system in the entire hearth.
PW R&E does recommend, however, to use copper staves in the critical hearth zones like tap hole areas to prevent tap hole or spool break-outs.

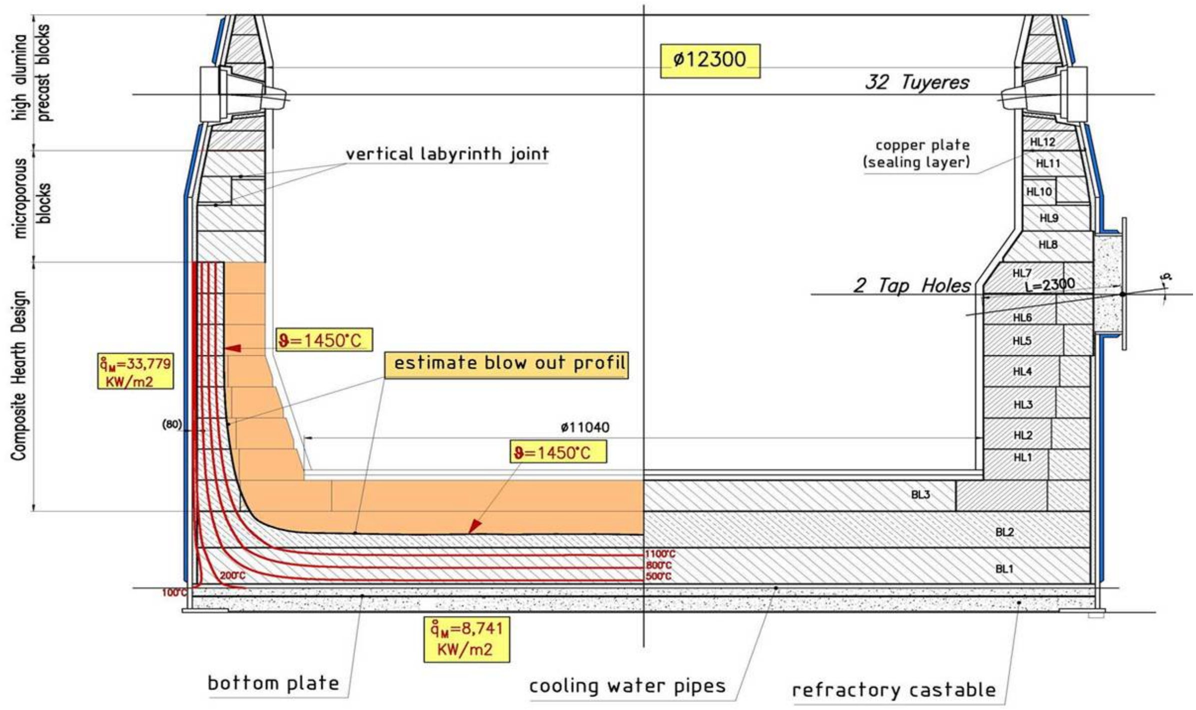


**Figure 11:** Example of possible even wear profile

Figure 11 shows, that an even wear profile, adapted to the isothermal line calculations, may be achieved even without the use of hearth copper stave cooling by observing all criteria mentioned in this presentation.

A theoretical heat load of approx. 34 kW/m² has to be eliminated in case of extensive hearth wear. This heat load can be eliminated without any problems even by using a cassette cooling system.

Regardless which hearth wall cooling system is applied, PW R&E strongly recommends using a water bottom cooling system even for smaller blast furnaces, with cooling pipes located above the bottom plate.

This arrangement assures the best possible heat transfer combined with the lowest bottom plate temperatures and allows for thinner bottom designs than without water cooling. If seamless stainless steel tubes are used for such cooling systems, no problems with water tightness have to be expected, according to operational experience at many blast furnaces all over the world.

## HEARTH CONTROL BY THERMOCOUPLE ARRAYS

During a running campaign the blast furnace operator needs reliable information on the state of the hearth to be able act on any problems occurring and to properly determine the end of the campaign, if necessary.

Additional to the engineering for hearth linings (design, construction, selection of grades etc.), PW R&E became well known for designing suitable measurements both in the hearth and bottom.

Today the control system of choice are thermocouple arrays for both bottom and hearth wall. Thermocouples are well proven and comparably cheap. They are small and can be installed in nearly every place around the furnace.

Figure 12 shows a thermocouple layout at a German blast furnace, where the thermocouples are strictly located in six sections, each comprising measurement

points in hearth wall and bottom. Locating the thermocouples in sections is of utmost importance for reliable later wear calculations.
As thermocouples sometimes fail after years and years of operation PW R&E has developed changeable ones - even for the bottom area - to ensure a steady flow of information.

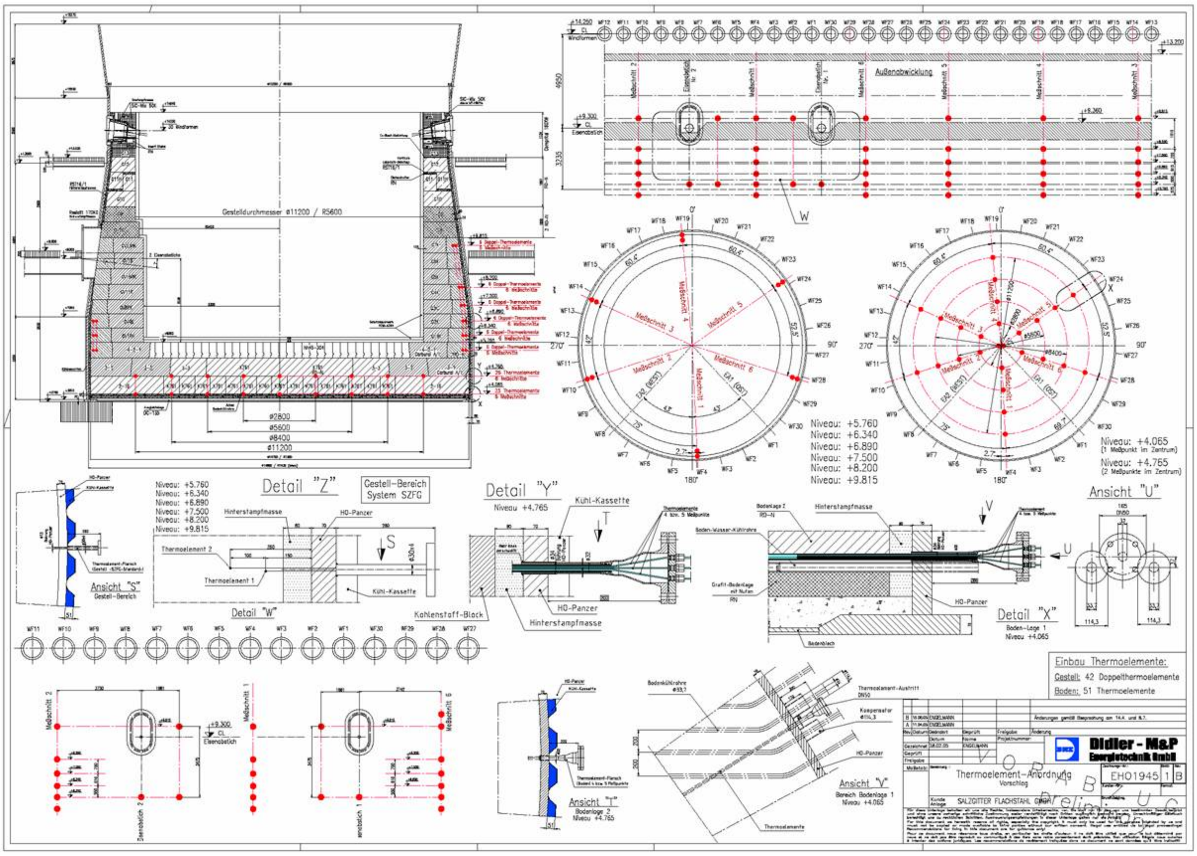

**Figure 12:** Thermocouple array for hearth monitoring

Based on the measurements of the thermocouples we are able to calculate wear profiles, which provide the lifetime related information to the operator. In Figure 13 one can see how important the distribution of the thermocouples is: In one layer no thermocouples have been installed, making a reliable wear calculation in this area impossible.

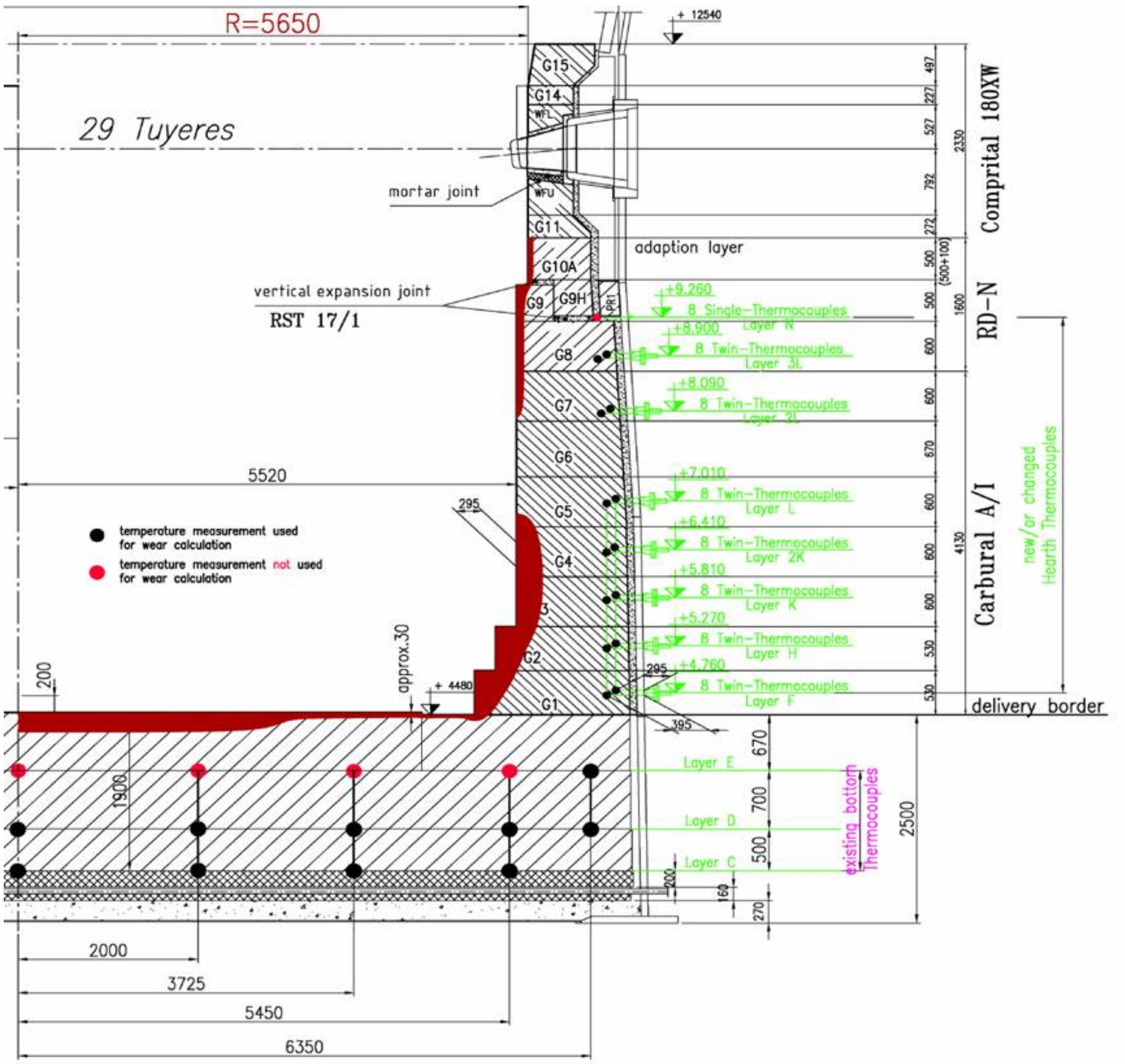


**Figure 13:** Example of thermocouple based hearth wear calculations

## SUMMARY

Large-sized blast furnaces require a continuous operation period of more than15 years and high production rates to be able to produce economically.

The analysis of wear and blow-out profiles led PW R&E to improve the design of the internal and external furnace profile, resulting in furnace campaigns of more than 10 years.

Improving the corrosion and erosion resistance of refractory materials by ceramic doping resulted in the implementation of microporous carbo-ceramic, composite block elements for hearth linings, which avoid the formation of brittle zones.

Improved hearth and bottom cooling technologies are integral parts of PW R&E's lining technology for hearth linings to achieve extended campaigns.

Individual solutions for BF hearth lining problems, suitable for operation at high specific production figures, can only be prepared in close cooperation with blast furnace operators.

As a conclusion PW R&E is confident to be able to offer controlled integrated lining and cooling systems able to fulfill the lifetime expectations for blast furnaces of today.

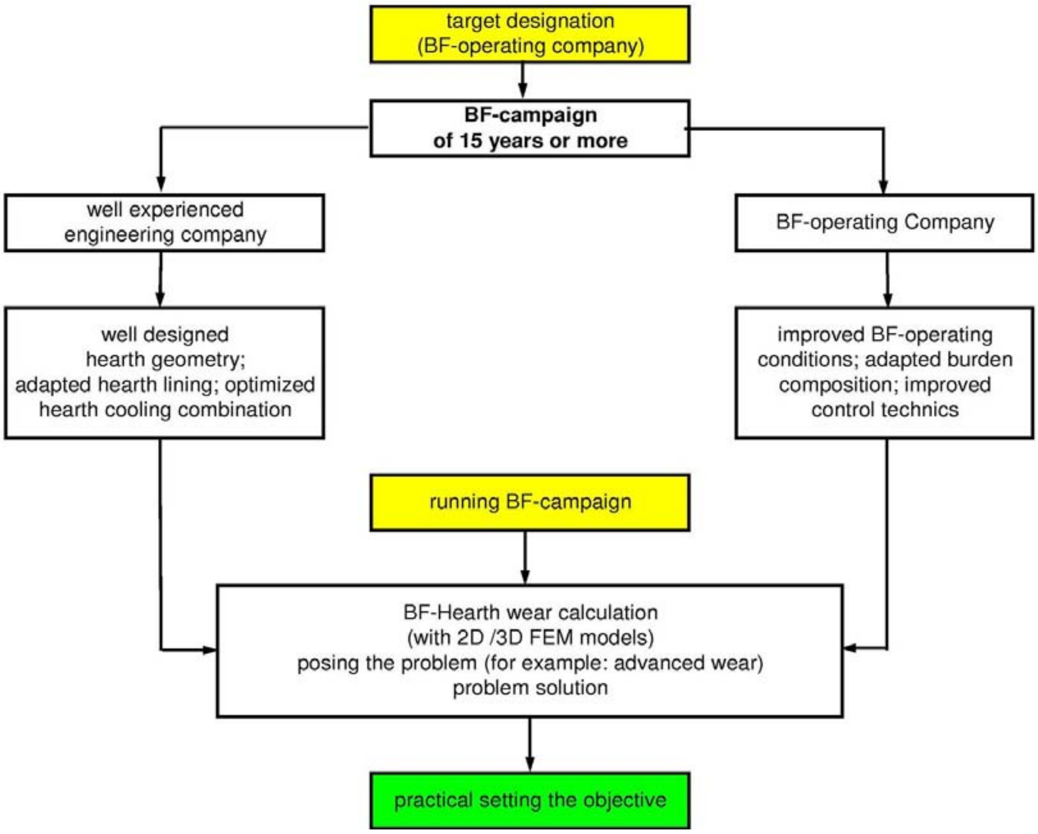


**Figure 13:** Cooperation of engineering companies and blast furnace operators