Operational Flexibility for the Blast Furnace Using the Sequence Impulse Process

Ross Edmond[1], Colin Morrison[1], Rainer Klock[2],
Jiho Juen[2], Bartosz Smaha[3], Hauke Bartusch[4]

[1]Primetals Technologies Ltd
7 Fudan Way, Thornaby, Stockton-on-Tees, TS17 6ER, United Kingdom
Email: ross.edmond@primetals.com
colin.morrison@primetals.com

[2]thyssenkrupp AT.PRO tec GmbH
thyssenkrupp Allee 1, 45143 Essen, Germany
Email: rainer.klock@thyssenkrupp-materials.com
michael.juen@thyssenkrupp-materials.com

[3]thyssenkrupp Steel Europe AG
Kaiser-Wilhelm-Straße 100, 47166 Duisburg, Germany
Email: bartosz.smaha@steeleurope.com

[4]VDEh-Betriebsforschungsinstitut GmbH
Sohnstraße 69, 40237 Düsseldorf, Germany
Email: hauke.bartusch@bfi.de

Summary

Sequence Impulse Process (SIP) technology is attributed with providing a positive influence on blast furnace performance during a period of reduced burden material quality. Regular oxygen pulsing at the tuyere provided by the technology is credited with improving raceway conditions, and in turn the blast furnace process, to such an extent that the anticipated negative impact was largely mitigated.

The changes in material properties at the time are shown and compared to their typical quality, with the factors driving the deterioration in quality explained. The resulting performance difference between two large blast furnaces, both charged with very similar material quality but with one of them able to operate with SIP, provided a basis for the evaluation.

The approach to the theoretical minimum fuel rate of both blast furnaces during this period was determined from operational data and the findings are reported. The evolution of other key performance indicators and the changing process conditions during the reduced burden material quality period provided further evidence of the SIP effect.

The developmental path and principles at work with SIP technology are also briefly discussed within this paper.

Keywords

SIP, Oxygen, Pulsing, CO_2, PCI, Raceway, Permeability, CSR, CRI

Introduction

The operation of blast furnaces, especially of large units, close to a thermodynamic minimum input of energy and a low rate of reducing agents, requires a high-quality consistent feed of raw materials [1,7,8]. In addition, approaching a high productivity output is normally only achieved under a condition of continuous and consistent operation of the blast furnace. If the thermodynamic optimum is not reached, and the deviation is too large, then a decline from the ideal point of operational efficiency can only be expected. The desired physical and chemical properties required for a particular blast furnace to perform well and support this operational ideal, are known by operators, who often define a specification based upon a minimum quality criterion.

The German steel producer thyssenkrupp Steel Europe AG (tkSE) operates four blast furnaces at their integrated steelworks in Duisburg. The two larger units at the site are Schwelgern BF1 (IV 4,416m^3) and Schwelgern BF2 (IV 5,513m^3). BF1 is equipped with SIP technology, an oxygen pulsing technology at the tuyeres which has been credited with providing a significant improvement to BF1 performance since it came into service in late 2020 [2].

Image 1: View from cast house floor at Schwelgern BF1 where SIP Technology is installed

This paper examines an operational period at the Duisburg steelworks when all the blast furnaces were required to receive raw materials of a quality significantly below their standard specification. Introducing challenges for operational control and productivity. Similar material qualities were used at each blast furnace - but the impact upon the operations, was not necessarily the same. Of particular interest is a remarkable contrast in the performance of the two large units during this period.

The paper explores how SIP technology demonstrated an operational flexibility for the blast furnace during this period as the reduced burden material quality was much more easily accommodated by BF1, using SIP. The evidence is presented and discussed within the paper. It includes for the operating conditions at the time, establishing the approach to the expected thermodynamic optimum, as determined through a propriety model. Differences in the stack permeability and wall temperatures experienced by BF1 & BF2 during this time are also shown and discussed, as well as key performance indicators from all the Duisburg blast furnaces. Firstly, the development of SIP technology and its principles is briefly explained.

Technology Development & Principles

SIP technology was initially developed by thyssenkrupp AT.PRO tec GmbH and more lately in partnership with tkSE. The development path has been previously documented [3] and was achieved within a framework of research projects, both at a laboratory and industrial scale. The technology was advanced and successfully adapted for blast furnace application, leading to the full system installation at Schwelgern BF1. Image 1 shows a view from the cast house floor, where dedicated SIP boxes for each tuyere can be seen located above the tuyere platform. An exclusive cooperation agreement with Primetals Technologies makes SIP technology available to the worldwide market for operators to use to stabilize their process and increase the performance of their blast furnace assets.

SIP is an oxygen pulsing technology with high kinetic energy. A proportion of oxygen, currently used by the blast furnace process and delivered through hot blast enrichment, can instead be used by SIP, maintaining the desired level of total oxygen addition required by the production process.

The principle of SIP technology is to reduce the negative impact of fine particle accumulation at the raceway boundary. This can result from coke degradation and incomplete conversion of injected coal. The fine particles can form blockages ultimately impeding the ideal gas and liquid flow paths towards the center of the blast furnace.

SIP oxygen is injected through lances at the tuyeres, targeting the transition region at the back of the raceway and into the packed bed behind. The normal oxygen concentration profile into a blast furnace raceway depletes very quickly as, reactions proceed, and it is consumed [4]. However, with each pulse, SIP can extend this profile deeper into the raceway and beyond, as the two important properties of SIP - energy and oxygen, come into play. Blockages are disrupted and oxygen is made available for rapid reaction with fine particles, increasing coal conversion rates and preventing blockages from being re-established in the process. This is depicted in image 2.

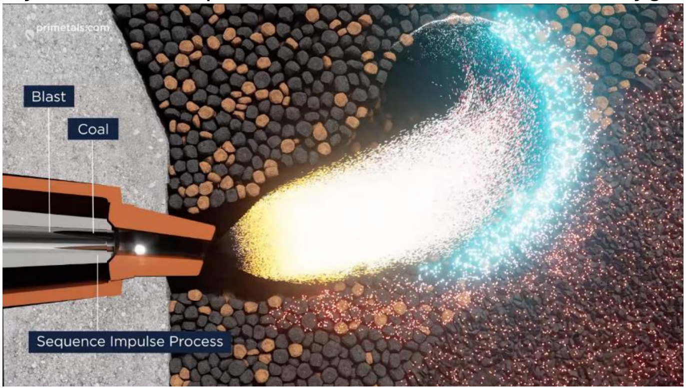

Image 2: Influence of the SIP Raceway effect

Applied at every tuyere, the benefits originating from the raceway such as, increased local permeability, the improved flow paths, and an increase to the raceway length, have translated into benefits for the overall blast furnace process. A reduction in the total fuel rate, reduction of CO_2 emissions, a more stable operation at high PCI rates and the potential to unlock a greater productivity, have all been attributed to the influence of the SIP effect [2].

Impact During Reduced Burden Material Quality

The period of reduced burden material quality lasted for approximately six weeks and is defined as between CW44 and CW50 of the 12-week window shown in figure 1 in dark red color. It is characterized by an overlapping deterioration and increased variation of the coke and sinter properties. In addition, frequent burden changes occurred with swings in the quantities of pellets and lump ore charged.

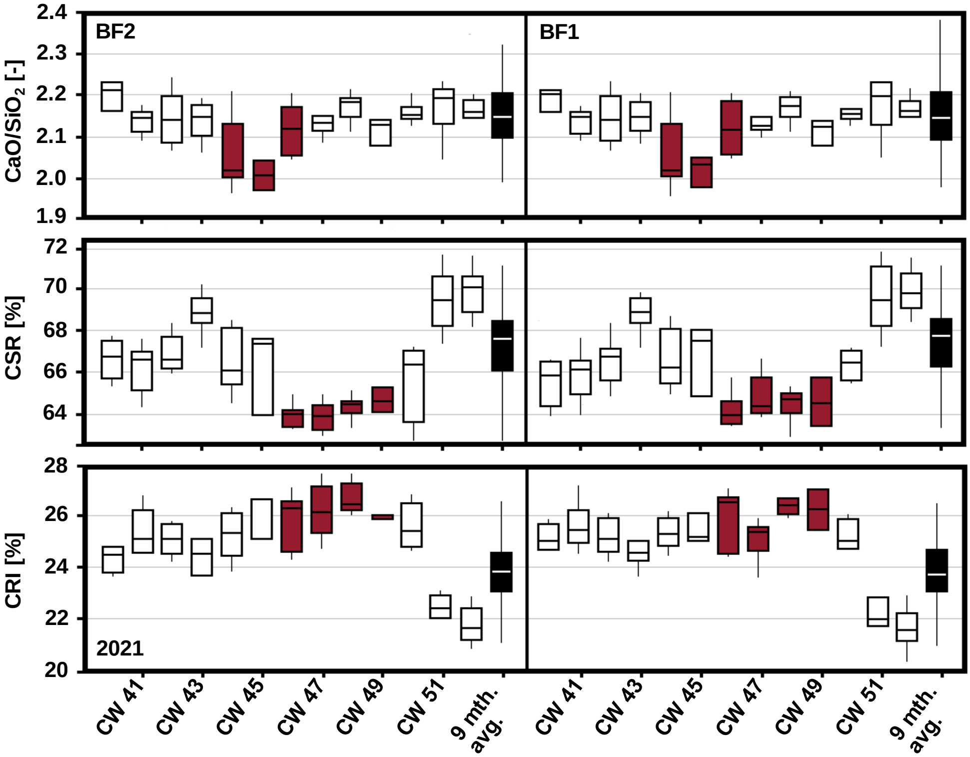

Figure 1: Evolution of Coke & Sinter properties during the 12-week window

The individual “box and whisker” plots summarize a period of one calendar week, except for the single boxplot in black, in which the values of the previous 9 months are summarized and can be considered the ‘normal’ value for the parameter. They show the median value, interquartile range, and the boundary beyond which sample values can be considered as outliers.

The blast furnaces operate a predominately sinter burden and it was necessary to work with a strongly fluctuating sinter basicity introducing unstable conditions. Both large blast furnaces received approximately the same mix from the three sintering plants available and were thus both confronted with a rather demanding situation.

During this period, a remarkable decrease in coke quality can be seen - sharply falling CSR and correspondingly rising CRI values. Both blast furnaces had to work with this poor coke quality during this time. A rapid drop in the weighted CSR values to approximately 63% with large fluctuations especially in CW 46, was caused by the supply of a poor-quality external coke.

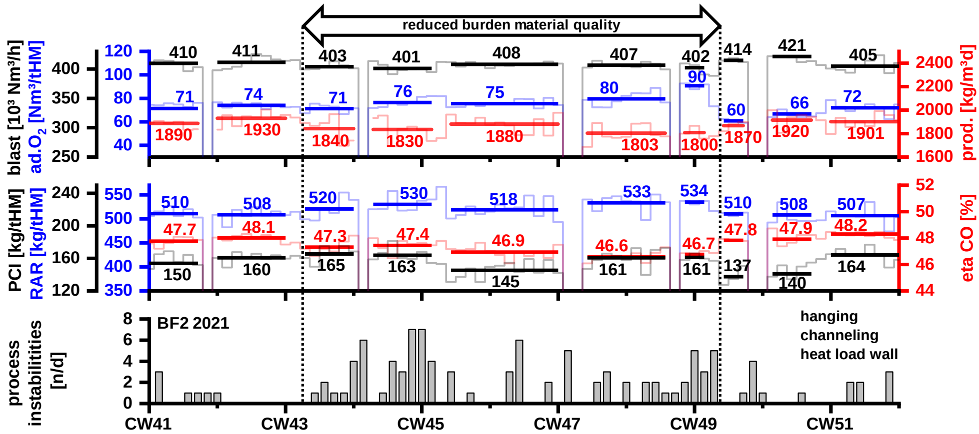

Figure 2: Changes in production relevant parameters and events of BF 2

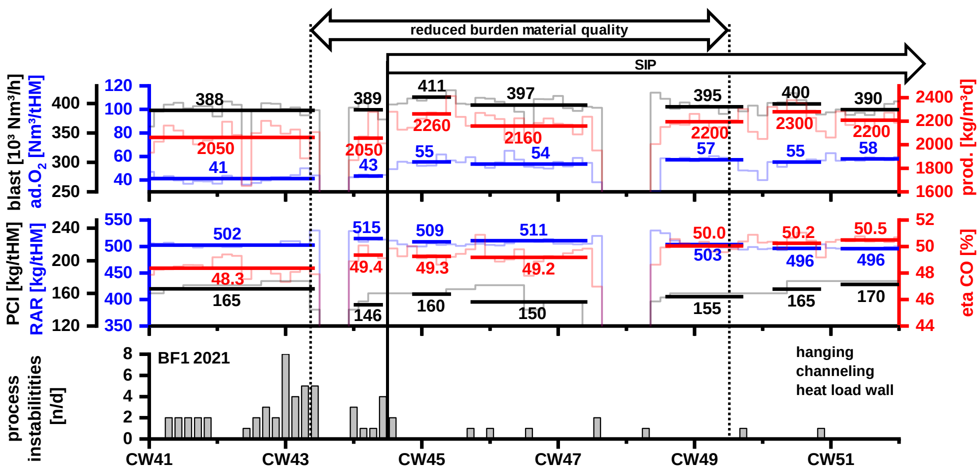

Figure 3: Changes in production relevant parameters and events of BF 1

Figures 2 & 3 show the development over time of some selected operating parameters for both BF2 and BF1 respectively. The period of reduced burden material quality is again shown and, in the case of BF1, the start of SIP operation.
A description of the full operational phenomena has been given elsewhere [5]. In summary, the direct comparison between a blast furnace operating with SIP technology (BF1) and a similar blast furnace without it (BF2), shows a higher productivity at a lower fuel rate. This performance was accompanied by a smoother furnace operation on BF1, as seen in the dramatic decrease in process instabilities of figure 3 such as hanging, channeling and high heat load events.

Some of these effects can be seen in Figure 4. It shows the relative frequency of process conditions during the reduced burden material quality period for BF1 and BF2, compared to the conditions outside this period.

At BF2, the situation required a fundamental adjustment of the blast furnace process, particularly due to frequent instabilities. One of the measures implemented was the reduction of the blast volume. Essentially, this allowed the permeability resistance F2 to be set to typical values at BF2, (F2 is a function of the pressure difference between the blast and top gas, and other operational measurements [9]). However, critical values and process instabilities still occurred with low frequency. As a result of the raw material quality and adjustments, the productivity of BF2 decreased. On the other hand, a contrasting picture can be seen at BF1 with SIP. The improved permeability of BF1 enabled an acceptance of greater blast volumes leading to an increase in productivity.

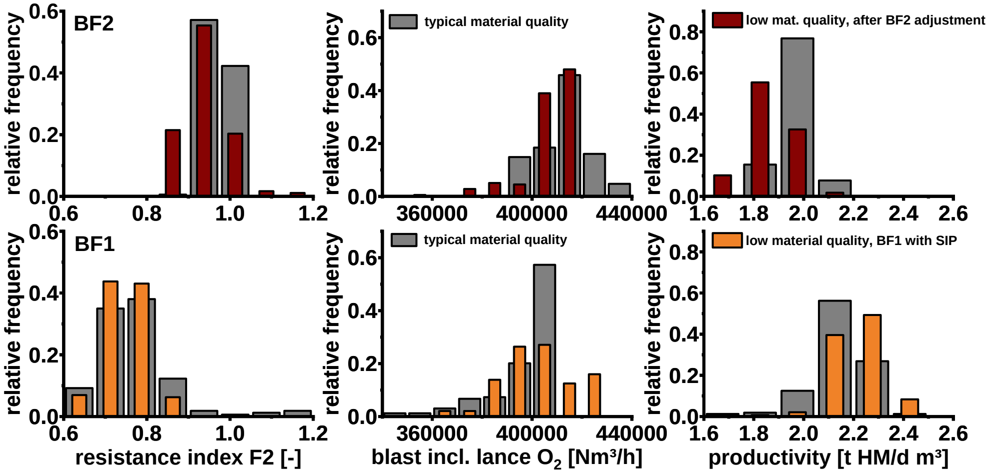

Figure 4: Permeability resistance, blast volume & productivity of BF 2 & BF 1 (with SIP) during reduced burden material quality compared to the performance during typical material quality

Figure 5 shows a difference in the occurrence of high wall temperatures in the shafts of the blast furnaces, which often indicates non-ideal gas flow. The measurements represent temperatures from the bosh to the stock line. On BF2, during the reduced burden material quality period, they increased dramatically compared to operation with a typical material quality. However, on BF1 the SIP effect was able to compensate the quality issue with a smoother operation, improved permeability, and a more central gas flow, which is seen as a positive effect of the SIP operation. This led to a reduction in the temperatures, even during the reduced burden material quality period.

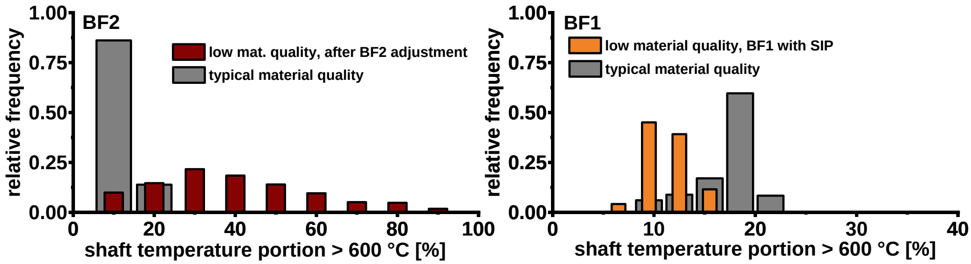

Figure 5: Wall Temperatures of BF 2 & BF 1 (with SIP) during reduced burden material quality compared to performance with typical material quality

Minimum Fuel Rate Model

For the blast furnace process optimization, tkSE uses various models developed in-house. To understand the approach to the thermodynamic optimum, is the so-called Minimum Fuel Rate (MKV) model. This model enables the calculation of the metallurgically feasible fuel consumption for the operating state of a blast furnace, under given conditions and its potential for fuel savings. The model illustrates a defined working area, determined by heat and chemical boundaries, using operational data, blast furnace properties, quantities of burden materials, and other measured parameters. The chemical boundary line, established by the gas/wustite equilibrium, and the heat boundary, determined by the required exposure of the burden to the ascending heat of the gas, describe the potential range of operational fuel consumption [6].

The graphical depiction of the model's calculation results can be seen in Figure 6. In this graphic, the left y-axis describes the specific carbon rate required for heating and reducing ores in kg/tHM. The right y-axis represents the actual used total amount of reducing agents. The x-axis shows the proportion of indirect reduction in the total reduction work of the blast furnace.

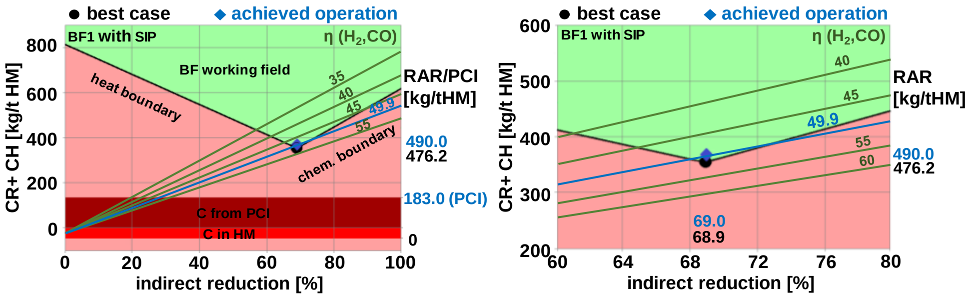

Figure 6: Example view of the graphical presentation of the MKV model results with detailed view (on the right)

The lines originating from bottom left to top right represent the possible gas utilization values (at a theoretical constant gas utilization η), and the blue line represents the actual gas utilization. Furthermore, the heat boundary (coming from the top left) and chemical boundary (rising towards the top right corner) for the given process data, are determined and shown. The intersection of these two lines is important and represents the optimal operating point of the furnace at a given time. This is indicated as the minimum possible fuel consumption. The field that emerges upwards, (shown in green) displays all the possible operating points above these constraints.

Using the MKV model, evaluation periods of the furnaces within the 12-week window were extensively examined before, during, and after the use of reduced burden quality material for BF1 and BF2. In the upcoming section, the results of the selected model calculations are presented and discussed.

Results – Before Reduced Burden Material Quality

The initial situation before the use of reduced burden material quality and the operation of BF1 without the SIP system, and BF2 are presented in Figure 7 using the MKV model.

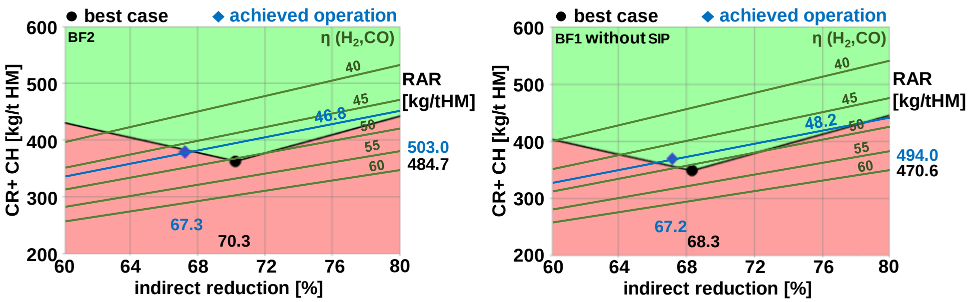

Figure 7: Results of the MKV model (left: BF2, right: BF1) for the initial state before the period of reduced raw material quality, and BF1 without SIP operation.

As both blast furnaces used similar feedstock compositions, the chemical conditions and enthalpies required for the feedstock were equally similar. The generally higher cooling losses of BF2 result in the heat boundary of BF2 being slightly higher. The lower heat demand of BF1 thus leads to a lower theoretical RAR (model best case) of BF1 of approximately 471 kg/tHM, while the model for BF2 has a value of approximately 485 kg/tHM. Due to the better gas utilization of BF1 it also has a lower RAR of 494 kg/tHM compared to 503 kg/tHM at the current operating point. The difference between the optimal RAR and the current RAR of BF1, is higher at 23 kg/tHM than that of BF2 at 18 kg/tHM. However, the current operating point of BF1 is well above the thermal and chemical limit, so its operating point can be considered "stable". In contrast, the operating point of BF2 sitting on the heat boundary is at the thermal limit.

Results – During Reduced Burden Material Quality

The situation of BF1 and BF2 during the use of reduced burden material quality with the help of the MKV model is shown in Figure 8. During this period, BF1 was operated with the SIP technology.

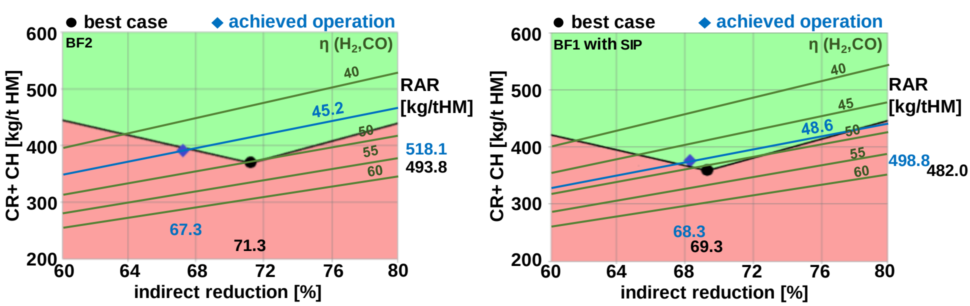

Figure 8: Results of the MKV models (left BF2 and right BF1) for the situation during the period of reduced raw material quality with SIP operation on BF1.

The model data shows that, compared to the initial situation, the heat demands of both BF1 and BF2 have shifted to slightly higher values due to a change in feedstock composition. However, the shift in the thermal limit of BF2 is much more pronounced. The cause of this is the increase of cooling losses in BF2 by more than 60%, (similar to the effect of figure 5) due to the negative impact of the lower quality raw materials. Thus, the operating range (green area) of BF2 was more strongly restricted and the position of the optimal operating point (model best case) was accordingly negatively influenced. In contrast, no significant increase in the cooling losses were observed for BF1. The reason for this is the improved permeability and blast furnace operation brought about through SIP technology.

The production data evaluation period for BF2 shows a significant decrease in gas utilization of 1.6%-points. The RAR has increased significantly from 503 kg/tHM to 518 kg/tHM (max. 534 kg/tHM, see Figure 2) compared to the initial situation. Similarly, the distance between the current operating point and the optimal operating point has significantly increased from 18 to 24 kg/tHM. The current operating point is now slightly outside the working range calculated by the model, reflecting the observed unstable state of BF2 during the production data evaluation period.

The operation of BF1 with SIP during the reduced burden material period provides a completely different picture. At or shortly after the beginning of the reduced burden material campaign, BF1 was operated together with the SIP plant. This allowed for the direct investigation of the influence of the SIP technology on the blast furnace working state under a poor raw material situation. The RAR remained almost the same with 499 kg/tHM compared to the initial value of 494 kg/tHM, although the working range was also limited at BF1 due to the altered burden composition. This was achieved by increasing the gas utilization by 0.4%-points and the indirect reduction by 1%-points. The distance between the current operating point and the optimal operating point decreased from 23 kg/tHM to 17 kg/tHM. The current operating point is stable due to sufficient distance from the thermal and chemical limits while still being close to the optimal operating point predicted by the model.

The results achieved at the BF1 with the SIP technology are particularly remarkable, considering that the production could be increased despite the raw material problems, while the production level of BF2 could not be maintained. Figure 9 shows the changes in production for all tkSE Duisburg blast furnaces including BF8 and BF9, during the reduced burden material quality period as well as other key performance indicators.

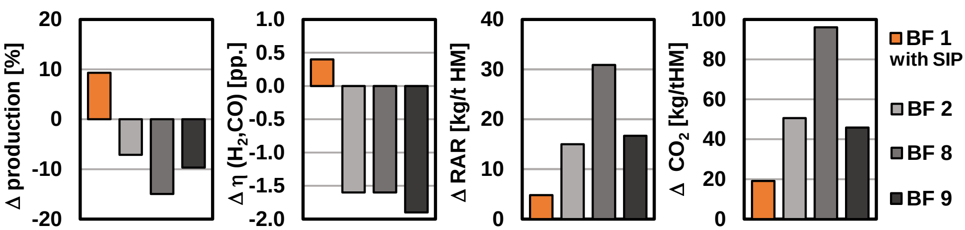

Figure 9: Performance indicators of all four blast furnaces at tkSE during reduced burden material quality period

Conclusion

Blast furnace operation was positively influenced by SIP technology during a reduced burden material quality period. Comparisons with blast furnaces at the same site, using the same material supply - but without SIP technology, showed they did not perform as favorably.

In contrast to the BF2, at the BF1 with SIP operation it was possible to approach the theoretical minimum fuel rate during this time. In addition, a smoother furnace operation was observed with a dramatic decrease in process instabilities such as hanging, channeling and high heat load events. This introduces possibilities for operators to increase the performance of their blast furnaces during periods of reduced burden material quality through oxygen pulsing technologies, such as SIP.

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