INTRODUCING SIP TECHNOLOGY AND ITS IMPACT ON BLAST FURNACE OPERATION

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SYNOPSIS:

Achieving a stable and high productivity blast furnace operation, whilst at the same time, lowering consumption of reducing agents, improving efficiency and delivering steps towards decarbonization, are often the ideal aims of operators in modern iron-making. The Sequence Impulse Process (SIP) is an oxygen pulsing technology installed on the 4416m^3 inner volume Schwelgern BF1, which is operated by thyssenkrupp Steel Europe AG in Germany. The blast furnace application of this technology is the first in the world of its kind and has demonstrated a significant operational improvement, contributing toward such aims.
Key findings include a reduction to the total fuel rate and a reduction of CO_2 emissions. In addition, SIP has enabled the stable use of higher PCI rates on the blast furnace and unlocked a potential for higher productivity.
This paper discusses the technology and learnings from the Schwelgern BF1 operation with SIP and explains how an increase to the permeability in the lower part of the blast furnace has led to many operational benefits.

Keywords: blast furnace, SIP, oxygen, CO_2, raceway, efficiency, PCI, decarbonization, raw material quality, coke quality

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Introduction

The operation of blast furnaces, especially of large units close to the thermodynamic minimum input of energy or reducing agents, requires a high consistent quality of the raw materials used. The targeted nominal output can only be achieved under the condition of continuous and thus constant operation of the blast furnaces. If the thermodynamic optimum is not reached or if the deviation from this condition is too large, a rapid decline in raw material efficiency must be expected.

Blast furnace operators have always been confronted with increasingly demanding tasks, which certainly include a high production level with a consistently high iron quality. This, however, must often be achieved against a backdrop of operational and process challenges. The limited availability of high-quality raw materials and irregular properties of available alternatives can lead to a departure from ideal operating conditions to a reality under which production targets must be made [1] [2].

A new technology that has already demonstrated a positive influence on blast furnace performance, and at the same time, provided mitigation against such challenges, is a welcome addition to the set of operational tools available at the world's first blast furnace reference. The Sequence Impulse Process (SIP) is a new blast furnace technology that first began full operation at Schwelgern blast furnace 1 at the end of 2020. The blast furnace is a large 4416 m^3 inner volume blast furnace, operated by thyssenkrupp Steel Europe AG at their Duisburg plant in Germany. The SIP technology has demonstrated an impressive impact on blast furnace operation to date. Therefore, the SIP plant at Schwelgern BF1, is now fully adopted and incorporated into blast furnace operating practice. SIP is a technology that is available now to provide incremental change aligned to reducing carbon emissions and can readily be incorporated into existing blast furnace plants. This paper first outlines the technology principles and plant description before describing the decarbonization credentials and operational results experienced so far. Also discussed is the potential for further gains at different blast furnace operating points. The Sequence Impulse Process technology pushes the blast furnace process beyond current limitations. Figure 1 memorably shows the possibilities as key points.

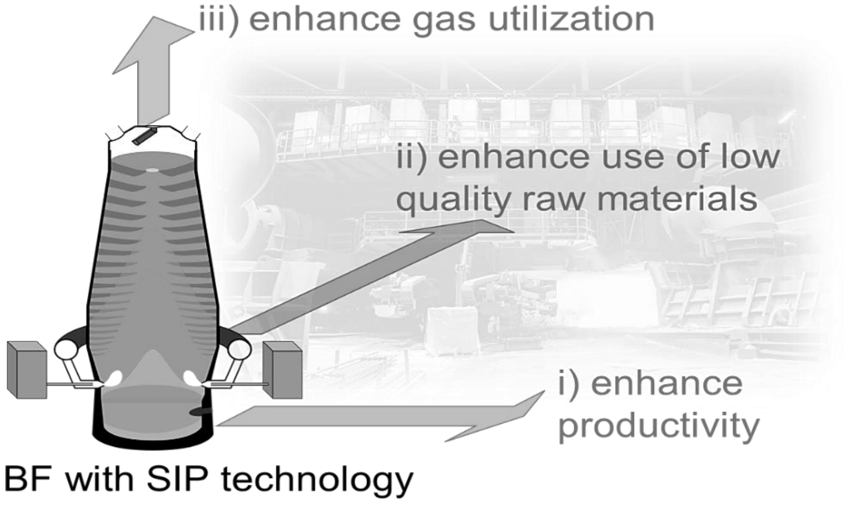

Figure 1: Schematic representation of the potential optimizations of the blast furnace process (i and iii) and extended freedoms in raw material selection (ii).

This pioneering and exciting new technology was developed by thyssenkrupp. The first blast furnace SIP plant installation was done at Schwelgern BF1. An exclusive cooperation agreement with Primetals Technologies makes it now possible for blast furnace operators worldwide to use this technology to stabilize their process and increase the performance of their facilities.

First trial results

The influence of SIP was first investigated on a blast furnace by means of operating tests on one tuyere at Schwelgern BF1, which was equipped with a SIP test facility. For a comparative assessment of the results, additional investigations were also carried out on reference tuyeres. The observations of the temperature fields in the raceway showed that 80% of the pulsed oxygen reacts in the coke bed behind the raceway and that the chemical conversion of the injected coal is significantly improved during the pulsing effect. The examinations of the numerous material samples taken from the tuyeres showed that the raceway is reproducibly and significantly enlarged by the pulse oxygen, on average from approx. 1.10 m to 1.50 m. A smaller fine fraction and larger equivalent grain diameter of the coke, in the transition zone between the raceway and the dead man, were repeatedly observed. Furthermore, a shift in the proportion of liquid phases (iron and slag) towards the center of the furnace was observed from the material samples. The chemical analyses of the iron and slag samples taken indicate a shift of the high temperature range towards the center of the furnace. By means of helium tracing, the addition of helium into the tuyere and measurement of helium concentration in the center position of the in-burden probe, a significant change of the gas flow through the SIP process to the furnace center was detected [3] [4]. These studies clarified the temporary local depth effect of SIP oxygen.

Functional principle of SIP

For blast furnaces operating with injected coal it is a fact, that coal is incompletely chemically transformed in the raceway due to the short retention time of the injected coal in the raceway and insufficient mixture generation.
The idea behind SIP is, to create a supersonic free jet with unsteady start-up range and a leading shock wave. This condition is beneficial for the blast furnace process, it influences and intensifies the local manifestation of turbulence in the raceway. In this way, the formation of reactive mixtures and the necessary mass transfer for the respective chemical reactions are improved [5] [6]. The use of SIP technology not only enhances the ignition condition, but also the turbulence itself and as a result, a cleaning of the rear area of the raceway. Otherwise, deterioration of these sub-processes usually leads not only to a reduction in permeability, but also to an increase of the flow resistance, and in the result the direction of escaped gas shifts towards the sides of the blast furnace. In addition to these effects, there is a possibility of deposition of the finest particles in the blast furnace hearth [6]. In this way, a negative influence on the flow behaviour of the liquid phases of iron and slag along the entire path - from the melting zone to the tap holes - is the result. These effects are even stronger when coke qualities are insufficient [7] [8] [9]. In relation to the mass of the injected coal flow, during a pulse and thus extremely time-constrained, the oxygen injection contains a multiple of the stoichiometric oxygen necessary for a reaction of the injected coal. In

addition, the conditions for mixing coal and the injected oxygen are enhanced because of the transient open jet. A high chemical conversion of the injected coal can take place temporarily during a pulse. The influence of SIP technology on the raceway is shown in Figure 2, depicting raceway conditions created with and without SIP operation.

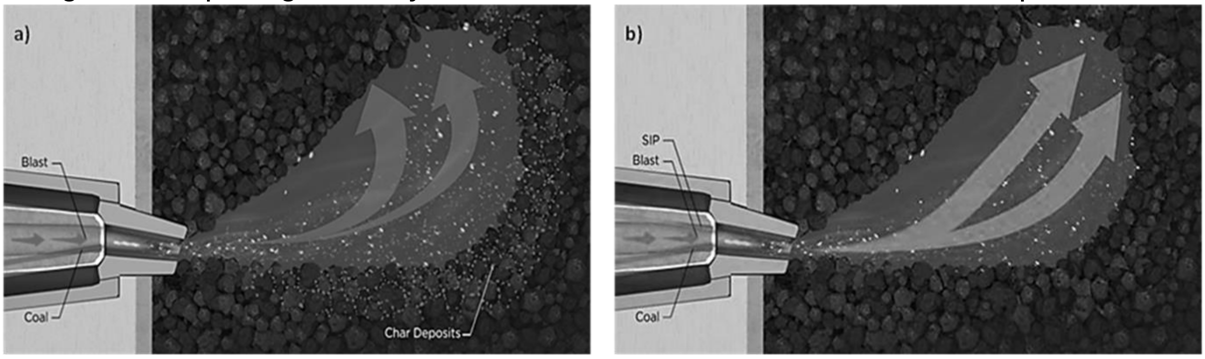

Figure 2: Conditions in the raceway and surrounding coke area a) without SIP, b) with SIP.

SIP plant description

Thyssenkrupp Steel Europe has an integrated steel mill at Duisburg in Germany with 4 blast furnaces with a maximum hot metal production of 34,000 t/d in total. Schwelgern BF1 has an inner volume of 4416 m^3, a hearth diameter of 13.6 m and 40 tuyeres. It is one of the two large units at the site along with the Schwelgern BF2 and has a nominal capacity of 3.5 million tpy. Following extensive development and research work, the newly developed oxygen technology, the world's first SIP plant, was successfully commissioned at Schwelgern BF1 at the end of 2020.

The SIP plant uses quantities of oxygen previously used by the blast furnace through either conventional stove blast enrichment or oxy-coal injection. The oxygen is supplied via a connection to the site high-pressure network and is delivered to the SIP plant. An associated pressure control station, buffer vessel and oxygen ring main around the blast furnace service the key plant components within specialist SIP boxes. One SIP box is used for each tuyere of the blast furnace, and they are located just above the tuyere platform. The boxes ultimately send oxygen to the SIP injection lances inserted through the blowpipe at each tuyere. The use of high-pressure oxygen (typically > 20 bar g) is a requirement of SIP technology. There is also a nitrogen supply, available for use primarily in safety functions, including a filter station and another ring main around the blast furnace. Both media serve the 40 specialist SIP boxes. The principal function of each SIP box is to provide the means for the generation of the shockwave and a high kinetic energy oxygen pulse to a dedicated SIP lance inserted through the blowpipe of each tuyere. Figure 3 shows an example of the on-site installation situation of the SIP boxes in the combined network.

Each lance, in addition to the periodic pulses of high energy oxygen, receives a continuous flow of the so-called basic load oxygen, to ensure adequate lance cooling. Nitrogen is also available for this purpose via the SIP box supply and automatically switches to emergency cooling in the event of oxygen becoming unavailable. The plant is equipped with a safety function which, when required, quickly diverts stored oxygen away from the blast furnace via a vent pipe and nitrogen purge.

Figure 3: Image of tkse BF1 SIP boxes, located on a platform above the tuyere level.

Under normal operation, the short duration oxygen pulse is periodically superimposed onto the basic-load at a certain frequency. Each pulse lasts for only a very short duration (typically 0.5s) but the frequency of them is set to be at regular intervals by virtue of the dedicated control system. The control of the system and the admission of individual tuyeres is freely selectable to suit the blast furnace operation. For example, the pulse pattern, cycle time and total oxygen flow can be adjusted accordingly to match production requirements. However, the operator is provided with a great flexibility in how to use the system. For example, the admission of individual tuyeres is freely selectable and specific tuyeres can easily be targeted for additional oxygen should it be deemed necessary. An option currently not possible for all blast furnaces. The installed SIP plant can supply the blast furnace with up to 25,000 Nm^3/h of oxygen.

Operational experience / Operational insights

Understanding the impact of the full SIP system using all of the 40 tuyeres at Schwelgern blast furnace 1 (BF1) has been made possible through analysis of the operating data of thyssenkrupp Steel Europe AG.

As described at the beginning, the oxygen pulse improves the permeability of the packed bed through its penetrating effect. The resistance index K can be used for the consideration of permeability:

$$K \sim \frac{p_1^2 - p_{Top}^2}{\left({}^{RGV}/_{A_1}\right)^{1,7}}$$

where:

p_1 = bosh gas pressure

p_{Top} = top gas pressure

RGV = bosh gas volume

A_1 = shaft cross-section

This blast furnace specific index describes the pressure difference between the bosh and the top, which is set in relation to the bosh gas volume and the shaft cross-section of the furnace. When interpreting the calculated values, the inverse proportionality to

the permeability of the entire material stack in the shaft must be considered. Low resistance indices indicate good gas permeability.
The histograms in Figure 4 illustrate the changes detected during SIP operation compared to conventional blast furnace operation. First of all, one can see how the calculated values of the resistance index K has shifted to significantly lower values, indicating the permeability has improved.
A uniformly distributed gas pressure over the furnace cross-section is a characteristic feature of a stable blast furnace process. **Fehler! Verweisquelle konnte nicht gefunden werden.** also shows the maximum deviation of the measured shaft pressure differences between four measuring points positioned symmetrically around the furnace (histogram for stack pressure fluctuations Δp2).

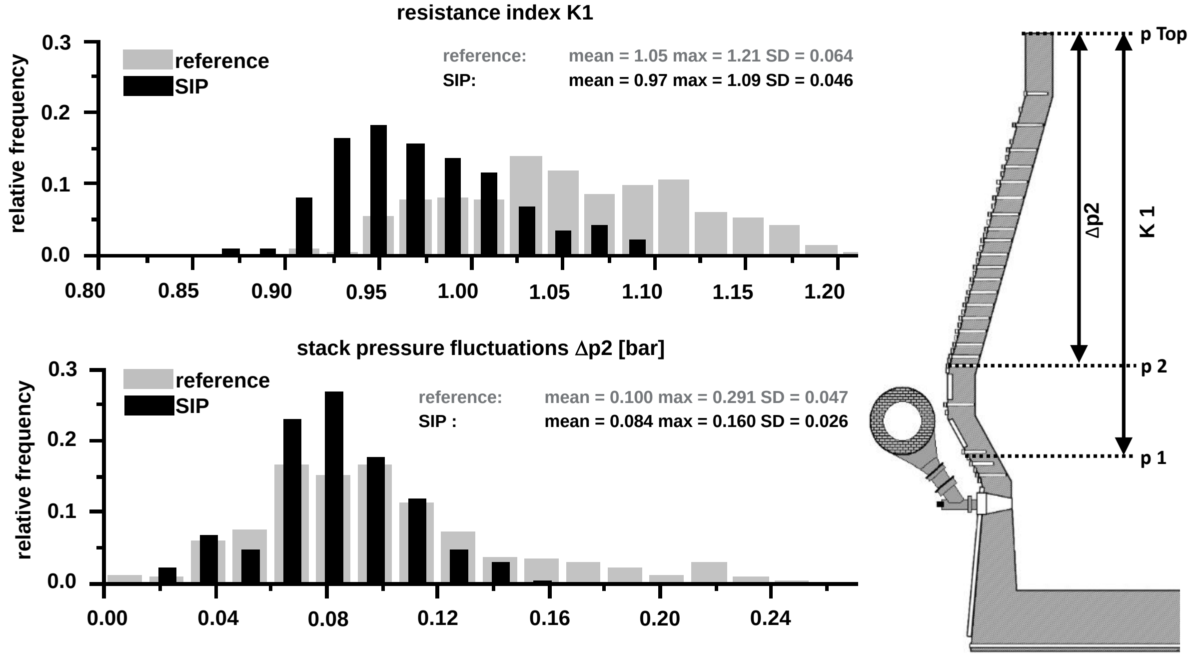

Figure 4 Comparison of the relative frequency distributions for the resistance index K1 and the measured delta p values between the reference and a SIP evaluation period.

The distribution function of the blast furnace operation with SIP shows a significantly smaller range of variation as well as a shift of the mean value towards smaller values, which suggests a significantly more stable process condition in the shaft (smooth blast furnace operation).
The injected SIP oxygen influences the gas flow profile and thus the temperature profile of the blast furnace. Schwelgern BF1 experience, shows the changes are fully pronounced after approximately 14 days and could be observed in all SIP campaigns and are therefore reproducible. This is characterized by lower blast furnace wall temperatures and the resulting lower heat load on the cooling elements in the blast furnace shaft, which results from the significantly improved permeability due to the center gas penetration.
A commonly known means of controlling the necessary permeability of the blast furnace is to adjust the burden distribution. As a rule, a large proportion of coke is charged in the center of the shaft, especially at high PCI rates, so that a coke channel is created in the center of the furnace. With the help of the central gas flow in the coke channel, the gas distribution mechanism is to be ensured via the coke windows in the cohesive zone. Good gas distribution across the furnace cross-section leads to an efficient blast furnace process and must be considered indispensable. However, there are certain limits to the control of gas distribution that can be achieved with the help of the burden

distribution pattern. This important parameter is checked regularly by recording temperature and gas concentration profiles through measurements with an in or above burden probe.
During the use of the SIP technology, a good gas distribution could be achieved without widening the coke channel by adjusting the burden distribution pattern. **Fehler! Verweisquelle konnte nicht gefunden werden.** shows the measured center temperature of the in-burden probe before and during a SIP campaign. The temperature range was initially at a level between 600°C and 800 °C with an average value of about 700 °C before the campaign. After the start of the SIP system, an increase in temperatures was measured. The temperature level of 1000 °C on average, which experience at Schwelgern BF1 has shown to be conducive to production, was reached after approx. 14 days. This temperature range was measured during the entire test period.
After the end of the SIP campaign, the original temperature level was gradually restored. A time-delayed drop in values with a dip after about 14 days, possibly shows an "echo" reverberation of the SIP technology on the process. The comparison of the measured temperature profiles of the periods with and without the SIP technology shows that an improved central gas flow was achieved.

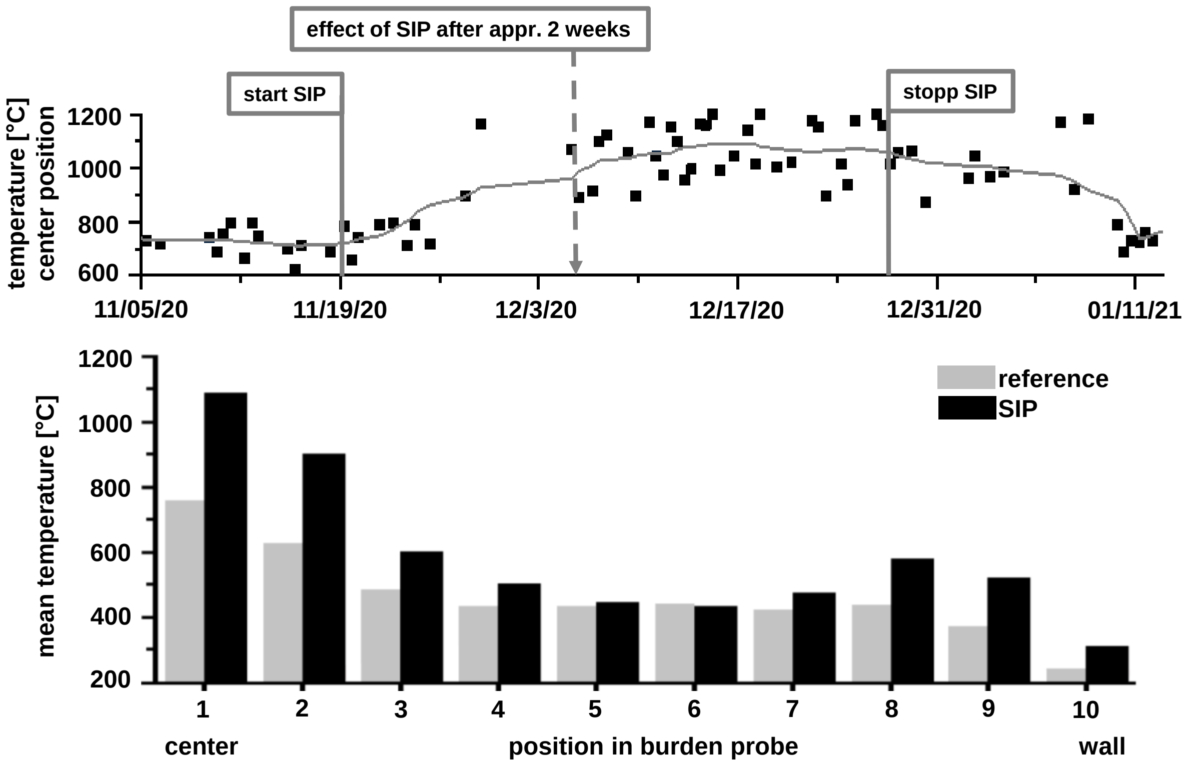

Figure 5: BF 1 in-burden probe temperature measurements, without and with SIP

An improved central gas flow also implies a lower gas flow at the blast furnace wall, thus also an effect on temperatures at the blast furnace wall. Figure 5 also shows this correlation - can be seen in the lower bar chart below the time series. During the same period, wall temperatures measured in the vertical orientation above tuyere level showed a noticeable improvement following operation of the SIP system. A shift from frequent to infrequent temperature peaks was initially observed, leading to stable temperature measurements at a lower level, after establishing the 14 day pattern already described.

Looking at the heat load of the lower mid stack, the lower stack and the tuyere band, it is noticeable that the fluctuation range in the three areas was significantly lower when the SIP system was in operation. The corresponding histograms are shown in **Fehler! Verweisquelle konnte nicht gefunden werden.**. The clearly lower loads of the tuyeres are particularly striking here. The area at the height of the lower stack also shows lower thermal loads. In conclusion, it can be said that by lower blast furnace wall temperatures and through this lower heat load on the cooling elements in the blast furnace shaft, a significantly improved central gas flow is confirmed.

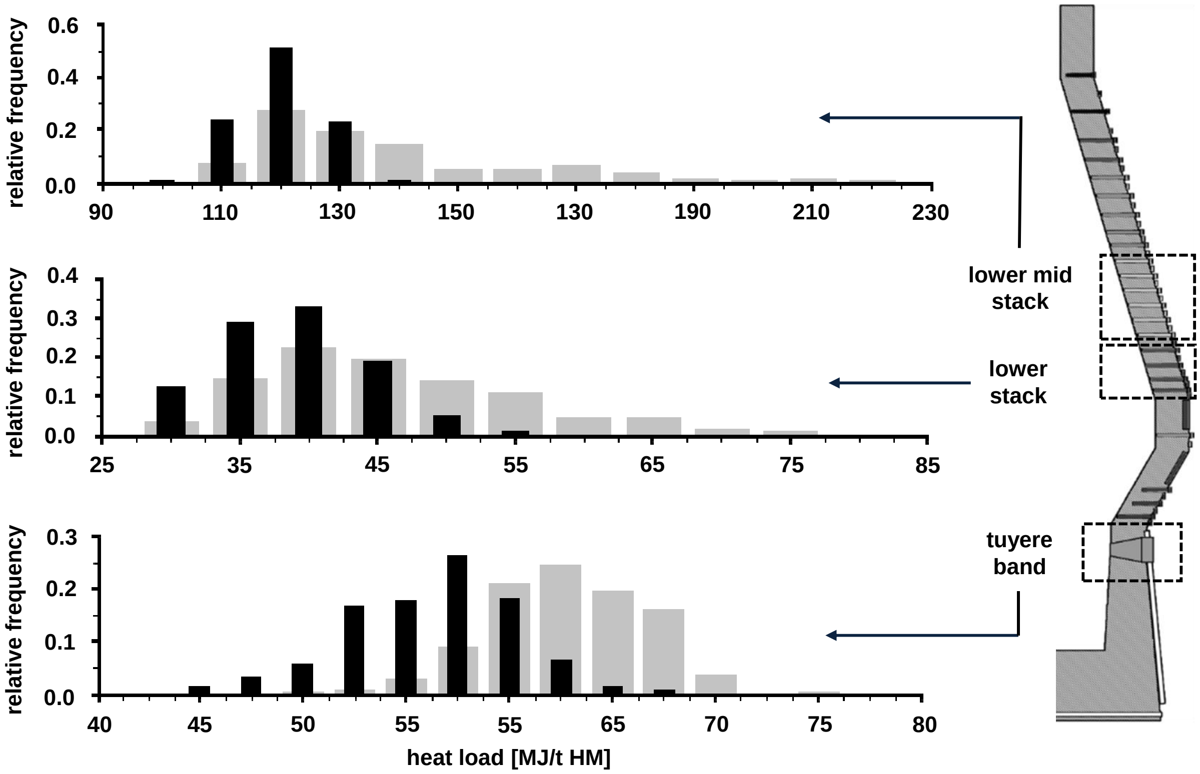

Figure 6: Comparison of the relative frequency distributions for the heat load values in 3 different areas of the BF1 between a reference phase and a SIP evaluation period.

Gas utilization optimized burden distribution

The positive effect on the ascending gas flow from the lower part of the blast furnace, allows the proportion of central coke to be adjusted. With the blast furnace able to adequately accept the gas through a reduced central coke chimney, more gas overall can be diverted through the coke windows in the areas of the cohesive zone into the burden layers. As a result, the descending burden achieves a better gas contact across a larger cross section area. In this way, gas utilization can be increased and blast furnace reducing agent consumption reduced.
The cleaner coke bed and enhanced raceway characteristics that are established by SIP, help enable an increase in the PCI rate. An increase in the generation of fine particles following a rate change can only be expected, as more coke degradation and less coal conversion can take place. However, SIP allows the change to be supported and if necessary, compensated for by a higher number of oxygen pulses to maintain conditions.
The burden distribution pattern remains the same, but the amount of coke charged is reduced at the same time due to a higher PCI rate, the coke chimney is consequently

reduced in size. However, this decrease takes place to a smaller extent than would be the case of a single coke portion change in the burden distribution.
During SIP campaigns it was possible to increase the PCI rate significantly, and to reduce the coke consumption consequently. A SIP campaign labeled as SIP 1a, (cf. **Fehler! Verweisquelle konnte nicht gefunden werden.**7) demonstrated a very good coke replacement ratio resulting from an improved gas utilization η CO. In the following SIP campaign, labeled as SIP 1b, the coke consumption was reduced beyond the increase in PCI rate, resulting in an achieved coke replacement ratio of greater than 1. This effect can be explained by the further improvement in gas utilization compared to the preceding SIP campaign, due to the greatly reduced coke chimney size that could be targeted from the burden distribution.

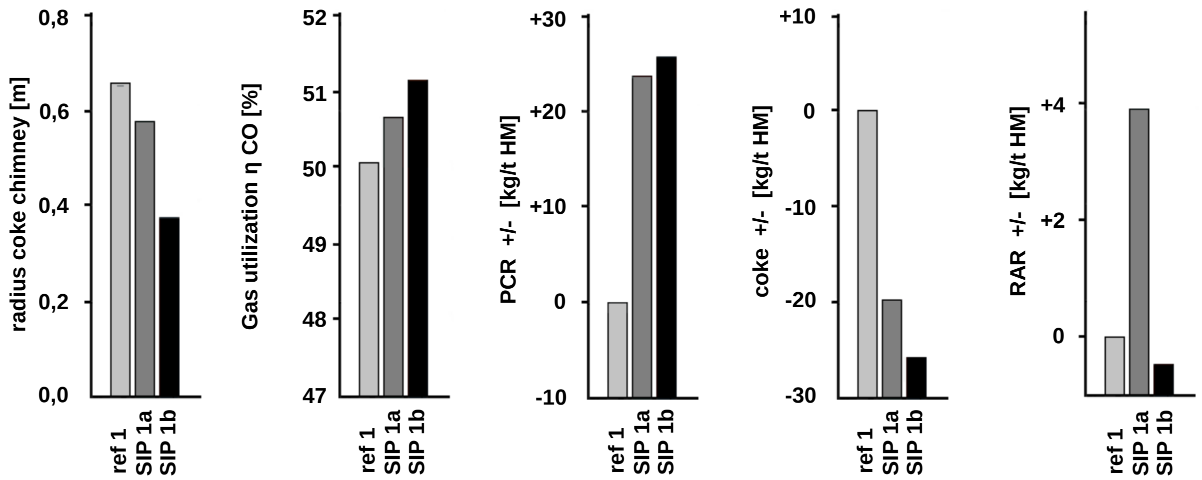

Figure 7 Comparison of average values of reference period with SIP evaluation periods

Improving of blast furnace operation and reducing carbon footprint

SIP substantially changes the gas flow paths in the blast furnace and therefore the location of process reaction zones. This, in combination with operational measures, also has an influence on the total blast furnace gas utilization and therefore directly on the efficiency of how the supplied reducing agent is utilized in the process. During all reference and SIP evaluation periods the gas utilization data defined as $\eta\ CO = (CO_2 / (CO + CO_2))*100$ was gathered from top gas analysis. For all evaluation periods (reference and SIP operation) the median value was determined. The results are given in Figure 8 (left). Summarizing, for each SIP evaluation period the gas utilization was between 0.6 % and 1.4 % higher than during the reference periods - even though periods with already good blast furnace working state were chosen as reference. It is also visible, that the first (reference 1, SIP 1a and SIP 1b) periods and the second periods (reference 2, SIP 2a and SIP 2b) have different total levels of gas utilization.
This is caused by the well-known fact, that gas utilization in a blast furnace usually decreases with an increase of production rate. To better visualize this effect Figure 8 (left) shows the gas utilization vs. the increase of production rate in relation to the reference 1, which had the lowest production rate.
During reference 1 the gas utilization median value was 50.1 % and during reference 2, the median value was 48.1 % but with a 61.6 tHM/h increased production rate. This gives a loss of around 0.32 % η CO for each increase of 10 tHM/h production. Also,

low production scenarios (not shown), for example, faced by thyssenkrupp Steel Europe during the COVID-19 pandemic situation, lie perfectly on this line, confirming this linear behaviour of the blast furnace process for normal operation.
As for the reference periods, the SIP evaluation period operational points can also be linearly connected to a good accuracy as visible. The highest gas utilization median value of 51.1 % was achieved during SIP 1b but with the lowest production rate of all SIP evaluation periods. SIP 2b reached the highest production rate of all SIP evaluation periods with 87.1 tHM/h more than reference 1, but in reverse has the lowest gas utilization median value of 49.1 %. In contrast to the normal operation line, the line for SIP operation is on a higher level and shows a slightly lower declination. Here the loss of gas utilization is only around 0.24 % each 10 tHM/h of production increase.
An increased gas utilization consequently comes in line with a reduced carbon footprint. Figure 8 (right) shows the median specific CO_2 emissions per tHM/h vs. the increase of production. Besides gas utilization also other factors influence the CO_2 emissions. For example, the first SIP 1a period was executed with conservative operational settings including a quite high reducing agent rate, whereas the following SIP periods more efficiently made use of the potential of the technology. Concerning the operational set point, mainly the hot blast and reducing agent rate, each 2nd SIP period, marked by the letter (b), better coincide with the corresponding reference. Comparing those SIP1b and 2b periods with the ref1 and ref2 periods of normal operation, depending on the production, a CO_2 reduction between 50 kg/tHM up to 100 kg/tHM was observed.

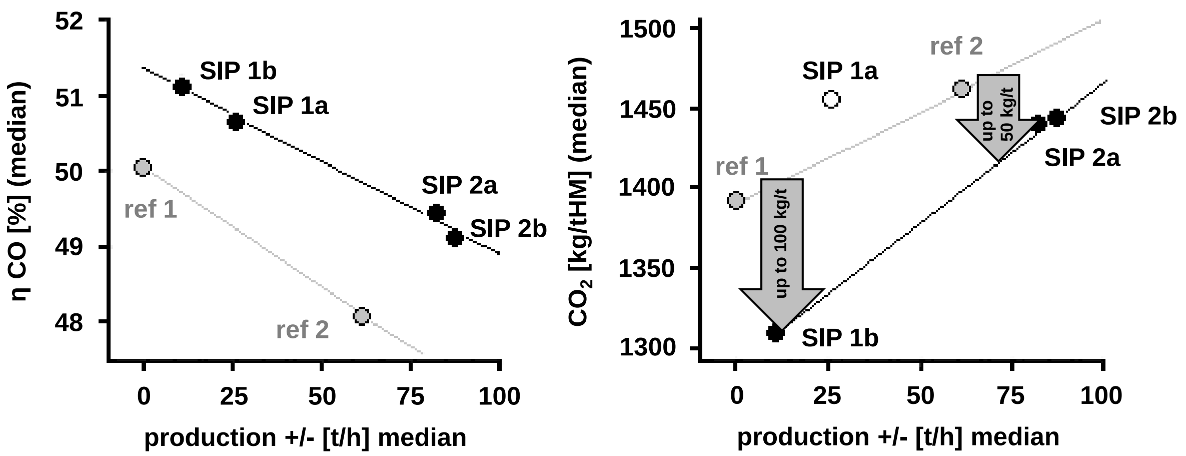

Figure 8 Gas utilization during reference and SIP evaluation periods in relation to production rate (left) and resulting CO_2-emission saving potential (right).

BF performance under reduced raw material qualities with SIP - a comparison between BF 1 (with SIP) and BF 2 (without SIP)

A period of approx. 6 weeks during the year 2021 was characterized by unusually poor raw material quality. At this time, 3 of the 4 blast furnaces, reacted to this situation with significantly worse blast furnace performance and increased reducing agent consumption. For clarification, a comparison between the two larger blast furnaces, Schwelgern BF1 and Schwelgern BF2, is provided in Table 1.

Table 1: Key data of the two large blast furnaces at thyssenkrupp Steel Europe in Duisburg.

	BF 1	BF 2	
inner volume	4.416	5.513	[m³]
working volume	3.775	4.769	[m³]
hearth diameter	13,6	14,9	[m]
tuyeres	40	42	[n]
tap holes	4	4	[n]

BF1 and BF2 can be compared with each other in terms of performance because they are supplied with the almost same mix of raw materials due to their proximity.
The already mentioned deteriorating qualities of sinter and coke are shown for both furnaces on the basis of selected key figures (cf.Figure 9 and 10). The individual box-plots summarise a period of one calendar week, with the exception of the black box-plot, in which the values of 9 months of 2021 were summarised. This boxplot is intended to show a comparison of the weekly values with these summarized 9 months. The light grey boxes indicate the 4-week period of lower coke quality.

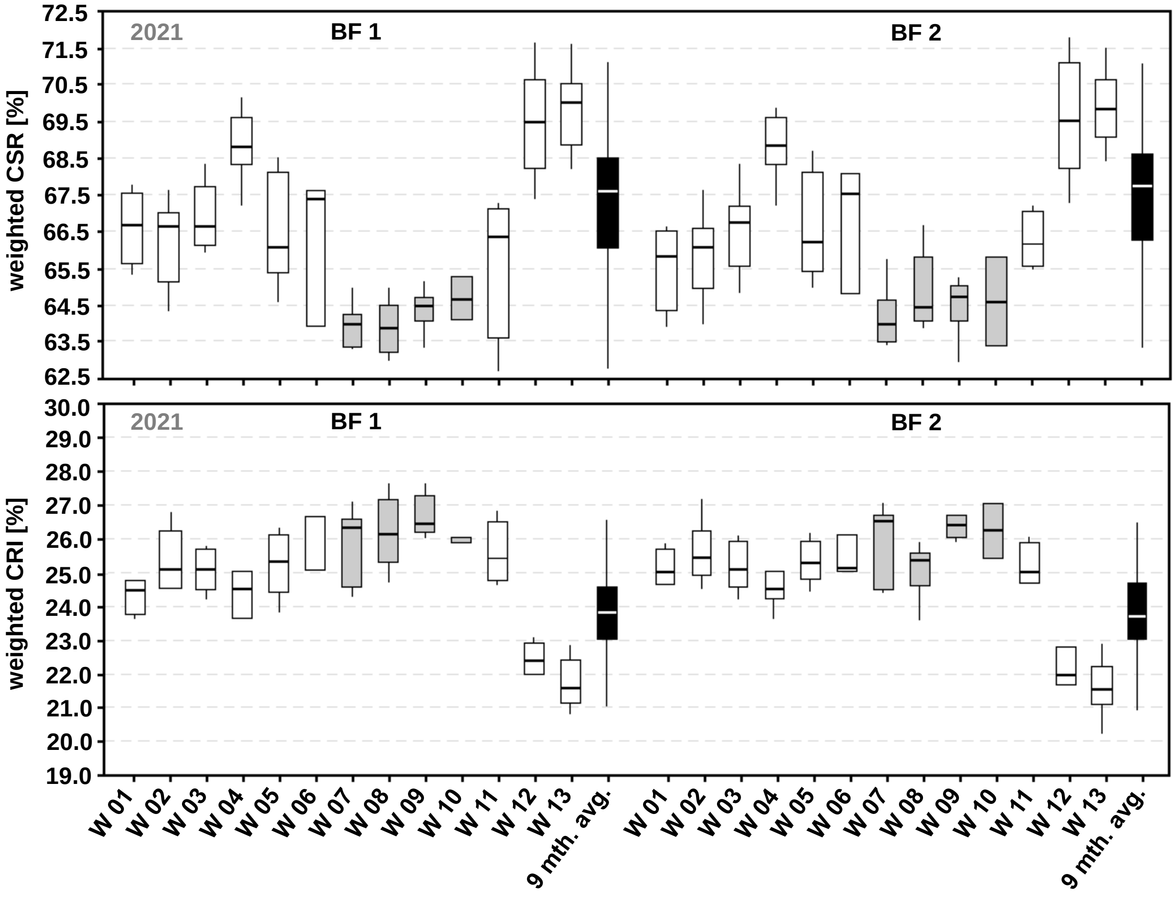

Figure 9: Development of the weighted CSR and CRI of the coke used at BF 1 and BF2

During this period, a remarkable decrease in coke quality can be seen - sharply falling CSR and correspondingly rising CRI values - see Figure 9. Both blast furnaces had to work with this unusually poor coke quality during this time. A rapid drop in weighted CSR values to partly 63 with large fluctuations especially in week 6 was caused by the supply of poor quality external coke sorts. The BF 1 values are slightly lower than BF2 due to a higher used portion of the external coke. As expected, the CRI value behaves correspondingly the other way round during this period and increases, with annual highs being reached in particular at blast furnace 1. In addition to this decrease in coke quality, it was also necessary to work with a strongly fluctuating basicity of the sinter used (cf.Figure 10). Basicity values ranging from just below 1.9 to just under 2.1 indicate very unstable conditions for fulfilling furnace performance. Both blast furnaces received the same mix from the three sintering plants existing at thyssenkrupp Steel Europe and were thus both confronted with a rather demanding situation.

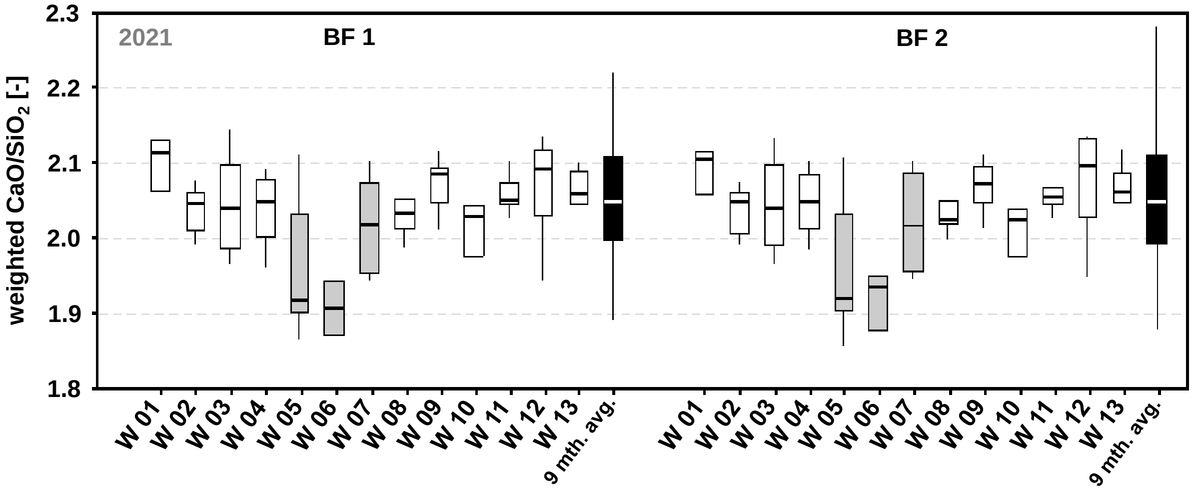

Figure 10: Development of the weighted basicity of the sinter used at BF 1 and 2.

Figure 11 and Figure *12* show in the upper part the development over time of some selected operating parameters (daily averages) in the period of 12 weeks for blast furnaces 1 and 2. For a better overview, horizontal lines also show average values for selected interim periods. In the lower part of the diagrams, the bar charts show the number of strong process instabilities per day. The periods of reduced burden material quality and, in the case of BF1, the start of SIP operation are shown.

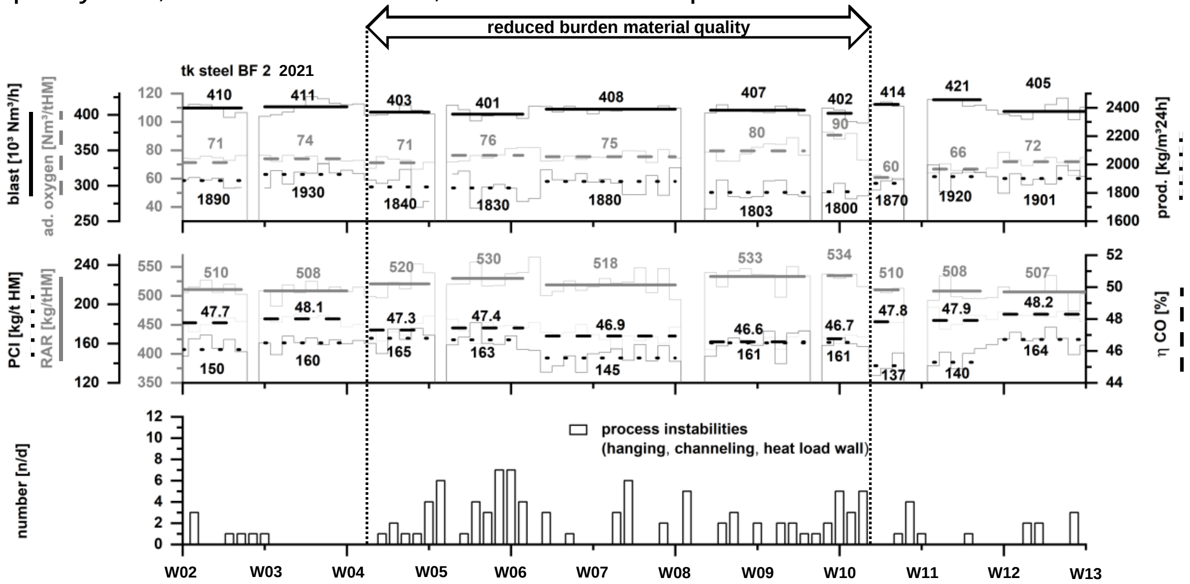

Figure 11: Changes in production-relevant parameters and events of BF2

BF2 shows a typical operating point with high oxygen input at the beginning of the mentioned 12 week period. For such an operating point, the reductant consumption of approx. 510 kg/t HM is in a typical range. The production as well as the PCI rate were limited by the hot blast pressure level. During week 4, a different type of ore was used at BF1 and BF2 for more than 2 weeks. This was accompanied by an adjustment of the basicity of the sinter; this short-term adjustment also resulted in greater fluctuations in the chemical analysis. The BF2 reacted to this change or to the change in softening and melting temperatures with frequent and strong process instabilities (heat load wall, hanging, channeling). The result was an increase in the consumption of reducing agents by approx. 10 kg/t HM to an average of 520 kg/t HM due to the drop in η CO. However, the measures taken to stabilize the process only had a limited effect, as imported coke of reduced quality was now used also. During this period, the process instabilities increased repeatedly and the reducing agent consumption rose to 530 kg/t HM on average. To support the stabilization efforts already made, the PCI rate was now also lowered to approx. 140 kg/t HM. The frequency of process instabilities decreased slightly, the reducing agent consumption was lower at 520 kg/t HM on average. The target production could not be reached, but the production level could be stabilized. After the repair shutdown in week 8, the PCI rate was increased slightly and an attempt was made to realise production with a higher oxygen input. Despite a specific oxygen consumption of up to more than 90 Nm³/t HM, the production level decreased and the reducing agent consumption increased to more than 530 kg/t HM. Finally, the operating mode was changed considerably, the use of oxygen was greatly reduced and the PCI rate was repeatedly lowered. At this time, the coke quality also improved. In week 12, the typical operating point like before the period with the reduced raw material quality could be reached again.

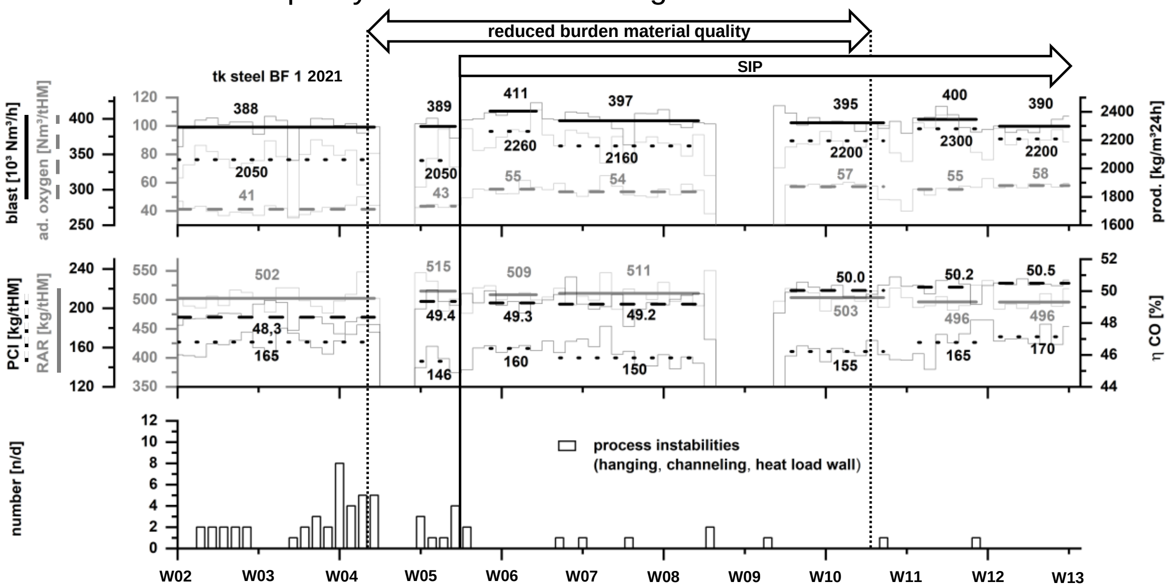

Figure 12: Changes in production-relevant parameters and events of BF1

BF 1 was blown in after the relining and was at production level of approx. 90 % after the ramp-up phase (cf. Figure 12 starts after the ramp-up). However, the period was still marked by process instabilities such as hanging and channeling, which occurred far above normal levels. Despite this problem, the PCI rate could be increased to 175 kg/t HM by adjusting the process control. This resulted in an average reducing agent consumption of 502 kg/t HM and a PCI rate of 165 kg/t HM for this period. However, a higher production level could not be achieved.

A planned shutdown for maintenance work was carried out at the end of week 4. After recommissioning, the usual process adjustments were made, the reducing agent consumption was modified, and the PCI rate was increased. The SIP plant was restarted during week 5. The specific oxygen consumption was increased by approx. 10 Nm³/t HM as a result. It is noticeable, especially in comparison to BF 2, that the process instabilities almost no longer occurred. Furthermore, it is remarkable that the reducing agent consumption of BF 1 (509 kg/t HM) was approx. 20 kg/t HM lower than that of BF 2 (530 kg/t HM) during this period. A comparison of the η CO of the two blast furnaces also reflects this. The η CO of BF1 could be held at a stable high level of over 49 % (despite the poor coke quality), while the η CO at BF2 had decreased to approx. 47 %. In addition, the hot blast quantity could be increased by approx. 20,000 Nm³/h due to the improved conditions. The production output of 100% was achieved despite the raw material problem, whereas the BF 2 was not able to achieve more than approx. 85% of its production capacity despite all the process-related adjustments. The output of BF 1 even had to be throttled by reducing the amount of blast so that the officially approved production limit was not exceeded. In addition to BF 2, the other two tk blast furnaces (BF 8, BF 9) also had process-related problems due to the quality of the coke and did not reach the planned production output. Therefore, as a preventive step, the PCI rate at BF1 was also reduced from 170 kg/t HM to 140 kg/t HM for a short period of time. After a maintenance shutdown between week 8 and week 9, BF1 was able to operate with a reducing agent consumption of just over 500 kg/t HM and an η CO of 50 %. In comparison, BF 2 had a reducing agent consumption of over 530 kg/t HM and an η CO of less than 47 %. With the improvement of the coke quality, the efficiency of the blast furnace also improved, so that the blast quantity had to be reduced repeatedly in order not to exceed the officially approved production limit. Finally, the reducing agent consumption could be further adjusted to 496 kg/t HM, with an η CO of 50.5 %, whereas after optimization BF 2 only achieved a reducing agent consumption of 507 kg/t HM with an η CO of 48.2 %.

Conclusions

The evaluations shown above prove a positive influence on process stability as well as on productivity. By using SIP-technology, the BF carbon footprint can be reduced as well as the operational cost.
The improved process stability and permeability are shown in the comparison of the value distributions of several measured blast furnace parameters during reference and SIP periods. They demonstrate that the blast furnace working state, indicated as fluctuations of the pressure drop from hot blast to top, is smoother during SIP operation.

The direct comparison between a blast furnace operating with SIP-technology (BF1) and blast furnace without SIP-technology (BF2), both using almost the same raw materials shows higher productivity at a lower fuel rate accompanied by smoother furnace operation. It was also obvious, that the effects of the use of low quality raw materials onto furnace operation were significantly lower when using SIP.

Resulting from these positive effects the SIP plant at Schwelgern BF1 today is fully adopted and incorporated into blast furnace operating practice.

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