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RECIRCULATION OF SINTER OFF GAS – A SELECTIVE APPROACH*

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Abstract
Increasingly stringent global environmental regulations are forcing steel producers to continually improve the efficiency of sinter waste gas treatment. With the Selective Waste Gas Recirculation (SWGR) system from Primetals Technologies, lower production costs can be achieved and the size of downstream waste gas cleaning units can be reduced for investment savings. SWGR features the extraction and reuse of hot sinter off gas from selected wind boxes along the sinter strand, which contributes to improved energy efficiency and off gas treatment in the sintering process. With the next generation of SWGR, Primetals Technologies can provide an energy optimized, emission optimized and environmentally friendly solution that meet customer requirements and country specific regulations. This paper demonstrates the latest developments in selective waste gas recirculation, especially results from pot grate tests and comparison from lab to real plant data. Furthermore theoretical finding and mathematical modelling is presented.
Keywords: Waste gas recirculation; Selective; Emission process optimized; Waste gas treatment; Modernization; Coke saving; Sintering.

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1 INTRODUCTION

The use of selective waste gas recirculation reduces off-gas volume up to 50 %. With this technique the sensitive heat of waste gas from the wind boxes and / or from the cooler is mixed in the distribution duct and integrated back in the sinter process for an adequate length of the sinter bed.

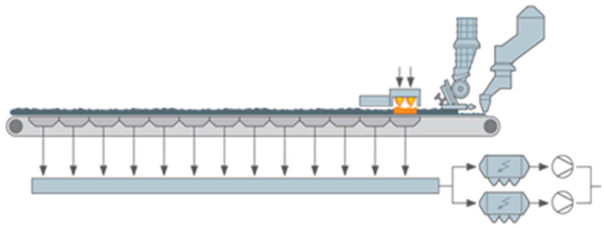

Figure 1: Conventional sintering plant without waste gas recirculation

Due to more stringent environmental regulations concerning waste gas emission standards, accurate prediction of the prospective emission content in waste gas is required. Therefore, characteristics for off-gas emissions from sinter plants have been studied. Additionally, small scaled laboratory sinter pot tests have been realized to examine different recirculation characteristics and their influence on sinter and waste gas.
This paper shows the results of sinter pot tests with waste gas recirculation and their consequential findings. Beyond, plant data concerning waste gas recirculation are compared with previous pot test results.

2 RECENT SWGR TECHNOLOGIES

In the past, Primetals Technologies offered two different selective waste gas recirculation processes. A conventional sinter plant can be seen in Figure 1. In the selective waste gas recirculation process the recirculation gas is taken only from selected wind boxes. The length of the suction area including all wind boxes typically can be split into three sections. For recirculation the second section (see Figure 2) or the first and the third sections (see Figure 3) can be used. The recirculated gas has to be pre-cleaned in cyclones or ESPs to protect the recirculation fan from wear. The part of the waste gas which is not recycled is transported to a waste gas cleaning unit (also cyclones or ESPs and additionally DeSOx or DeNOx plant for minimizing the gaseous emissions). With the next generation of SWGR this two waste gas recirculation technologies are combined to utilize each advantage dependent on requirements regarding emission limits, guarantee parameters, consumption of raw materials and downstream aggregates such as waste gas cleaning units.

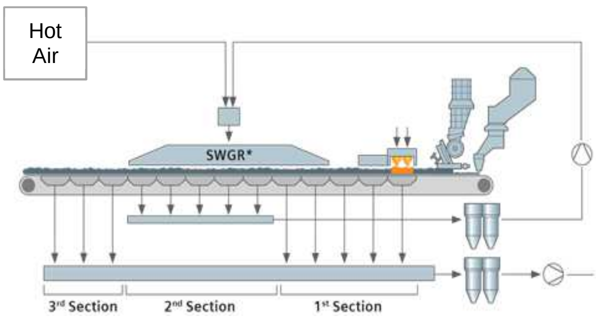

Figure 2: Waste gas recirculation of section II

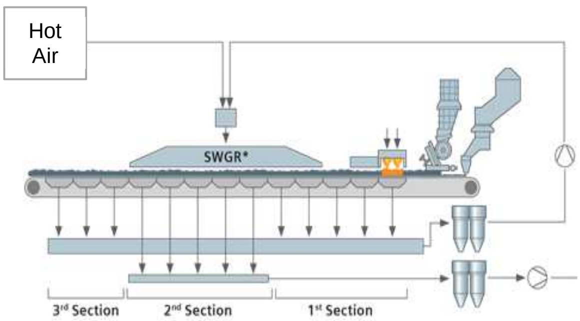

Figure 3: Waste gas recirculation of section I + III

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3 DISTRIBUTION PROFILES WITHOUT SWGR

Ad Figure 4, **Temperature**: The temperature profile along the sinter strand has a characteristic distribution. After ignition, the temperature of the waste gas is about 50 to 100°C. The evaporation of water in the wet mix and the partial condensation of steam results in an increased temperature.
After drying of the sinter raw mix the waste gas temperature rises continuously to a maximum. The sinter process is finished when maximum of temperature is reached. For SWGR the temperatures in the wind boxes have a high importance (dew point, fan design).
There are characteristic distribution profiles [2] along the sinter strand for waste gas components, such as CO, CO_2, SO_2, O_2, NOx and dioxins. It has high importance for the chemical composition of the waste gas whether the second, or the first and the third part
of the waste gas is recirculated. This paper focuses on SOx, NOx and CO emissions and its influence on the sinter product, waste gas and environment.
Ad Figure 5, **SOx**: Sulfur oxides (mainly SO_2) originate from the combustion of sulphur compounds in the raw mix. The primary source for SO_2 emissions are coke or oil components in the raw materials. Apart from the sulfur input the quantity of emitted SO_2 is dependent on other factors. One of these is the degree of sulfur uptake in the sinter, dependent on the basicity of the sinter feed. Another factor is the grain size distribution of the coke.

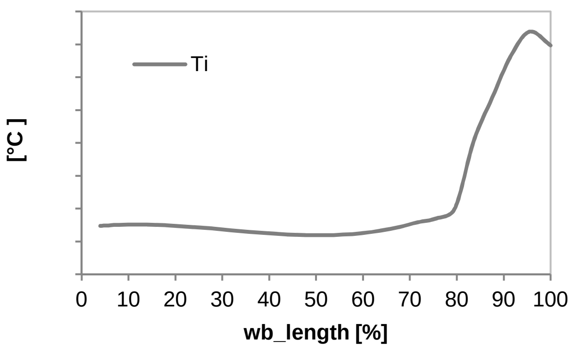

Figure 4: Normalized temperature profile along the sinter strand.

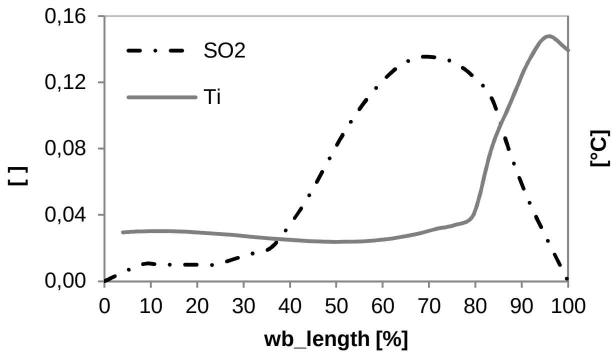

Figure 5: Normalized distribution profile along the sinter strand for temperature Ti and SO2

Ad Figure 6, **NOx**: Nitrogen-oxide emissions occur mainly because of the nitrogen in the fuel. NOx (typically NO) emissions are generated at high temperatures from:

– Fuel NOx: combustion of organic nitrogen
– Compounds in the raw material mix
– Prompt NOx: reaction of decomposing components with molecular nitrogen
– Thermal NOx: reaction of molecular O_2 with molecular nitrogen in the combustion air

The flame front temperatures in the sinter bed cause NOx formation. A remarkable increase of the NOx emissions starting at the ignition zone can be recognized. Fuel NOx is the major source of NOx emissions.
CO, CO_2: Carbon-oxide emissions are generated from complete and incomplete combustion of coke breeze or anthracite. For a reduction of the CO emissions waste

gas is recirculated back into the agglomeration process, especially for sintering, to burn the CO further to CO_2.
CO2 peak appears just after ignition phase of the raw mix. The maximum CO_2 concentration appears at a minimum oxygen value. Oxygen and CO_2 emission values are connected as can be seen in Figure 7.

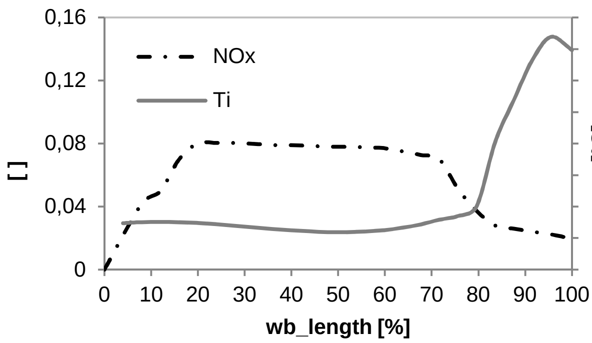

Figure 6: Normalized distribution profile along the sinter strand for temperature Ti and NOx

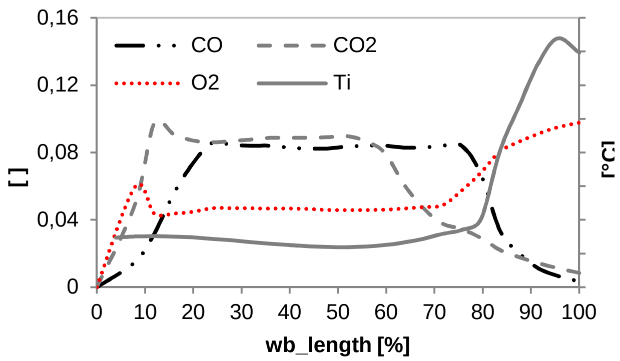

Figure 7: Normalized distribution profile along the sinter strand for CO, CO2 and O2

After a peak of CO_2 in the first third of the sinter strand length there is a characteristic drop to the original CO2 content at the end of the sinter bed. This fact indicates the end of the sinter process. The CO missions rise within the first wind boxes and remain on a lower level compared to the CO_2 emissions.
O_2: Oxygen is needed for the coke combustion. In the first wind boxes the oxygen amount rapidly decreases.
Until nearly the ambient oxygen input value is reached, an increase of the oxygen content can be remarked in Figure 7. This point indicates the end of the sinter process.
The variable amount of wind boxes requires a simple way of adapting these distribution curves. With the implementation of a dimensionless distribution profile, a flexible calculation of the chemical composition in each wind box is possible. Therefore the length of a wind box is normalized to 100% like the value of distribution, which makes a calculation of the gaseous species in each zone feasible.
With this method, also emission distribution curves from reference models can be easily integrated in the calculation model. If small scale laboratory tests are available, the sinter time [min] can be set equal to the normalized sinter bed length. Otherwise, distribution profiles can be available from literature or process simulations.
The dimensionless, normalized distribution curves allow an easy adaption of the distribution curves dependent on the specific geometrical criteria such as sinter bed length and wind box length

4 SINTER POT TESTS

Sinter pot tests are downsized sinter tests in laboratory scale. The reason for performing the sinter pot tests was to simulate the waste gas recirculation process. Main focus was the variation of the SO_2 concentration in the recirculation gas.
To make the pot tests representative, parameters such as moisture, temperature of recirculation gas, mixing and granulation parameters, bed height and time of waste gas recirculation were held constant.

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In principal, three different test series were made:

- Reference tests: without SO2 in the recirculation gas at three basicity's (B2: 1,2 / 1,8 / 2,4).
- Variation of the SO2 concentration in the recirculation gas: as comparison for recirculation of section I and III or recirculation of section II; to see the influence on the S-Binding factor
- Variation of fluxes and its mixtures for comparison

Analysis of each during pot tests produced sinter:

- Sinter: RFA Analysis for each basicity
- Sinter: Sulphur for each test in each grain size (<4, 4-10, >10 mm)
- Waste gas: SO2 Concentration, CO2, CO and O2 concentration, Waste Gas temperature

Raw material chemistry is shown in Table 1.

Table 1: Raw material analysis for pot test series x… variation of ratio

	ratio	Fe	SiO2	Mn	CaO	MgO	Al2O3	P	TiO2	K2O	S	C	LOI
Ore 1	20	64,9	5,65	0,04	1,09	0,24	0,26	0,012	0,054	0,031	0,06		-0,55
Ore 2	40	61,40	9,28	0,03	0,47	0,28	1,13	0,027	0,036	0,057	0,025		1,35
Ore 3	40	66	2,30	0,3	0,01	0,01	1,16	0,043	0,099	0,025	0,012		2,1
Flux 1	x	0,35	0,65	0,01	50,3	4,14	0,24	0,003	0,013	0,025	0,012		44,08
Flux 2	x	0,11	1,26	0,01	79	0,75	0,25	0,074	0,007	0,072	0,057		17,84
Fuel 1	4,75	1,03	5,44	0,02	0,765	0,32	3,065	0,04			0,65	87,65	89,2
Fuel 2	x	34,00	6,48	0,35	6,28	1,46	3,61	0,04	0,11	0,13	0,35	28,5	32,63

4.1 Recirculation Gas Properties

The SO2 concentration was changed for the different tests. The time of recirculation, which is appropriate to a constant recirculation hood length, is constant.
The other parameters for the recirculation gas are:

– CO2 7,5 vol%
– CO 1,5 vol%
– O2 13 vol%

The sulphur balance from the reference tests without SO2 (0 S_g input) in the recirculation gas are in good accordance. The highest deviation is < 3.5 %.
Exemplary, the sulphur balance for the pot tests with the highest SO2 recirculation rate are chosen. The deviation is < 0,1 % between mass input and output.
Note: An increase in basicity indicates a higher value of sulphur, which is bound in the sinter.

4.2 S-Burnout

In general, the S-Burnout was considered in literature with > 90 %. [1]
The S-Burnout is strongly dependent on the basicity and results for every tests < 90% were achieved (seen Figure 10).

$$S - Burnout = \frac{S(WG)}{\sum S(Input)} * 100$$

S(WG)… sulphur in waste gas
S(Input)… mass of sulphur in raw material
S-Burnout … sulphur (s) -> sulphur (g) [%]

This can be seen in Figure 8 and Figure 9 for S_S, where the mass of bound sulphur in sinter (S_S, output) is rising with increase of basicity.

5 RESULTS

5.1 Sulphur Balance

Figure 8 and Figure 9 show the results of the sulphur balance of the respective sulphur balance

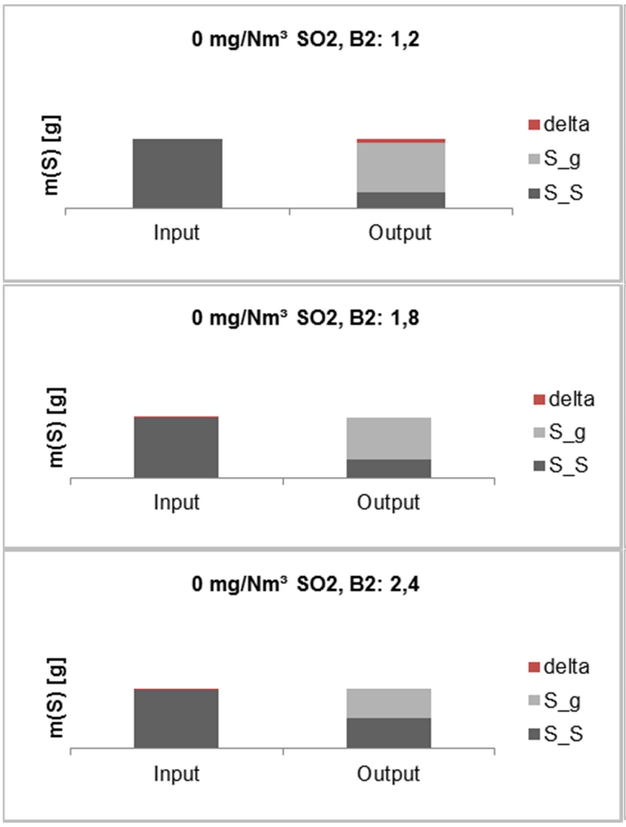

Figure 8: Sulphur balance for reference test without SO2 in the recirculation gas

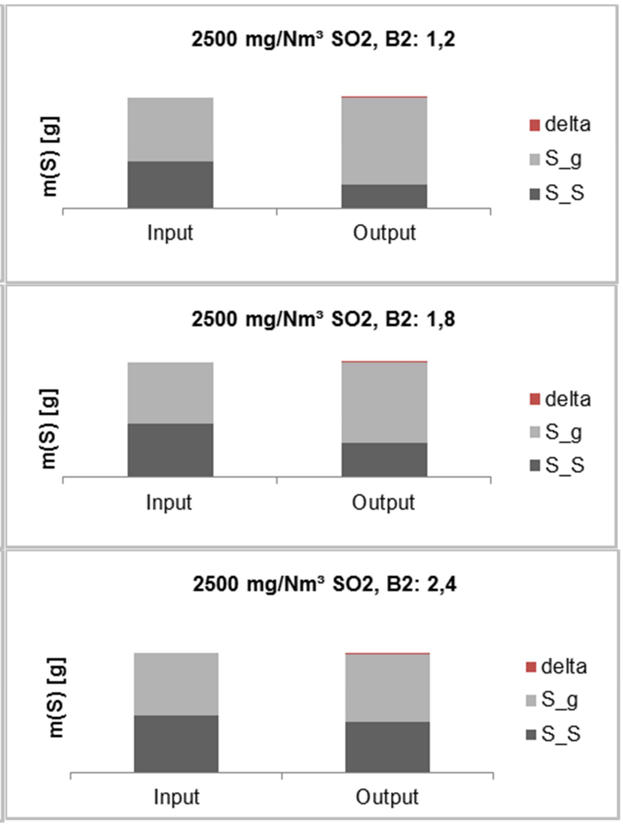

Figure 9: Sulphur balance for 2500 mg/Nm³ SO2 in the recirculation gas

$$Sg(in) + Ss(in) = Sg(out) + Ss(out)$$

Sg(in) sulphur, gaseous, input (equal to mass of sulphur from recirculation gas)
Ss(in) mass of sulphur, solid, input (equal to mass of sulphur in raw material)
Sg(out) mass of gaseous sulphur, output (equal to sulphur in waste gas)
Ss(out) mass of solid sulphur (equal to sulphur bound in sinter)

5.2 S Binding Factor for Recirculated SO_2

To evaluate the S-binding factor of the SO_2 in the recirculation gas, the amount of SO2 has to be formulated. Therefore, the conversion XSO_2 of SO_2 was compared. The fractional conversion gives the amount of a reactant, which has been converted to some product. [3]

$$X_{SO2} = 1 - \frac{(m(SO2, RG))}{(m(SO2, RH)_0)}$$

m(SO_2,RG)   Concentration of SO_2, at the end of sintering
m(SO_2,RH)$_0$ Concentration of SO_2, before reaction (equal to the SO2 content in RH)
X_SO_2 Conversion from S(g) to S(s)

5.3 Balance for SO_2

$$X_{SO2} * m(SO_2,RH)_0 + m(SO_2,RM) = m(SO_2, WG)$$

m(SO_2,RM)   mass of SO_2 in raw material
m(SO_2, WG)   mass of SO_2 in waste gas

The SO_2 from the raw materials can be calculated with the S-Burnout curve in Figure 10.

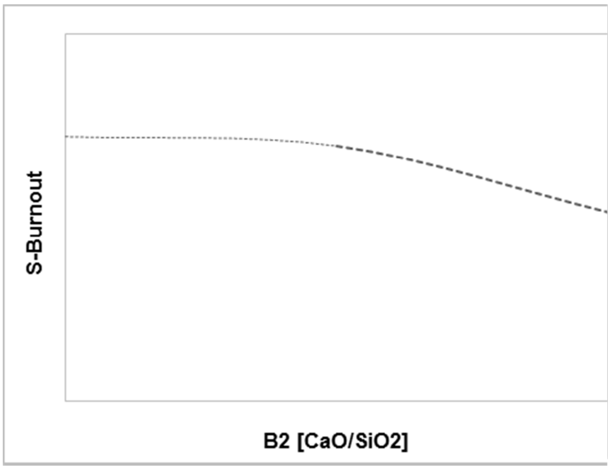

Figure 10: S-Burnout for reference tests with 0 mg/Nm³ SO_2 in the recirculation gas

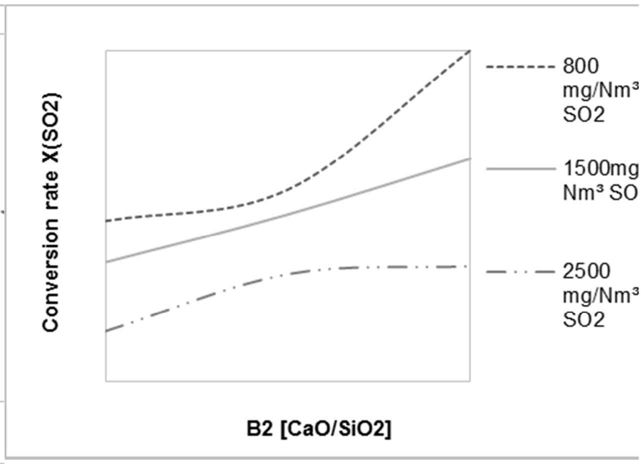

Figure 11: Conversion rate for SO_2 in recirculation hood

In the following examination the dependency of the basicity was considered.

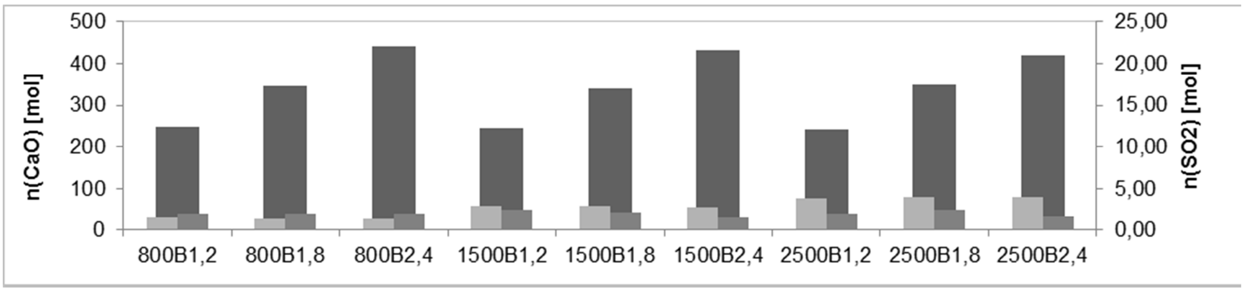

Figure 12: Stoichiometric relations between reactants influencing sulphur binding in sinter

As can be seen from the diagram, the binding factor is influenced by the basicity. Increasing basicity means increasing sulphur content in sinter.
Other influences are varying concentration of SO_2 in the recirculation gas. If there is less SO2 in the recirculation gas, nearly all of the available SO_2 in the recirculation gas can be bound in sinter. If there is a high content of SO_2 in the recirculation gas, the conversion rate did not exceed 30%, independent from basicity.

S-BINDING **increases**
S-BURNOUT **decreases**
… when basicity B2 is increased.

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Additionally the stoichiometric relations are compared. An extreme excess of CaO as reactant could be noticed for all of the tests (see Figure 11). The sulphur input was calculated as SO_2 from raw material (RM) and recirculation hood (RH).

5.4 Grain Size Dependency

According literature, in smaller sinter fractions more S can be found because of higher surface area, where reaction is favored, which means that more S can be bound in smaller fractions (< 4 mm) than in bigger fractions.
The same characteristics can be recognized in the other pot tests with SO2 in the recirculation gas.

5.5 Oxygen Content

Minimum oxygen value, where sintering is theoretically possible, is about 9% O2. In general, with SWGR the oxygen content in the waste gas is reduced compared to sintering without waste gas recirculation.

5.6 Coke And Energy Savings

With the selective waste gas recirculation technology, a considerably amount of coke can be saved. Three sources of energy can be reused in the sinter process
- Heat from recycled waste gas
- Heat from hot air from cooler
- Combustion of CO from the recirculation gas

The coke savings mainly are a result of burning the CO, which is available in the recirculation gas.

$$CO + ½\,O_2 = CO_2 \text{ (exothermic)},$$

Dependent on which part of the wind boxes is recirculated, the amount of CO can vary. With SWGR coke savings up to 10 % were achieved in real plants.

6 POT TESTS VS. REAL PLANT DATA

The illustrated findings from the pot tests are compared with real plant data.
In general, the chemical content in the recirculation gas can vary and is dependent on

- Raw material chemistry, temperature
- Distribution profile along the sinter plant length, in particular, part which is recirculated
- Location and length of recirculation hood

6.1 Real Plant Data: Oxygen

Sources for oxygen are process air and false air (margin air). Using SWGR, The amount of process air is reduced, which leads to a decrease in the oxygen content as shown Figure 15. This plant has a recirculation ratio of approximately 30 %, which means the ratio of total waste gas used for recirculation.
Because of the specific distribution profile of oxygen along the sinter strand (see Figure 7), the selection of specific wind boxes used for SWGR influences the content of the oxygen in waste gas and recirculation gas duct.

6.2 Real Plant Data: B2 and sulphur in Sinter

Focused on the sulphur content in sinter, a dependency of basicity can be seen in Figure 13. Increasing basicity results in increasing sulphur content in sinter, which is equal to the knowledge from the pot tests.

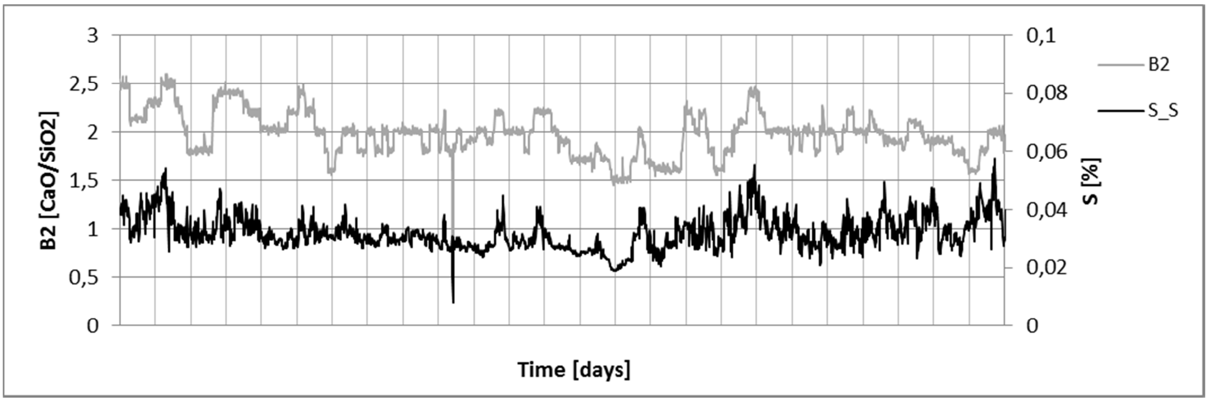

Figure 13. Real plant data; Dependency of basicity B2 and sulphur content in sinter

If pot test data and real plant data are compared, a positive slope can be recognized. To make a more detailed comparison regarding the amount of sulphur in sinter, raw material mix from a real plant should be compared directly in a pot test.

7 CONCLUSION

It has high importance for the chemical composition of the waste gas which sections are recycled. The following points have to be considered for selective waste gas recirculation.

1. reduction of waste gas leads to smaller waste gas volume to the stack: the reduction of up to 50% of the waste gas volume results in smaller size of further waste gas cleaning units as DeSOx or DeNOx
2. recirculation of the first and third section leads to lower SO2 , NOx, and CO freights [t/h] in the waste gas. The emission values are often related to a specified oxygen content. It is advantageous to have a low oxygen reference value for the gas emission concentrations in mg/Nm³ at a related oxygen content
3. recirculation of the second part: with this recirculation mode most of the SOx emissions can be recirculated, which can be advantageous for the installation of further waste gas units

Gaseous emission characteristics

1. Sulphur burnout is strongly dependent from basicity; independent if with or without SWGR
2. Sulphur burnout decreases with increasing basicity B2
3. Sulphur binding increases with increasing basicity B2
4. The concentration of SO2 in the recirculation gas has an impact on the S-Binding factor.
5. B2 and sulphur binding effect are directly linked to each other.
6. With SWGR the oxygen content in the waste gas is decreased, which can be favorable in case of emission standard limits, related to specific oxygen content.

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These findings are implemented in the process calculation with mathematical models, representing the behaviour of the gaseous emissions in case of different process parameters. With mathematical models the prospective ratio of each species such as NOx, SO_2, CO, CO_2 and O_2 can be determined for each wind box.
The higher accuracy allows a more detailed prediction of emission values and enhanced design of SWGR systems

7.1 SWGR – Next Generation

With the next generation of SWGR a customer specific solution and high flexibility could be gained for the selective waste gas recirculation technology.
Furthermore, with consideration of recirculation of hot waste gas from the sinter plant mixed with hot air from the sinter cooler, solid fuel savings up to 10% per ton of sinter were achieved.
The choice of selective wind boxes has an impact on emission values and process parameters. Varying raw materials influence the waste gas characteristics significantly and require a high flexibility regarding the process operation.
The next generation of SWGR combines recirculation of first and third or second section of the wind boxes with switchable flaps to use SWGR which is advantageous for the customer specific requirements. This recirculation strategy can also be used for modernization of existing plants.

7.2 Forecast

Within the next years the main gaseous emissions such as NOx, CO, CO_2 and dioxins will be verified in pot tests and simulations for more advanced mathematical models.

7.3 Abbreviations

B2	basicity B2 (CaO/SiO_2)
DeSOx	desulphurization system
DeNOx	denitrification system
ESP	electrostatic precipitator
LOI	loss of ignition
RFA	x-ray fluorescence analysis
SWGR	selective waste gas recirculation

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