THE EFA PROCESS – STATE-OF-THE-ART SINTERPLANT OFF-GAS CLEANING TECHNOLOGY*

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Abstract

At Rogesa in Dillingen, Germany, a joint venture company of AG der Dillinger Hüttenwerke and Saarstahl AG and at Salzgitter Flachstahl GmbH in Salzgitter the sinterplants are equipped with the Paul Wurth EFA™ process for the final sinterplant off-gas cleaning. In Dillingen two and in Salzgitter one EFA™ plant are in operation at the respective sinterplants to comply with the very stringent environmental rules prevailing in Germany according to the German Clean Air Act called “TA Luft”. The main target is to eliminate or reduce emissions like dust, sulfur components, dioxins/furans and others in the sinter process off-gas. Since 2006 and 2011 the two EFA™ plant are in operation at Rogesa while the EFA™ plant in Salzgitter was also commissioned in 2011. These installations significantly contribute to the improvement of the emission situation of the Dillingen and Salzgitter Works. The EFA™ technology is the state-of-the-art process for such kind of application in terms of additive and energy consumption, reliability and availability. The report gives an overview of the EFA™ process and the performance results of the Dillingen and Salzgitter plant.

Keywords: Sinterplant; Waste gas cleaning; EFA™ process; Entrained flow absorber; Desulfurization.

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1 INTRODUCTION

The process routes for steel making (Figure 1) are mainly distinguished by raw material input: Based on iron ore sintering or pelletizing through the blast furnace to produce hot metal, direct or melting reduction and through the electric arc furnace route with mainly scrap and DRI.

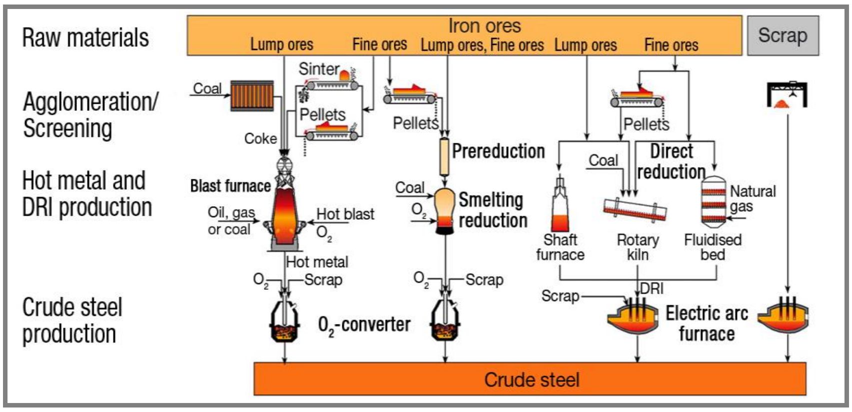
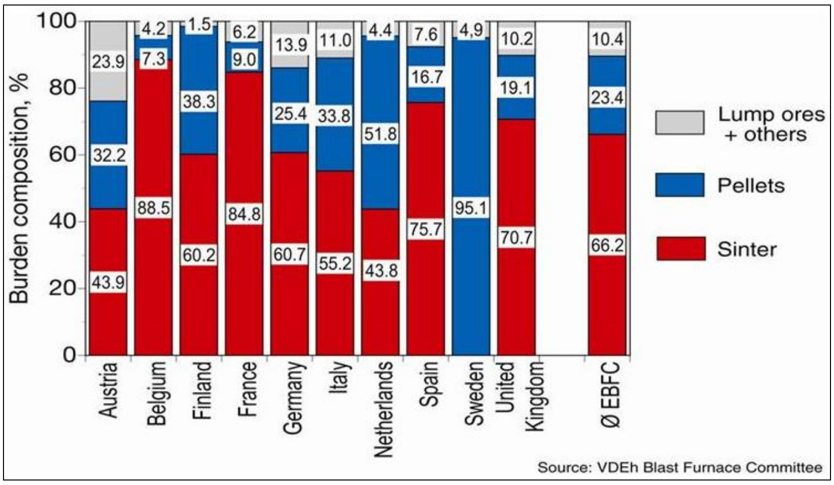


Figure 1: Steel Making Routes

In 2008 1.30 and in 2009 approx. 1.20 billion tonnes of crude steel were produced in total of which approx. 65 % were produced through the blast furnace and BOF converter route. The importance of sinter for the hot metal production and subsequently also for the crude steel production can be shown with the development of the world production figures. The significant increase of the crude steel production was achieved by an increased amount of hot metal. It is well known that the availability of scrap is very limited. The world's iron ore production raised from 950 Mio. tonnes in 2000 up to 1360 Mio. tonnes in 2005. Based on the iron ore deposits, more and more fine ores and concentrates are produced which need to be agglomerated for the blast furnace operation. Accordingly, sinter and pellet production increased over the recent years.



Source: VDEh Blast Furnace Committee

Figure 2: Burden Composition in 2008 (Europe)

Fig. 2 shows as a snap-shot the burden composition of blast furnace works in Europe in 2008. With the exception of one country, Sweden, all blast furnace plants use a

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significant amount of sinter in the burden for an economic and high quality hot metal production.

2 THE SINTERPLANTS OF ROGESA AND SALZGITTER FLACHSTAHL

During the last twenty years there have been no new sinterplants commissioned in Europe, therefore, most of the operated sinterplants are already relatively old and their environmental equipment is different from plant to plant. However, only few companies in the iron and steel world are able to give-up the sintering process because of the insufficient supply of pellets. The environmental problems of the sinterplants can be solved to the necessary extent.

Company		Rogesa GmbH	Rogesa GmbH	Salzgitter GmbH
Sinterplant		No. 2	No. 3	A
Year of construction		1961	1981	1940
Last modernization		1997	2006	1963
Suction area	m2	180	258	180
Depression	mbar	100	140	120
Waste gas temp.	°C	150	150	160
Bed height	mm	500	510	430
Primary dedusting	-	ESP	ESP	ESP
Productivity	$t/(m^2 \cdot 24h)$	29-32	36-41	~38

Figure 3: Rogesa's and SalzgitterSinterplants

At the site of Rogesa which is a joint venture of two steelmaking companies: AG der Dillinger Hüttenwerke and Saarstahl AG, two sinter strands (No. 2 and No. 3) are in operation. Fig. 3 shows the technical data of the two sinter strands. The total sintering capacity amounts to 5 Mio. t/a where strand No. 2 has a suction area of 180 m^2 and strand No. 3 of 258 m^2. As there are different depressions of 100 mbar respectively 140 mbar, the productivity differs from 29 – 32 t/m^2 24h at No. 2 strand to 36 – 41 t/m^2 24h at strand No. 3.

Salzgittergitter Flachstahl operates only one sinterplant. The general details are also given in Fig. 3. Although the sinter sinterplant is rather old, by applying appropriate off-gas cleaning technology the operation of such a plant is not in conflict with the very stringent environmental rules prevailing in Western Europe (in particular in Germany) as well as economicaly worthwhile.

Figure 4 shows the tasks which had to be fulfilled with the new PAUL WURTH Entrained Flow Absorber (EFA™) process: The simultaneous removal of dust, SO_2, HCl, HF, and dioxins. Another important topic also for the decision towards the PW technology was the flexibility of the plant regarding the optimization of the reaction temperatures and consequently to minimize the consumables. As a result a cost optimized operation of the plant by fulfilling all necessary emission limits could be established.

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- Construction of a plant for simultaneous cleaning of
  - Dust
  - SO_2/HCl/HF and
  - Dioxins
- Plant has to be flexible according to
  - Adjustment to optimum reaction temperature
  - Minimizing of consumables and therefore
  - Cost of operation
- Future oriented safe technology
- Raw gas flow and temperature fluctuations during starting, stopping and normal operation of the sinterplant.

Figure 4: Tasks for the New Plants

3 LEGISLATIONAL ASPECTS

As shown in Fig. 3 the sinterplants in both location, Dillingen and Salzgitter are very old and the existing gas cleaning systems were no more suitable to fulfill the actual emission limits of the new German clean air act (TA – Luft 2002). The local environmental authorities did consequently claim for the renewal of the gas cleaning systems in order to respect the new legislation within a deadline until july 2006 for strand No. 2 in and January 2010 for strand No. 3 at Rogesa in Dillingen. For the Salzgitter EFA™ plant the due date for the plant operaton was in April 2010. The emission limits of the sinter waste gas have been continually and strictly tightened for the recent years.

Dust emissions must be lower than 50 mg/m^3 (STP) by using the electrostatic precipitator (ESP) as final dedusting stage. However, by using another technology, the dust content of the waste gas must remain below 20 mg/Nm^3. The emissions of heavy metals vary between 0,05 to 1 mg/m^3 (STP) depending on their classification. Concerning acid gas components, HF must be below 3 mg/m^3 (STP), HCl below 30 mg/m^3 (STP) and SOx below 500 mg/m^3 (STP), The NOx must be lower than 400 mg/m^3 (STP). The volatile organic compounds (VOC) measured as total carbon content have to be below 75 mg/m^3 (STP). Finally, the limit of dioxins and furans (PCDD/F) is 0,4 ng/m^3 (STP), however, the final target is to reach an emission value lower than 0,1 ng/m^3 (STP). Until now, the main problems for the sinterplant operators concern emissions of dust, heavy metals, SOx and dioxins, whilst the NOx limit of 400 mg/m^3 (STP) can be achieved by optimizing sinter raw materials and solid fuels. For these reasons and with regard to the fact that with improvements of the existing installations the new limits could not be respected with certainty, new gas cleaning plants at Rogesa and Salzgitter had to be planned.

4 THE PROCESS

Basis for the planning was a general specification of the raw gas, the sinterplant's off-gas: The plant had to be designed for 600.000 m^3/h (STP) wet at a temperature of 190°C with the following pollutants:

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Dust	95 mg/m³ (STP) dry
SO2	900 mg/m³ (STP) dry
HCl	19 mg/m³ (STP) dry
HF	3 mg/m³ (STP) dry
PCDD/F	3 ng/ m³ (STP) dry

Rogesa and Salzgitter have chosen the PAUL WURTH EFA™ technology as a so-called end-of-pipe-solution resp. as a by-pass solution. Together with the existing electrostatic precipitator which had to be kept in operation the Entrained Flow Absorber technology was finally deemed as best and optimum solution for both clients‘ sinterplants due to its best efficiency and flexibility even for the future.

In particular, the Paul Wurth EFA™ process has been selected due to the following reasons:

- Low investment costs,
- Low operating cost,
- Dry addition of the additives, consequently no risc for sticking,
- High flexibility in the temperature range, consequently no risc for condensation,
- High flexibility due to fluctuations of the raw gas flow,
- High potential of desulphurisation at low temperatures,
- Low maintenance costs because of less mechanical parts for operation, and
- References in powerplants.

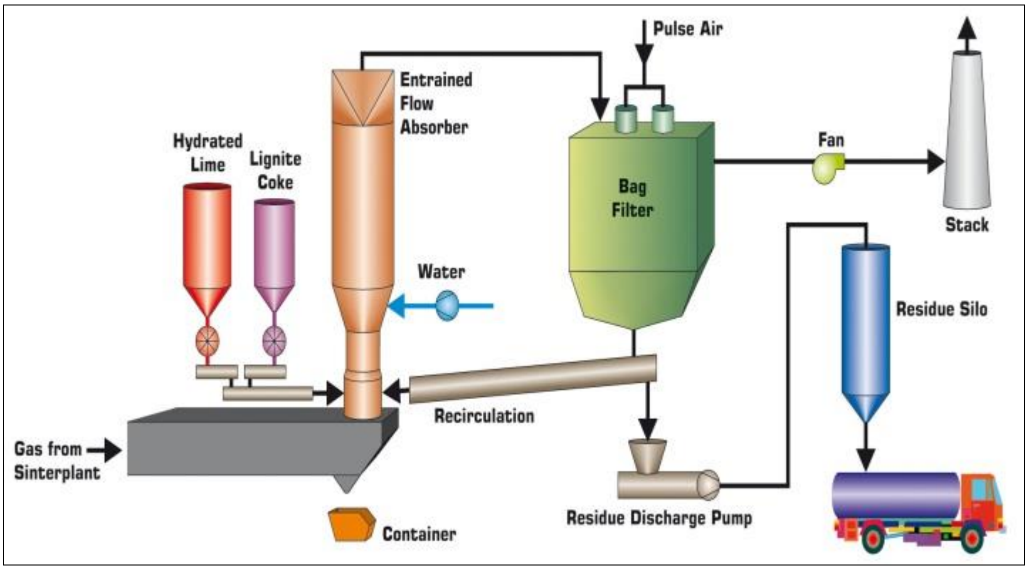

Figure 5: The EFA™ Process Flow Sheet

The principle of the PW Entrained Flow Absorber technology is highlighted in Figure 5 which shows a simplified process flow sheet. The key part of the process is the Entrained Flow Absorber (EFA™). Inside the EFA™ a fluidized bed of recirculated material mixed with fresh additives establishes ideal conditions for the evaporation of the injected water and the removal of the pollutants. Measurements have shown, that more than 90 % removal takes place inside the EFA™ and less than 10 % at the filter bags. The EFA™ itself is a rather simple construction consisting of an inlet pipe, the so called nozzle, where the gas is accelerated, a diffuser and a cylindrical pipe. There are no internal built in components inside the EFA™. At the upper end of the diffuser one spill back nozzle is located, injecting the water cross wise to the gas/solid flow. Due to the well known excellent mixing conditions in the fluidized bed, the solid particles keep absolutely dry even at high water flow rates. A small layer of water vapor at the surface of the solid particles is responsible for the enhancement of the chemical reactions taking place inside the EFA™.

Another main technology part of the process is the bag filter which can be seen almost in the center of Fig. 5. The fabric filter or bag filter technology was initially designed only for dedusting and is widely used in power plants and incineration industry. In the last years, the latest development enhances the fabric filter capability of de-dioxin and de-SOx, based on the adsorption of dioxins with activated lignite coke and the desulphurisation reaction of SOx with hydrated lime $Ca(OH)_2$. Typical features of the modern fabric filter technology are the following:

- A filter system consisting of a large number of bags arranged vertically in several chambers for dedusting,
- the addition of the activated lignite coke for adsorption of dioxins and heavy metals,
- addition of hydrated lime $Ca(OH)_2$ for the desulphurisation, and
- the particle recirculation inside the system to build up a layer at the surface of the bags to improve the dedusting efficiency and to increase the utilisation efficiency of the sorbents.

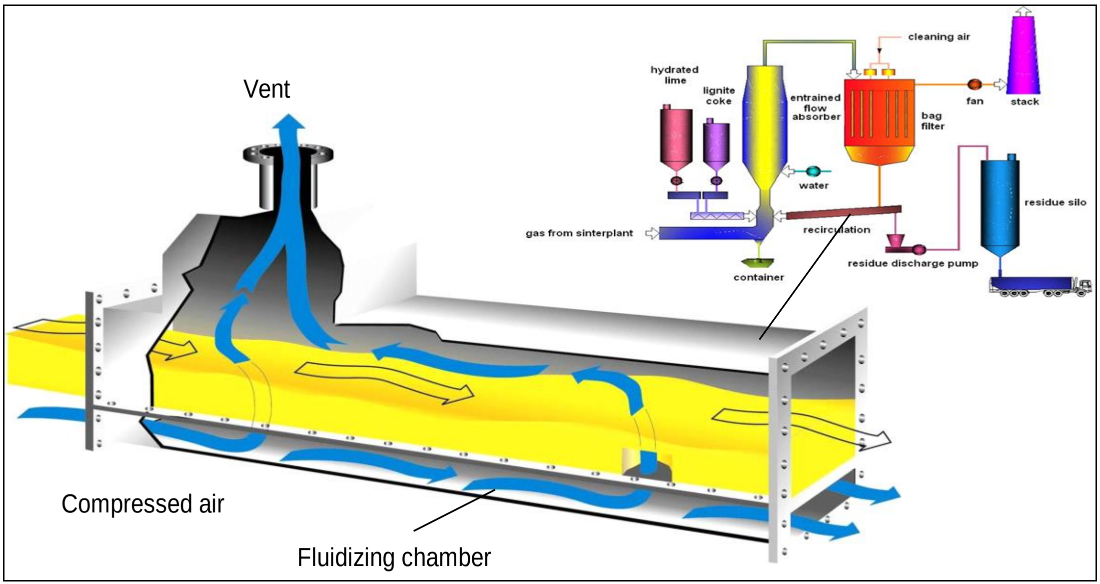

Figure 6: Fluid Slide

From the hopper of the bag filter the material is recirculated to the reactor by means of fluidized troughs, so called “Fluide Slides” shown in Figure 6. Only a small part of the solids is taken out of the system by a residue discharge pump and transported to the residue silo.

After being pre-cleaned in the existing electrostatic precipitator (ESP) and downstream the main blower, the waste gas enters the Entrained Flow Absorber. In the nozzle of the lower part of the absorber the gas is accelerated and the addition of the fresh additives of hydrated lime $Ca(OH)_2$ and lignite coke is taking place. At the same time the recirculated material coming out of the bag filters is added. The additives and the recirculated material react with the gaseous components.

For removal of acidic gas components like SO_3, SO_2, HCl and HF hydrated lime $Ca(OH)_2$ is used as alkaline compound.

The following reactions take place:

$$SO_3 + Ca(OH)_2 \longrightarrow CaSO_4 \bullet \frac{1}{2} H_2O + \frac{1}{2} H_2O$$

$$SO_2 + Ca(OH)_2 \longrightarrow CaSO_3 \bullet \frac{1}{2} H_2O + \frac{1}{2} H_2O$$

$$SO_2 + \frac{1}{2} O_2 + Ca(OH)_2 \longrightarrow CaSO_4 \bullet \frac{1}{2} H_2O + \frac{1}{2} H_2O$$

$$2\ HCl + Ca(OH)_2 \longrightarrow CaCl_2 + 2\ H_2O$$

$$2\ HF + Ca(OH)_2 \longrightarrow CaF_2 + 2\ H_2O$$

Figure 7 : Main Chemical Reactions

In Figure 7 the main chemical reactions for the removal of acidic gas components like SO_2, SO_3, HCl and HF with the hydrated lime $Ca(OH)_2$ as alkaline compound are shown.

The desulphurisation efficiency of $Ca(OH)_2$ depends mainly on the gas temperature, moisture content and retention time of the sorbent inside the filter system.

For the temperature control there is an injection of high pressurized water at 35 bar which evaporates and accelerates the reaction of the acidic components. There is no agglomeration of the dust and the temperature is always kept above the dewpoint.

One important aspect of the process is the consumption of the additives and the amount of residues. They are strongly influencing the operating costs. Figure 8 shows the required quantity of additives in order to surely fulfill the actual legislational and guaranteed limits of less than 500 mg/m³ (STP) [from 900 mg/m³ (STP)] of SO_2 and 0.1 ng/m³ (STP) [from 3 ng/m³ (STP)] of Dioxins/Furans.

The recirculation of the sorbens enables to reach very high efficiencies and is one of the major advantages of the process. This process feature allows to limit and to optimize the required consumables to a minimum. Based on calculations it is expected to consume about 300 kg/h of hydrated lime and approx. 30 kg/h of activated lignite. The expected quantiy of residues amounts to 600 kg/h which has to be deposited underground.

The control of the process as a whole is managed by three closed control circuits:

1. Control of the fluidized bed pressure loss in the absorber in order to keep the specific amount of recirculated material (up to 1 kg/m³ (STP)) constant at changing gas flow rates.
2. Control of the waste gas temperature at the outlet of the absorber by the amount of water injection.
3. Control of SO_2 in the clean gas by adding fresh hydrated lime. The addition of the acivated lignite coke is direct related to the raw gas volume flow.

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$SO_2 < 500$ mg/m^3 (STP)

hydrated lime powder, $Ca(OH)2$: < 280 kg/h *

95 % $Ca(OH)_2$, spec. surface > 18 m^2/g, granulometry 99 % < 90 µm

PCDD/F < 0,1 ng/m^3 (STP)

lignite coke, C: < 25 kg/h *

minimum quality: ground activated lignite coke, spec. surface approx. 300 m^2/g, granulometry 100 % < 125 µm, 63 % < 32 µm, d50 = 24 µm

Residues: < 500 kg/h *

* at raw gas conditions: 500.000 m^3/h (STP), SO_2 = 900mg, PCDD/F = 3ng/m^3 (STP)
In case of 2nd Rogesa EFA™ plant: average $Ca(OH)_2$ consumption at 250 kg/h

Figure 8: Quantity of additives and final residues

5 OPERATIONAL RESULTS

The start of the site activities for the 1st ROGESA plant was in April 2005. Fig. 9 shows a 3D model of the new plant with the essential components like silos for the additives, the two Entrained Flow Absorbers, the bag filters and the blowers (on the backside of the view). The arrangement is very compact in order to minimize the necessary area for the erection. The chimney is designed for two plants and is located in such a way that the second plant can easily be connected.

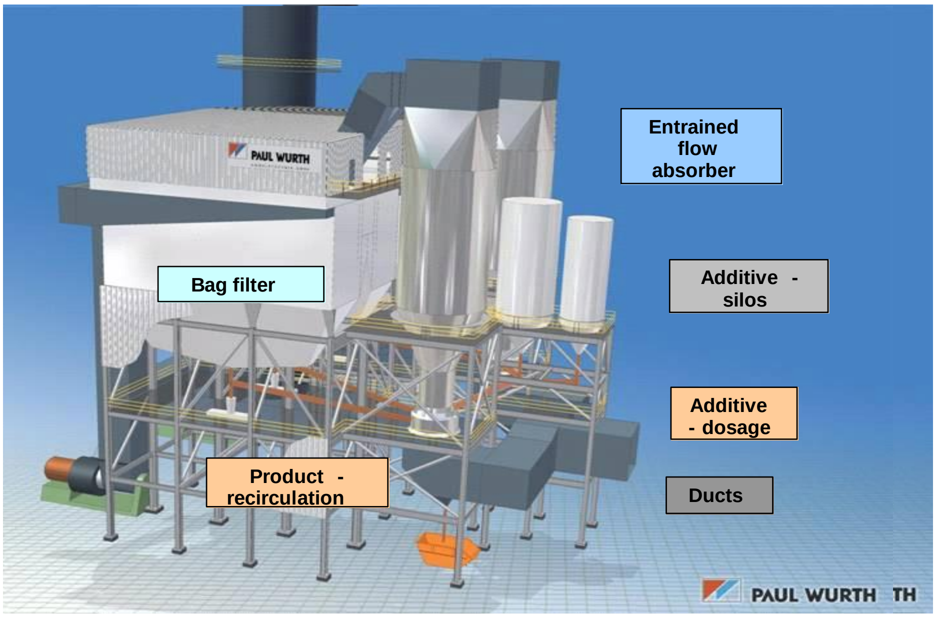

Figure 9: 3D Plant View

After the solution of different primary problems with the quantity of the gas volume entering the plant, the bag filter material, and the parameter adjustment of the closed control circuits in conjunction with the automation system the following results of the emissions in the clean gas are achieved (Figure 10):

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	Guarantee load case (clean gas)	Actual load data (average values)
Flow rate m^3/h (STP) dry	540.000	430.000
Flow rate m^3/h (STP) wet	600.000	480000
Temperature outlet °C	100	100
Dust mg/m^3 (STP) dry	< 10	< 5
SO2 mg/m^3 (STP) dry	< 500	480
HCl mg/m^3 (STP) dry	< 10	< 10
HF mg/m^3 (STP) dry	< 1	< 1
PCDD/F ng/m^3 (STP) dry	< 0,1	< 0,1
$m^{act}Ca(OH)_2$/ $m^{totl}Ca(OH)_2$ (stoichiometric factor)	1,6	1,1

Figure 10: Operational Results of the 1st ROGESA EFA™ plant

The optimization of the process is almost done and the operational results are beyond the expactations in particular regarding the consumables. Any improvement resp. any minimization of the amount of consumables means direct savings in the operating cost. The basic process principle, the recirculation, is one of the important steps to minimize the operating cost and to reduce the amount of consumables and residue material to its minimum by maximizing the rate of reaction. The value of the stochiometric relationship as defined in Figure 10 is an extraordinary achievement of the optimization progress. It finally leads to significant savings under two aspects: the procurement of hydrated lime plus lignite coke and the landfill of the reaction products.

	Guarantee load case (clean gas)	Actual load data (average values)
Flow rate m^3/h (STP) dry	820.000	710.000
Flow rate m^3/h (STP) wet	880.000	760.000
Temperature outlet °C	100	100
Dust mg/m^3 (STP) dry	< 10	< 3
SO2 mg/m^3 (STP) dry	< 500/350	< 350
HCl mg/m^3 (STP) dry	< 10	< 10
HF mg/m^3 (STP) dry	< 1	< 1
PCDD/F ng/m^3 (STP) dry	< 0,1	< 0,1
$m^{act}Ca(OH)_2$/ $m^{totl}Ca(OH)_2$ (stoichiometric factor)	1,6	1,1-1,2

Figure 11: Operational Results of the 2nd ROGESA EFA™ plant

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Figure 12: Plant view of the two Rogesa, EFA™ plants.

Figure 11 shows a picture the Paul Wurth EFA™ gas cleaninig facility at both Rogesa's sinter strand No. 2 and No.3.

The first operation results of the Salzgitter EFA™ plant are shown in Fig. 13. The plant is in operation since May 2010, final acceptance certificate is issued and the plant is operating to the full satisfaction of the client in all regards.

For the current sinter off-gas flow the plant is oversized. However, the client intends to enlarge the sinter strand slightly to increase sinter production, which was the basis for the design of the EFA™ plant.

	Guarantee load case (clean gas)	Actual load data (average values)
Flow rate m^3/h (STP) dry	680.000	450.000
Flow rate m^3/h (STP) wet	775.000	515.000
Temperature outlet °C	95	110
Dust mg/m^3 (STP) dry	< 20	< 5
SO2 mg/m^3 (STP) dry	< 500	< 500
HCl mg/m^3 (STP) dry	< 30	< 10
HF mg/m^3 (STP) dry	< 3	< 1
PCDD/F ng/m^3 (STP) dry	< 0,1	< 0,1
$m^{act}Ca(OH)_2/ m^{tot}Ca(OH)_2$ (stoichiometric factor)	1,4	1,2

Figure 13: Operational Results of the Salzgitter EFA™ plant

The start-up of the Salzgitter EFA™ plant went very well. The experience gained during the recent years of operation of the Rogesa plant was very helpful and led to optimum results. The following picture (Figure 14) shows the very compact Salzgitter plant schematically. Compared to the Rogesa plant there is only one Entrained Flow Absorber for the full gas flow. Up to now, there is, process related, no real advantage for the one or the other solution. However, the most compact plant is only possible with one absorber.

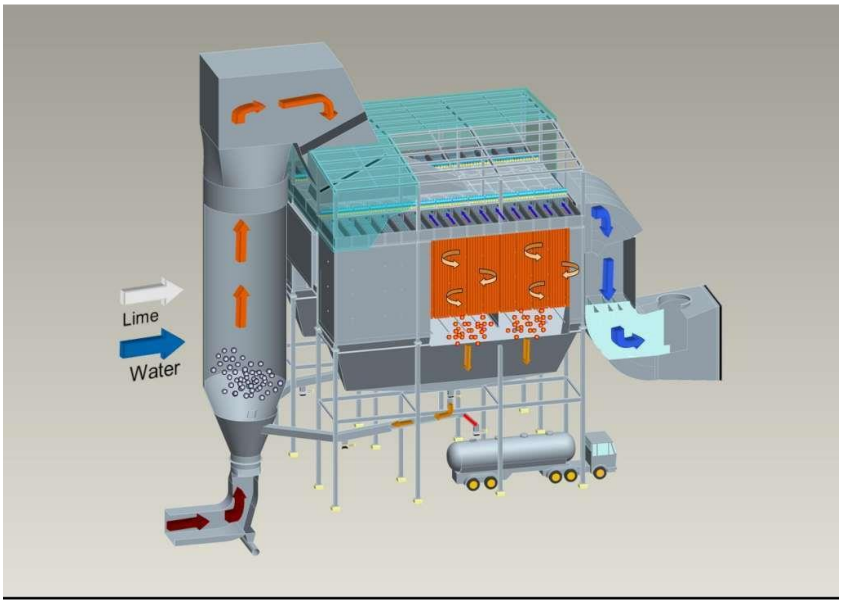

Figure 14: Schematic view of the Salzgitter EFA™ plant

Figure 15: Plant view on site of Salzgitter Flachstahl

7 SUMMARY AND OUTLOOK

Sinter plants are important facilities in the production chain of ironmaking. They are not only producing sinter as ironbearing burden for the blast furnace, but also recycle a lot of valuable secondary materials to avoid their landfilling.

However, the environmental legislation has been continually and strictly tightened by the environmental authorities concerning the emissions of pollutants in waste gases. The option, the two iron and steel producer Rogesa and Salzgitter have chosen to face this liability with maintaining of the existing electrostatic precipitator in conjunction with the Paul Wurth EFA™ process gives safety while operating the sinterplants in accordance with the strict environmental rules even for the future. With these installations the sinterplants are at the top of the environmental development for waste gas, sinterplant off-gas cleaning. This technology, the EFA™ process, has become a milestone in sinterplant desuphurization, state-of-the-art for dedusting and dedioxination.
