

## MONITORING THE BLAST FURNACE WORKING STATE BY A COMBINATION OF INNOVATIVE MEASUREMENT TECHNIQUES

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### Abstract

At blast furnace B at Salzgitter Flachstahl a series of innovative measuring techniques are installed to monitor the processes at the blast furnace top, making this furnace one of the best equipped furnaces in Europe. These techniques comprise full 2D measurement of the temperature profile of the top gas shortly above the burden surface, 3D radar scan of the whole burden surface and online measurement of the dust concentration in the top gas. After more than 5 years' experience with most of these techniques, they enable to better understand the complex chemical and physical interrelations occurring in the BF stack between the ascending process gas and the descending solid burden. A couple of examples of incidents that were monitored are presented in this article, including influences of charging programmes on top gas temperature profiles and influences of disturbed gas solids interaction on the BF working state. The new measuring techniques with tailor-made data processing enable the operators to gain a better picture of the processes currently occurring in the blast furnace, consequently supporting them in keeping the blast furnace operation as stable and efficient as possible.

**Keywords:** blast furnace; innovative measuring techniques; monitoring; SOMA; 3D TopScan; MAGS; DISSO.

### Introduction

Blast furnace Ironmaking has a history of centuries in Europe. During this period, the Blast furnace has matured and improved – a process which is still ongoing. Today, in Europe, the process line via the blast furnace and the basic oxygen furnace still accounts for more than 57% of the steel production [1]. Recent developments show that this share due to the high greenhouse gas emissions from the blast furnace will decrease in the future and will step by step be replaced mostly by direct reduction processes. But actual

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roadmaps of European Steel producers [2] still include the blast furnace process also beyond the year 2030.

Blast furnace B of Salzgitter Flachstahl GmbH in Germany is one of the best equipped furnaces around Europe concerning innovative measurement techniques. The latest improvements cover the measurement of a full 2D temperature profile at the BF top, Radar scanning of the burden surface, and experimental online measurement of the top gas dust concentration.

Even with the decades of experience how to operate a blast furnace and to constantly keep it as close as possible to its best working point concerning optimal usage of reducing agents and maximum productivity, situations occur where the process simply does not work as expected. Although no bigger changes of raw materials or the operational set point were carried out, the descend of material in the furnace might instantly start to get disturbed, which is known amongst operators as “hanging and slipping”. This describes a situation where the material descend firstly, starts to slow down, and then instantly slips down. Such slips in extreme cases, can end up in a stock line depth loss of 10 meters.

Also, an often-monitored process disturbance is the formation of preferential flow channels. Here the homogeneous process gas counter flow through the burden column is disturbed and local flow channels with high gas velocities build up. This results in a release of hot process gas to the top, bad gas utilisation and heterogenous reduction and melting of the burden.

Monitoring of the blast furnace process state by combined analysis of the innovative measuring techniques’ data is within the research focus of Salzgitter Flachstahl and VDEh-Betriebsforschungsinstitut for many years. Recent work revealed that there is a strong connection between the charging programme of a blast furnace and the top gas temperature development over time. Deviations from the typical top gas temperature profiles can be regarded as signs of bad working blast furnace stack processes.

## **Blast furnace B at Salzgitter Flachstahl**

### *Furnace description*

Blast furnace (BF) B is one of two medium sized BFs and one smaller BF operated at Salzgitter Flachstahl. It features a hearth diameter of 11.2 m and a working volume of 2,530 m<sup>3</sup>. 30 tuyeres blow in a hot blast volume of around 2.7 x10<sup>5</sup> m<sup>3</sup>/h leading to an average production of around 5,339 t of hot metal a day [4]. BF B is equipped with numerous measuring techniques to monitor its state, like pressure measuring lines and thermocouples at stack, belly and bosh level. The hearth refractory is also equipped with thermocouples to monitor the wear state. Additional to the measurements at the BF shell, several parameters at the in-and outflows of BF B are supervised. Besides these standard measuring’s, BF B is also equipped with some more innovative techniques, which will be discussed more in detail in the following sections.

### *SOMA 2D top gas temperature measurement*

SOMA measurement delivers information about a full 2D cross-section of the top gas temperatures just above the burden column. This is derived using an acoustical measurement principle. The speed of sound between senders and microphones, evenly distributed around the BFs top, is measured on multiple paths (Fig. 1).



Fig. 1. Installation situation of SOMA (source: [5]).

As the speed of sound depends, amongst others, on the gas temperature, the average temperature at each measuring path can be received. An advanced tomography algorithm then interpolates the path temperatures towards a full 2D profile [5]. The technique is not influenced by heat radiation and also not disturbed by influences of otherwise required constructions like measuring bars holding thermocouples. It offers a very fast and sensitive measurement interval of 30s. SOMA enables to measure the typical cycle of increasing top gas temperatures after charging and then the sudden temperature decreases after dumping of the next charge.

### 3D burden surface radar scanning

3D TopScan is a radar, mounted at the BF top. It scans the burden surface by radar beams multiple times a minute and delivers a 3D profile (Fig. 2).

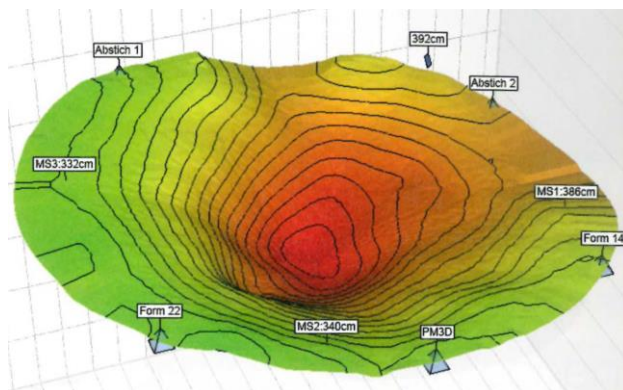


Fig. 2. Measuring result of 3D TopScan (source: [6]).

The current state-of-the-art at most other BFs is to plan and supervise the layer structure in the BF by charging models. Such models calculate the burden layers by the falling curves of the individual materials from the chute to the burden surface and by other material properties like angle of repose, friction coefficients, etc. These parameters are usually not fully validated to the real conditions and are often not very frequently adapted. Therefore the influence of material properties and their changes remains unattended. In contrast, 3D radar enables the monitoring of the real burden surface at the BF top. This also enables a better evaluation of the burden depth. Normally this is monitored by stock rods, sinking down with the burden surface. But such measurements only deliver the depth information at some points and do not allow to monitor the profile.

Additionally, the fast repetition of the radar scan enables to calculate local burden descend velocity profiles as well as to monitor effects like rolling of bigger particles on the burden top after charging during descend.

#### *Online top gas dust measurement by MAGS and DISSO*

A further new measuring technique developed by BFI and tested together with SZFG in the recent European research project DuMiCo are the online top gas dust monitoring devices MAGS and DISSO. The previous state-of-the-art was to only weigh the top gas dust mass when the dust bag or cyclone are emptied or when sludge is removed from the water treatment. This often only happens once a week and does not allow to draw conclusions on the short time BF working state. The continuously measured dust concentration emerging from the BF process via top gas is valuable information because the dust means loss of raw material, which must be disposed and causes disposal fees. Without online dust measurement, reasons for high masses of dust, stressing the water treatment system and causing high disposal fees can often not be explained.

To better track the dust generation from the BF process, at the up-take of BF B a sampling lance is installed. This lance guides a part of the top gas into a small scrubber at the BF top, positioned in front of the dust bag (cf. Fig. 3, right part). The water flow from this scrubber is then led to a stirring tank, where the DISSO sensor is installed. DISSO measures the washing water conductivity and therefore delivers an increased signal, when the concentration of solvable components in the top gas dust (e.g., alkaline compounds, heavy metal salts, etc.) increases. Furthermore, a flocculant is supplied to the water stream in the stirring tank to increase the size of the non-solvable dust particles. The water is then guided to a magnet sensor (MAGS [7], cf. Fig. 3, left part). The magnetisable and non-magnetisable dust particles flocked together are bound to the magnet sensor, which delivers a weight signal of the non-solvable dust from the top gas.

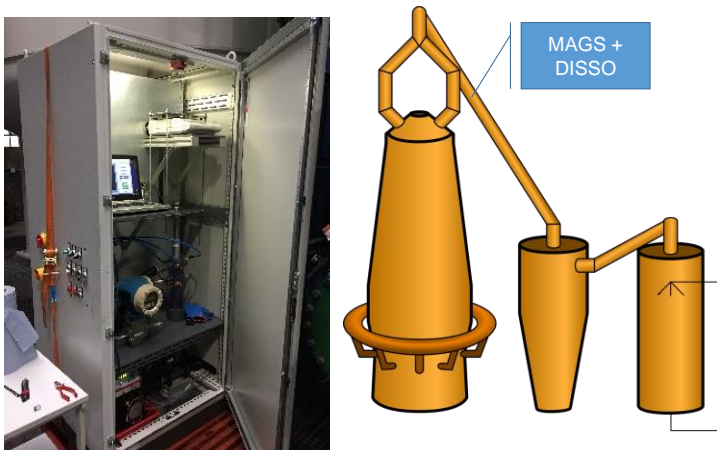


Fig. 3. MAGS sensor and measuring position of top gas dust concentration.

The DISSO and MAGS sensors measurement reliability has been proven by comparison to samples taken in parallel and analysed in the laboratory. The sensors deliver a high time resolved information (2 Hz) about the dust, currently carried by the top gas, which enables an explanation and observation of the dust generating mechanisms in the BF.

### Monitoring the blast furnace Working state

Starting in 2016 with the European StackMonitor project, SZFG uses the availability of the described innovative measuring techniques to systematically monitor the BF working state and to examine the interrelation between the different measured physical quantities. During this work, correlations between the charging programme, the resulting burden surface and the top gas temperatures were worked out. Also, interrelations between the burden layer structures, the burden descend behaviour and the gas flow homogeneity through the packed bed of the burden were examined. Both lead to an increased understanding of the relations between the multiple physical processes in the BF stack. Monitoring of these relations also helps during daily operation to better observe the BF process progress.

#### Monitoring the charging

Charging of the burden and coke layers in the BF defines the gas flow through the packed bed and, therewith material heating, progress of the reduction reactions and location of the melting zones. Therefore, many efforts are spent to optimise the charging programmes and the resulting layer structure within the BF stack. 3D radar and SOMA enable to supervise whether the intended layer structure is established in the BF as designated. The top gas temperature profile measured by SOMA has been found to be influenced mainly by two effects:

- the local thickness and material properties of the lastly charged layer and
- the temperature profile of the gas emerging from deeper stack regions.

The first effect is visualised in Fig. 4. The Figure provides at the upper part a diagram of the average top gas temperature over 1 hour. Vertical black lines mark the moment of charging a new layer. The charged material type (ore or coke) is noted at the

lines. The layer profile of the charged material measured by 3D TopScan is given as an example of three successive dumps in the lower part of Fig. 4. Red profiles mark ore charges, the black marks a coke charge. During that time, the BF was charged with a repeating programme of two ore and one coke charge.

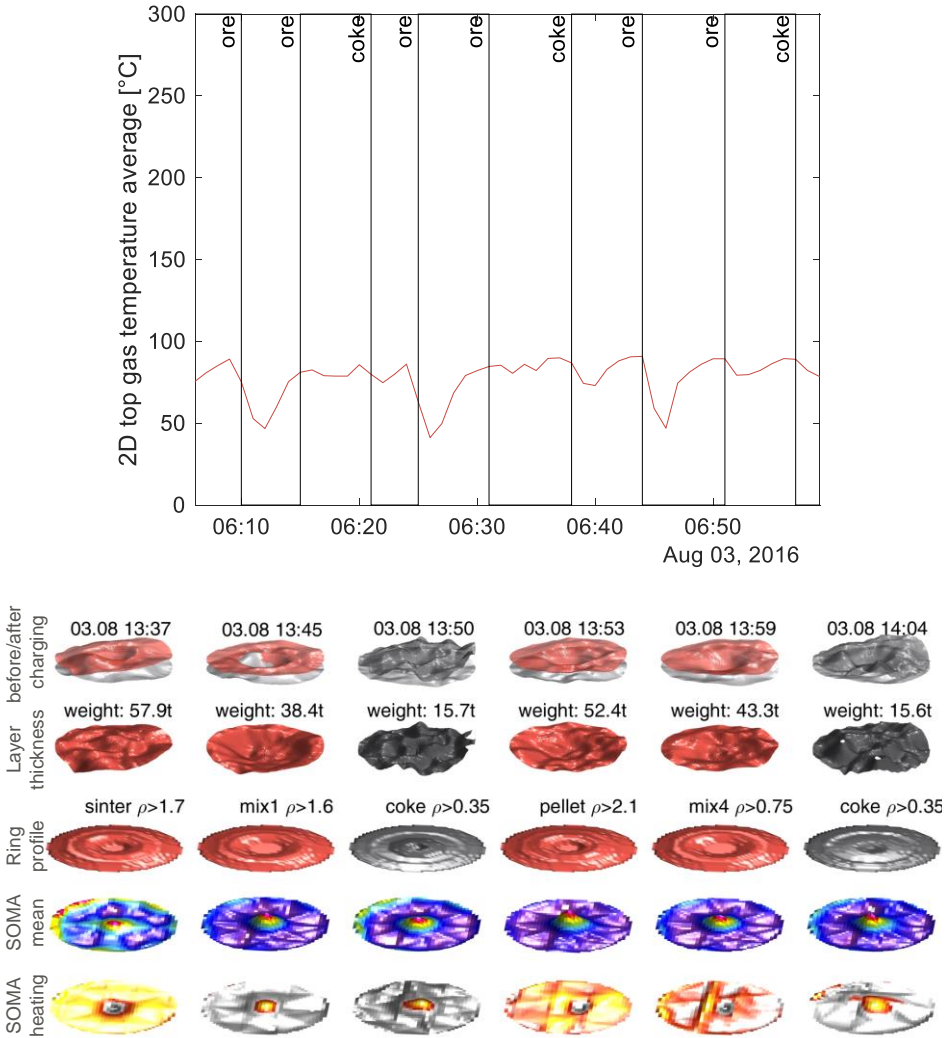


Fig. 4. Relation between top gas temperature and charging.

It becomes obvious in Fig. 4 that after charging the first ore charge, the top gas temperature noticeably drops, whereas after the second ore and the coke charge, the top gas temperature remains higher. The reason are the different rotation programmes the chute executes for the different layers. The first ore layer is distributed flatly over the whole top radius. This covers the hot centre chimney and temporarily decreases the top

gas temperature. The second ore charge is only distributed towards the BF walls, leaving the hot centre chimney open. The coke charge is also charged more evenly, but coke has a higher permeability, leading only to a very short top gas temperature decrease.

Monitoring of the top gas temperature over time, therefore, enables to supervise the heating behaviour. Sudden deviations from the normal profile can indicate different heating behaviour and, therefore, different properties of the charged material.

The same effect can be monitored not only in the time response of the average top gas temperature, but also in the top gas temperature profiles. Fig. 5 shows the top gas temperature profiles, measured by SOMA, shortly before a new charge is fed to the BF. The charging sequence, given above the profiles in the Figure, differs from that in Fig. 4 and features alternating coke and ore dumps, but with different layer profiles. The numbers mark the position in the charging programme matrix. The profiles progress from left to right with time and then from top to bottom. This way, each profile measured during the same step of the charging matrix is given in the same column, whereas rows mark one pass of a fully charging programme matrix. The colours in the profiles indicate the local temperature. Blue represents cold regions, green and yellow warmer areas up to 300°C, red over pink to white marks hot spots of more than 500°C.

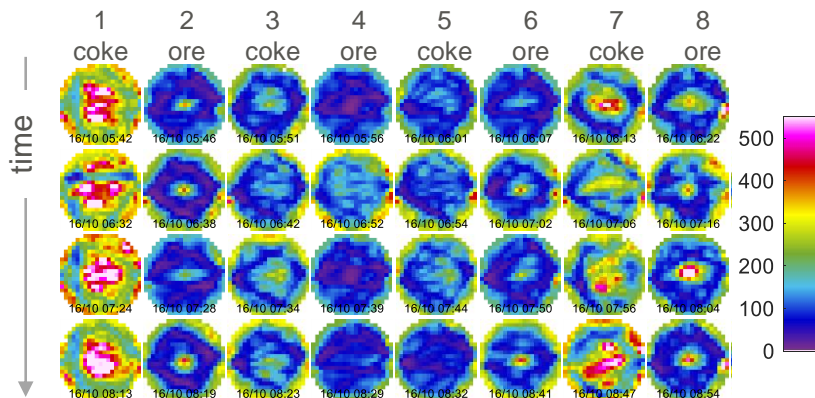


Fig. 5. Repeating top gas temperature profiles prior charging.

It can be seen in Fig. 5 that each time after the coke in step 1 is charged, the temperatures are very high and the centre chimney is wide open. This is due to the high permeability of coke and due to the fact, that step 8 before is an ore charge to the walls. Step 2 brings a flat ore charge and then covers the whole BF cross section, consequently lowering the top gas temperature. This way, the temperature profiles are influenced by the charging programme in each step from 1 to 8. Each profile in each column is strongly comparable to the others in the same column, in total leading to a repeating temperature profile pattern, strongly associated to the charging programme.

Those observations stated in Fig. 4 and Fig. 5 allow to observe the effect of the charging on the top gas temperatures. If repeated times, during one step of the charging programme, the top gas temperatures are too high, this programme line can be adjusted, e.g., by slightly stronger covering the hot centre chimney. But possibly even more interesting for the monitoring of the BF state are deviations from these repeating patterns.

Such deviations point out to either changes in the material properties or to disturbances of the gas flow homogeneity and smooth material descend. Also, chute defects leading to a deviation of the layer structure in the BF are not only visible in the 3D burden radar but also in the top gas temperature profiles.

#### *Monitoring of the burden layer structure*

As written in the previous section, beside the short time correlation between charging and top gas temperature, a second influence on the top gas temperature profile is the temperature of the gas emerging from deeper process zones.

A strong factor influencing the gas-solid interactions is the local coke / coke+ore ratio in the stack. Coke layers have higher permeability and preserve the gas flow through the packed bed in the cohesive zone, where the burden softens and melts. The coke to ore ratio is therefore strongly optimised during planning of the charging but it was up to now not possible to monitor it in the real process. State-of-the-art to conclude on the coke / coke+ore ratio is the calculation from theoretical burden models, with the already described shortcoming of relying on a model and not on up-to-date measurements. But it is also possible to estimate the ratio from the layer structure, measured by 3D radar.

For this task, a method to extrapolate the 3D radar burden scans into the BF stack has been developed. This is done by storing each burden surface, measured by radar, prior to the next charging in combination with related charging data. From the bulk density and the weight of the charged material, the charged material volume is known. To determine the geometry of a charged layer the upper surface of the layer is directly measured by radar. Then, the scanned profile of the previous layer is shifted downwards until the volume between the previous and the current surface matches the volume of the charged material. This reveals the geometry of the charged layer. Repeating this procedure downwards the stack for all charges until the tuyere level is reached, provides an extrapolation of the layer structure in the whole stack, belly and bosh (cf. Fig. 6, left part). If the layers and the coke mass in each layer (including nut coke) are known, also a radial coke / coke+ore ratio can be computed on this base (cf. Fig. 6, left part, small diagram in the upper stack). Often this ratio also shows a correlation to the long-time averages of the top gas temperature profiles due to the influence of the higher coke permeability on the gas flow.

The layer structure model derived from the 3D radar with this approach (“burden layer tracking”) also enables comparison between this structure with the profiles of the vertical pressure measurement lines (cf. Fig. 6, right part).

The example in Fig. 6 shows a moment where a coincidence of a charging material change with a change of the vertical pressure profile was monitored. The Figure shows the moment where the first sinter layer, belonging to a burden programme change, reaches the height of the cohesive zone, derived from a cohesive zone model. At this moment the vertical pressure profile changed and the pressure difference between the last pressure measurement position above the cohesive zone and the first below strongly increased. This was interpreted as a sign, that the newly charged material had a different softening and melting behaviour and decreased the permeability at the cohesive zone.

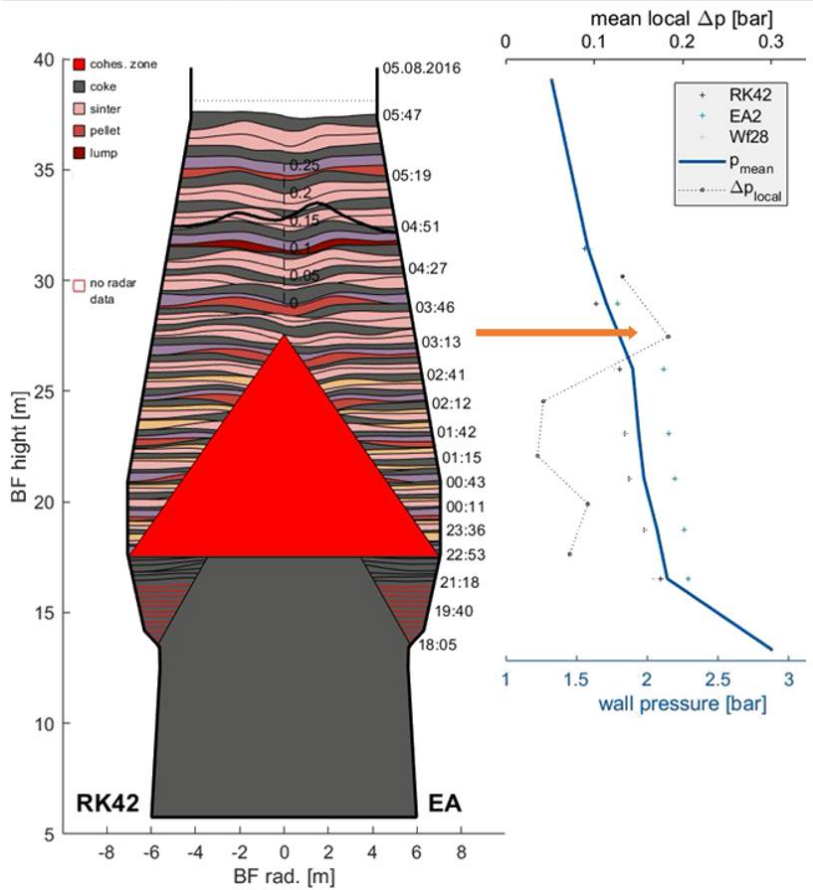


Fig. 6. Burden layer tracking and comparison to gas flow disturbances.

*Monitoring of the stack gas flow*

Another very strong relation to the gas and solid flow was found for the online top gas dust monitoring system consisting of DISSO and MAGS. DISSO and MAGS first time enabled to quantify the influence of different dust generating mechanisms in the BF. By comparing the dust amounts measured during and in-between charging it was found, that during charging of an ore charge the dust emerging from the BF was slightly increased, whereas this effect could not be found for coke chargings. The increased dust amount during charging is believed to be formed mechanically due to the friction of the material during sliding down the chute and due to the impact of the falling material on the burden surface.

But in parallel to the earlier described relation between charging and top gas temperature there is also an influence of the charging programmes on the dust release. Fig. 7 shows (top to bottom) the changes of burden depth, top gas temperature, top gas temperature profile and dust concentration measured by MAGS and DISSO after the charging of one layer.

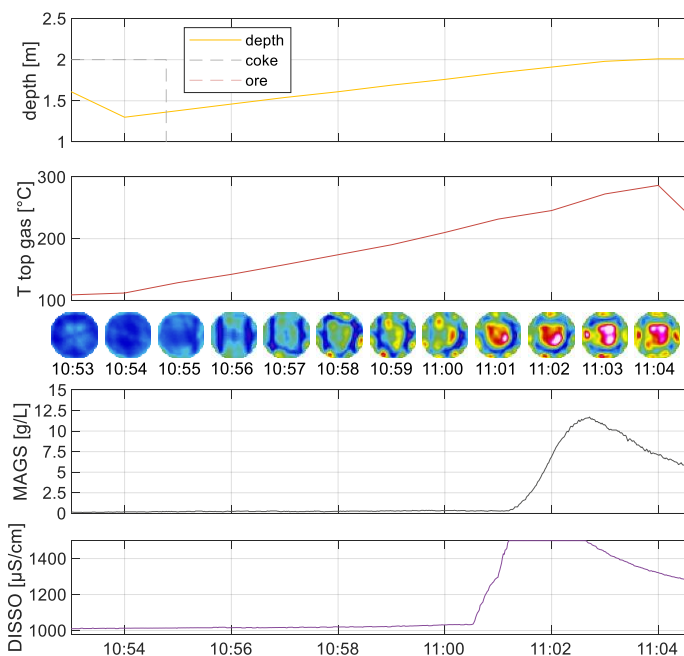


Fig. 7. Increase of dust generation with opening of the centre chimney.

At the left side of the diagrams, a new coke charge was fed to the BF until 10:55 o'clock. After that, the burden column descends, with a simultaneously linear increasing average top gas temperature since the gas heats the newly charged layer. Until 10:57 the top gas temperature profile stays comparably cold and even. Starting from 10:58 some first hot spots occur and at 11:01 the heating of the newly charged coke has reached a stage, where the hot centre chimney is again visible at the burden surface. In parallel the dust emissions from the BF start strongly to increase in both sensors, MAGS and DISSO. This can be interpreted as sign, that the dust is emitted mainly from the hot centre chimney and the emission starts when the gas flow from the centre chimney through the newly charged layer has re-established. The parallel reaction of MAGS and DISSO points out to a comparatively high share of solvable compounds in the dust. This can be explained by an origin of the dust from deeper process zones, where alkaline and heavy metal compounds are evaporating.

A further influence increasing the dust emissions by a factor up to ten times stronger than the described influence of charging was the BF working state and the gas / solids interaction. Fig. 8 shows (from top to bottom) time-series of burden depth, average top gas temperature as well as MAGS and DISSO over a period of 24h with bad BF working state. During this period the burden descend was disturbed. The whole burden column instantly dropped several times up to 2 meters (marked by vertical red dashed lines in Fig. 8). Such a bad BF working state is called "hanging and slipping". If such hanging and slipping occurs, this often causes a deterioration of the burden layer structure, which might take up to 8 hours to recover. Also, gas utilisation, meaning the efficiency of the carbon usage in the process, is often decreased after hanging and slipping. If the

behaviour goes on, blast volume must be reduced, which results in production loss. Consequently, the hanging and slipping state should be avoided.

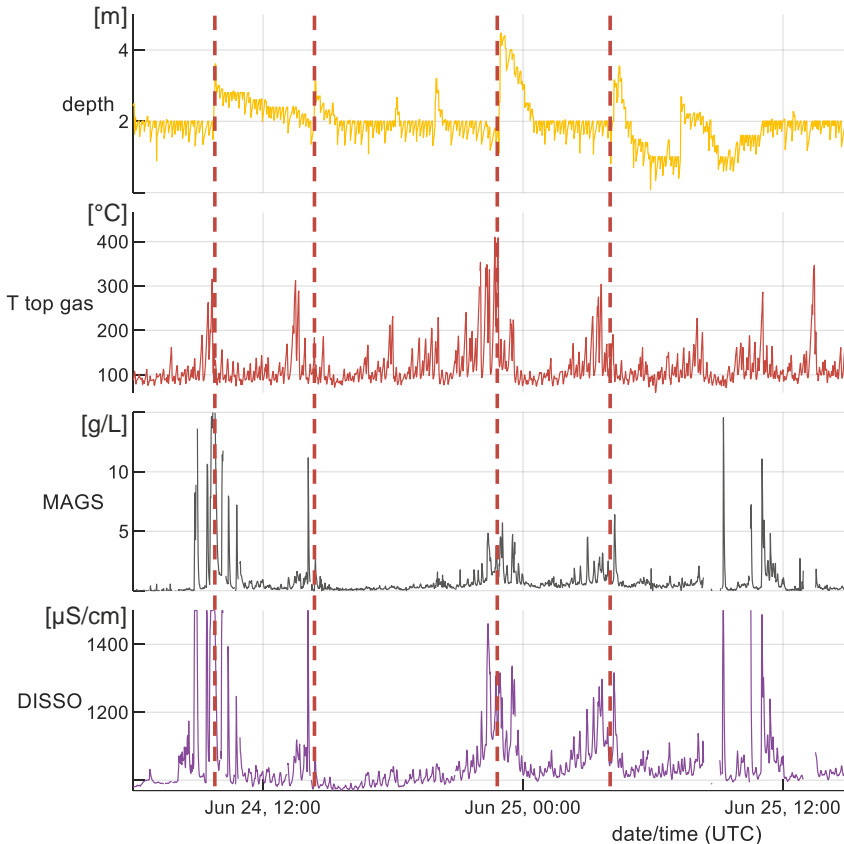


Fig. 8. Increase of dust amount in top gas and temperature prior to slipping.

Reasons for hanging and slipping can not be fully explained as the process inside the BF can not directly be monitored, but it is assumed that during the “hanging” period of decreased or completely halted burden descend, regions of high porosity up to cavities form in the burden column, due to bridging of the burden material. Such conditions have an interrelation with the gas flow. A high pressure drop of the gas during ascend in the stack introduces an upwards directed force on the burden promoting reduced burden descend. Cavities or impermeable layers above redirect the gas flow and increase gas velocity in the remaining still permeable areas. After a while, the bridging or uplifting forces can no longer hold the weight of the burden above and the cavity collapses with the whole burden column “slipping” downwards.

This effect on gas flow becomes noticeable in the data given in Fig. 8. Already 15-30 minutes before a slip, top gas temperatures start to deviate from the normal behaviour (as given in Fig. 4) and strongly increase. In parallel top gas dust emissions (noticeable by MAGS and DISSO) increase. This is a strong sign for shortcut gas flows from deeper,

hotter process regions towards the burden surface, named “channelling”. Such flow channels have higher flow velocities, enabling to fluidise smaller burden particles that then form dust. Also, alkaline and heavy metal compounds evaporated in deeper BF regions can escape quickly through those channels. Often such channels are also visible as hot spots, often near the BF walls, in the SOMA measurement.

Careful monitoring of the top gas temperature and dust concentration already enables to recognise such channelling conditions during their start of formation – up to half an hour before a slip occurs. This gives the operators the possibility to react in an early stage, avoiding the stronger consequences of a slip mentioned before.

## **Conclusion**

Application of innovative measuring techniques:

- acoustical 2D top gas temperature profile,
- 3D burden surface radar and
- online top gas dust concentration

enables to better monitor and examine the complex physical interrelations occurring in the BF stack:

- Short time top gas temperature development over time and 2D profiles strongly depend on the burden and coke charging sequence and profile. Repeated too high top gas temperatures and dust concentrations before charging of a new dump can be avoided by proper adjustment of the chute charging programme. Sudden changes in the temperature pattern point out to process disturbances or changed material properties.
- Monitoring of the burden surface by radar allows to extrapolate the layer structure in the stack and to compare the layer positions to locations of permeability disturbances.
- Dust is generated from the BF process during charging and due to disturbances in the BF working state – the dust emitted during a bad working state can be up to ten times higher than the dust mechanically generated during charging.
- Monitoring of the top conditions, mainly the top gas temperature and dust generation, enables early recognise arising burden descend and gas flow disturbances.

In overall these observations support the BF operators at SZFG in maintaining the BF operation as efficient and productive as possible.

### Acknowledgement

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