REDUCTION IN EMISSION LEVELS IN SINTER PLANTS WITH LÜHR CONDITIONING ROTOR – RECYCLE PROCESS FOR PARTICLES (ALKALINES), DIOXINS/FURANS, SO_x, HEAVY METALS[1]

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Abstract
The emission limit values requested in these days for gas cleaning plants downstream sinter plants can only partly be maintained with the currently installed systems – in most of the cases multistage electrostatic precipitators. The integration of an additional fine cleaning stage in the crude gas cleaning system serves for the observance of the necessary degrees of separation for particles / alkalis, heavy metals, acid crude gas components such as HF, HCl, SO_x and dioxins/furans requested today and in the future. In this respect, the LÜHR FILTER Conditioning Rotor – Recycle Process offers a reliable and well proven system. In the base variant it comprises the component parts reactor, flat-bag filter, particle re-circulation and additive powder injection device. The Conditioning Rotor – Recycle Process is characterised by a high efficiency, a good potential for being integrated into the existing process technology, a high reliability at low maintenance as well as low operating costs. The first large scale plant has already been installed in 1993. Besides the presentation of this process, this lecture also gives information about the extensive operating experiences gathered from this plant - which has meanwhile been in operation for 15 years - and also about other realised projects. The achievable degrees of separation are presented.
Key words: Sinter plant; Emissions; Flue gas treatment.

Resumo
Os atuais valores limites de emissões após os sistemas de limpeza de gás de processo de sinterizações – na maioria dos casos precipitadores eletrostáticos de vários estágios - só podem ser atingidos com restrições. Com a integração de um estagio complementar de limpeza fina vira possível atingir os limites de emissão atuais e futuros para particulados/alcalinos, metais pesados e componentes ácidos nocivos como HF, HCl, SOx e Dioxinos/Furanos. Um dos processos comprovados e testados para isso é o processo recirculatório com rotor de esferas da empresa LÜHR FILTER. Na versão básica o processo é composto de um reator, um filtro com mangas achatadas, recirculação de particulados e admissão de aditivos. O processo recirculatório com rotor de esferas apresenta como pontos marcantes a alta eficiência, a facilidade para integração em plantas existentes, a grande disponibilidade com pouca necessidade de manutenção bem como os baixos custos operacionais. A primeira instalação em escala industrial foi implantada em 1993. Apresentamos aqui o processo e relatamos sobre a vasta experiência operacional após 15 anos de operação na primeira planta e sobre outros projetos já realizados. Os limites de emissão alcançáveis são mostrados.
Palavras-chave: Sinterização; Emissões; Limpeza de gás de processo

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1 INITIAL SITUATION

Sinter plants are usually equipped with multistage electrostatic precipitators or, in exceptional cases, with cyclones in order to limit the dust emission. The currently requested limit values for particles can only partly be observed with this kind of separators. Especially the alkaline components affect the efficiency of electrostatic precipitators due to their adhesive character.
Besides the separation of dust, the requirements of today increasingly request the reduction in emission of further gas components such as heavy metals, acid crude gas components (HF, HCl, SO_x) and/or dioxins/furans.
The Conditioning Rotor – Recycle Process developed by LÜHR FILTER is suited to separate the above-mentioned components in simultaneous operation in a fine cleaning stage to values below the requested emission limit values. The system mainly comprises a flat-bag filter with upstream installed reaction chamber and particle re-circulation system.

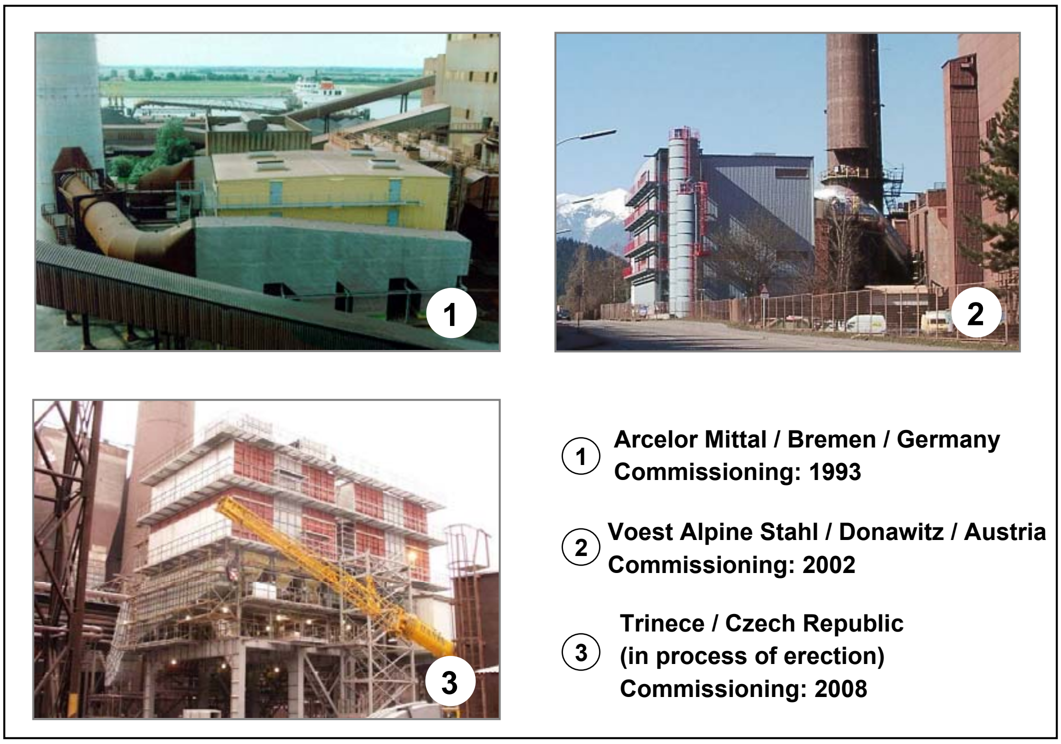

Figure 1: Examples of realised plants

The system has already been installed downstream several sinter plants.

- Operation of demonstration plants at Arcelor Mittal, Bremen / Germany (> 10,000 operating hours), HOESCH KRUPP STAHL, Dortmund / Germany (> 4,000 operating hours) and VOEST ALPINE STAHL, Donawitz / Austria (> 6,000 operating hours)
- Large scale plants at Arcelor Mittal, Bremen / Germany (1993), VOEST ALPINE STAHL, Donawitz / Austria (2002), RDM / Brazil (2006), expansion of plant at Arcelor Mittal, Bremen (2007), Trinece / Czech Republic (2008), Siemens VAI Project DSC / Taiwan (in process of erection).

In the following the system will be presented as well as the experiences gathered from the operation of above-mentioned plants.

2 SECONDARY MEASURES FOR REDUCTION IN EMISSION

2.1 Particles/alkalines and Particulate Heavy Metals

Already the first examinations with a demonstration plant in 1991 led to the conclusion that the multiple re-circulation of particles separated in the filter into the gas flow upstream filter combined with the additional injection of additive powders proved to be advantageous for the ability of the filter fabric to regenerate successfully in continuous operation. Without those measures the extreme fine and adhesive alkalines would blind the filter fabrics. In addition, without particle re-circulation and additive powder injection, gaseous components such as e.g. C_xH_y may lead to irreversible deposits in the filter fabric, causing an early increase in the filter differential pressure.
As a result of the re-circulation of particles and the injected additive powder particles, a mobile pre-filter layer of particle agglomerates is formed on the filter bags on which the adhesive primary particles are separated (Figure 2). Also gaseous components such as C_xH_y are separated at the mobile pre-filter layer if necessary. The particle layer on the bags serves for the protection of filter elements.

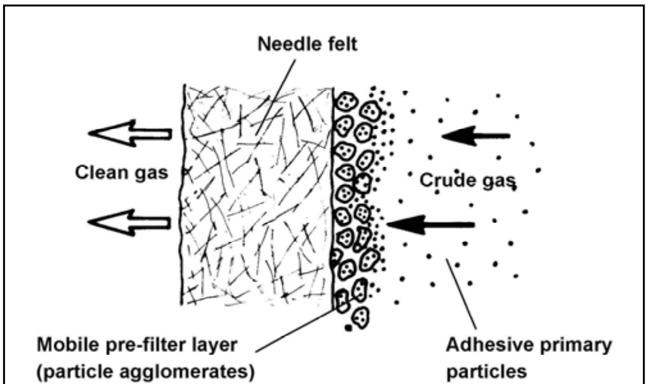

Figure 2: Mobile pre-filter layer for the separation of fine, adhesive particles

In general $Ca(OH)_2$ is used as additive powder. As alternative $CaCO_3$ can be used. Both additive powder qualities are suited for the reliable separation of SO_3 from the gas, thus avoiding corrosion in the fine cleaning stage. SO_3 has a considerable influence on the acid dew point.

2.1.1 LÜHR conditioning rotor – recycle process

For many types of applications the Conditioning Rotor – Recycle Process proved to be suitable for the reliable realisation of re-circulation of particles separated in the filter into the flue gas flow upstream filter (Figure 3).

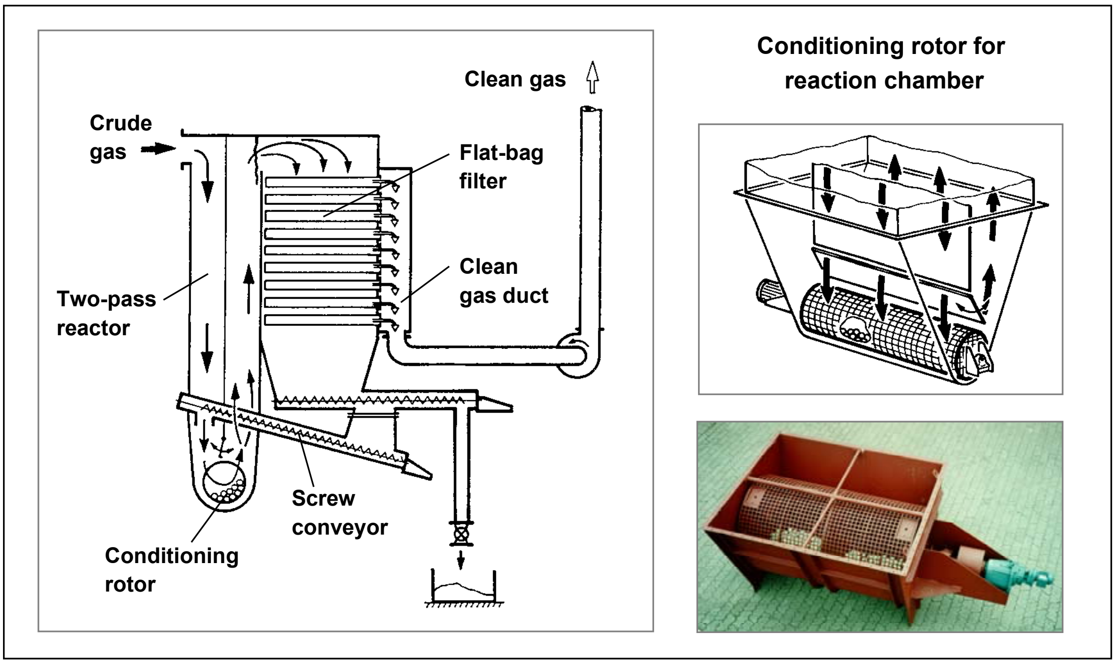

Figure 3: Schematic view of Conditioning Rotor – Recycle Process

The conditioning rotor is a hollow cylinder, manufactured of a perforated plate with openings of approx. 30 x 30 mm. Up to 5% of its volume is filled with balls made of heat- and wear-resistant ceramics. The rotor is continuously driven by means of a geared motor with a speed of approx. 1 rpm. The rotation causes the balls to move relative to each other and to the perforated shell. The rotor is located in the lower reaction chamber elbow upstream filter, passed through by the crude gas.
The main functions of a conditioning rotor are:

- prevention of particle deposits when reversing a particle-laden crude gas flow
- achievement of a homogeneous distribution of re-circulated particles in the crude gas flow even in case of a high particle concentration (e.g. up to several 100 g/m³)
- disintegration of larger particle agglomerates

Prior to their discharge, the particles separated in the filter are frequently reintroduced into the reactor by means of a conveying screw. The particle recycle rate is adjustable via the speed of screw conveyor and can be controlled on request depending on the current crude gas volume.
Compared to alternative, e.g. pneumatically working re-circulation systems, the Conditioning Rotor - Recycle Process offers among others the following advantages:

- mechanical particle transport by means of reliable screw conveyors
- discharge or possible interim storage of the recycled particulate is not necessary
- a homogeneous distribution of the reintroduced, recycled particulate in the crude gas flow
- high reliability in operation

2.1.2 Operating results

Extensive measurements have been realised at the fine cleaning stage installed in 1993 at Arcelor Mittal in Bremen / Germany for the determination of degrees of separation for particles and particulate heavy metals. Figure 4 shows the results, instancing the particle separation. The degrees of separation for particulate heavy metals proved to be comparably good. These good results could also be demonstrated at all other plants installed by LÜHR FILTER downstream sinter plants.

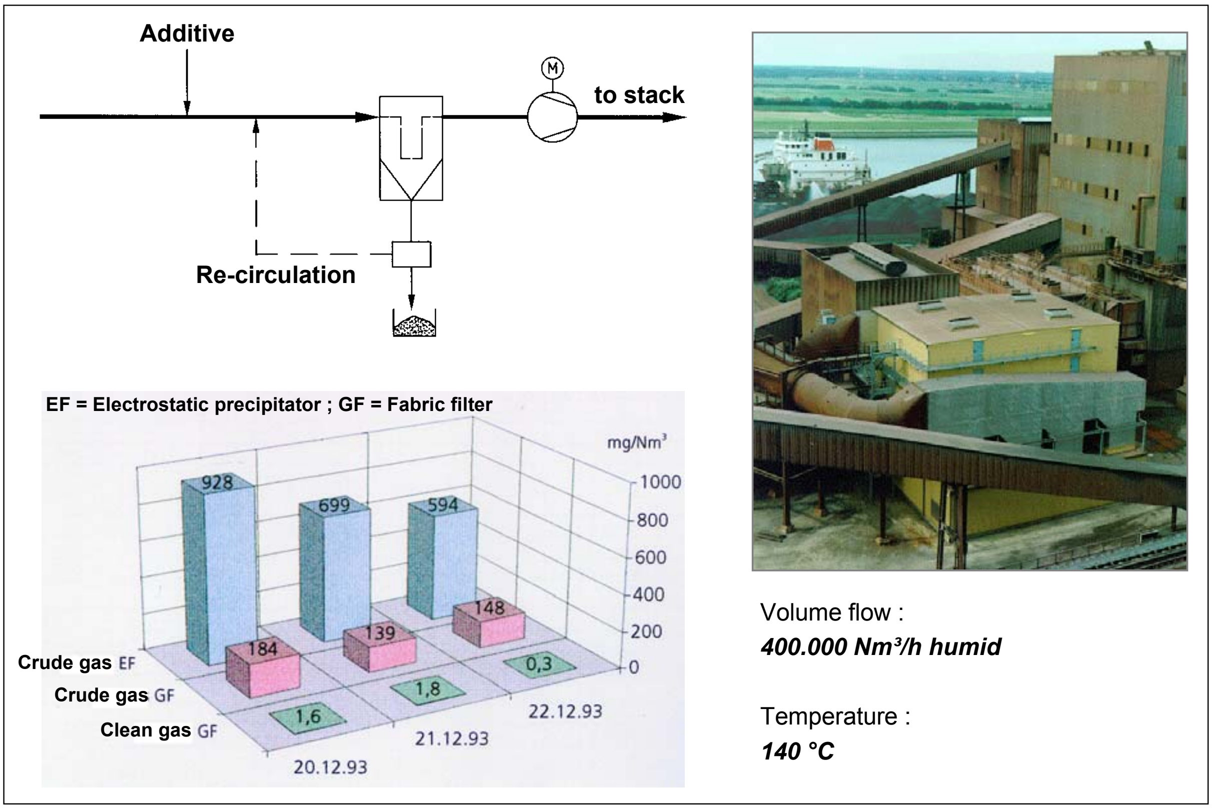

Figure 4: Simultaneous particle measurement upstream and downstream ESP as well as downstream fine cleaning stage

2.2 Dioxins/Furans

For the separation of gaseous dioxins/furans an additive powder quality with large specific surface is injected into the flue gas flow upstream fabric filter. The dioxins/furans are adsorbed at the additive powder particles and in this manner separated at the filter fabric. A multiple re-circulation of the particles separated in the filter has an advantageous influence on the achievable degrees of separation and/or leads to a reduction in operating costs regarding the additive powder consumption and disposal.

The re-circulation by means of Conditioning Rotor – Recycle Process results in the following:

- Improved chances of contact of additive powder / crude gas already during fly phase.
- An almost homogeneous distribution of additive powder on the filter bags.
- The quick formation of additive powder containing layers on the filter bags, independent of the current injection of fresh adsorbent (especially important after each cleaning).

In most of the cases activated coke and/or activated carbon with a specific surface of approx. 350 up to > 1,000 m²/g are used as additive powder. Due to the fact that these qualities are carbonaceous additive powders, preventive measures have to be taken to avoid dust explosions and smoulder within the filter. As far as a mixture of inert material (at least 70 weight%) and activated coke (max. 30 weight%) is used, dust explosions can be excluded. The additive powder already injected for the particle separation and for the protection of filter serves as inert material. With regard to smoulder, constructive measures have to make sure that larger particle deposits within the filter are avoided. In addition, the gas temperature should be < 160°C.
Figure 5 exemplary shows the measuring results of stated plants for the fine cleaning stage at Arcelor Mittal, Bremen.

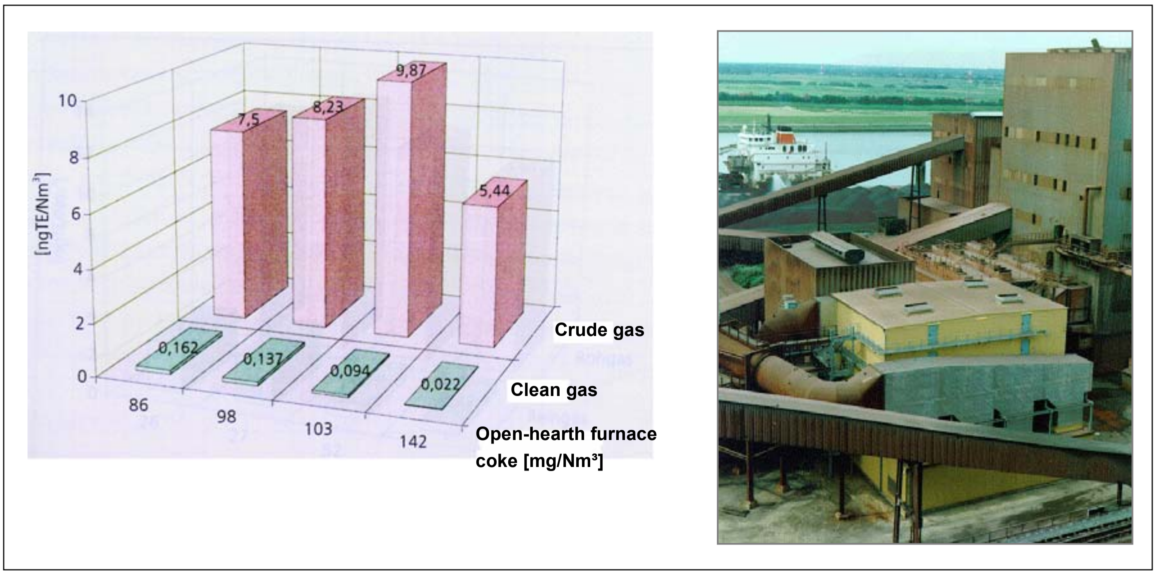

Figure 5: Measuring results concerning the separation of dioxin / furan

2.3 Acid Crude Gas Components HF, HCl, SO_x

For the separation of acid crude gas components commercially available hydrated lime $Ca(OH)_2$ with a specific surface of approx. 15 up to 20 m²/g is normally injected into the gas flow upstream filter. The reaction equations as well as the injection and remainder quantities at an additive powder utilisation of 100% are shown in Table 1.
In order to achieve the reliable compliance with the requested emission levels for the clean gas in the practice, the additive powder has to be injected above stoichiometry (normally 1.5 – 3fold referring to separated quantity).

Table 1: Reaction equations for Ca(OH)2

Equations of reaction	$Ca(OH)_2$ - injection quantity related to crude gas at 100% stoichiometric (i=1)	Resulting residual particle quantity (with crystal water content according to experience) related to crude gas
$2HF + Ca(OH)_2 \rightarrow CaF_2 + 2H_2O$	1,85 kg/kg	1,95 kg/kg
$2HCl + Ca(OH)_2 \rightarrow CaCl_2 + 2H_2O$	1,01 kg/kg	2,02 kg/kg
$SO_3 + Ca(OH)_2 \rightarrow CaSO_4 + H_2O$	0,93 kg/kg	2,15 kg/kg
$SO_2 + Ca(OH)_2 \rightarrow CaSO_3 + H_2O$	1,16 kg/kg	2,02 kg/kg

It is provable that especially in case of high additive powder recycle rates, the Conditioning Rotor – Recycle Process will lead to a clear improvement of the degree of separation for acid crude gas components and/or to a reduction in the additive powder injection quantity.

- The residence time of additive particles in the system is increased
- In the reactor upstream filter a higher additive particle density is formed (resulting reaction time in reactor up to > 2 sec.)
- Achievement of a frequent, spatial re-orientation of the re-circulated particulate with re-deposition of the filter cake on the filter fabric.

Regarding the temperature range of 100°C and 220°C which is typical for fabric filters, the following order of reaction results for the reaction rate of the separate crude gas components and the $Ca(OH)_2$:

$$SO_3 > HF > HCl >>> SO_2$$

The separation of SO_3, HF and HCl does not present any problem in the usual temperature range for sinter plants. However, satisfying degrees of separation for SO_2 with a good additive powder efficiency can only be achieved if the water steam partial pressure is at least in times near to the saturation steam pressure in direct near of the recycled particulate. This will be achieved when using the conditioned dry sorption by means of Conditioning Rotor – Recycle Process (Figure 6). In this procedure, the recycled particles are wetted prior to re-injection into the reactor. The humidification causes an increase in water steam content at the surface of additive powder particles, thus improving the reactivity compared to the acid crude gas components.
The application of this process variant allows degrees of separation for SO_2 as well as for all other acid crude gas components of up to > 90%

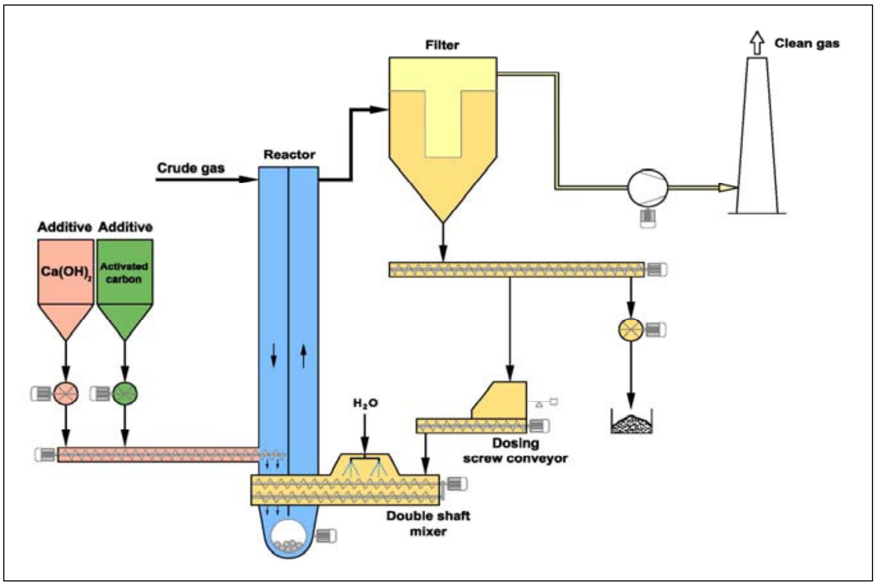

Figure 6: Conditioning Rotor – Recycle Process with particle conditioning

2.3.1 Operating results

Measurements at the fine cleaning stages installed by LÜHR FILTER downstream sinter plants confirm the above-mentioned explanations. The plant at Arcelor Mittal in Bremen has been provided with a mere dry sorption. The achievable degrees of separation for HF and HCl are satisfying but with regard to SO_2 only minor degrees of separation could be achieved (Figure 7).

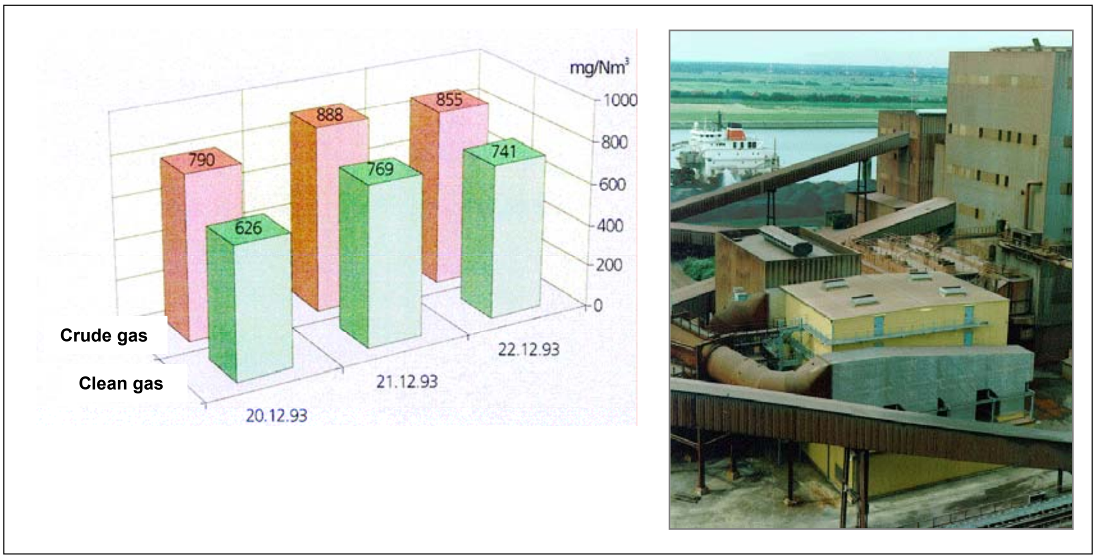

Figure 7: Simultaneous measurement of SO2 concentration of plant Arcelor Mittal Bremen / Germany

Compared to this, the plant at VOEST ALPINE STAHL in Donawitz / Austria has been provided with the Conditioning Rotor – Recycle Process including particle conditioning. Picture 8 clearly demonstrates the influence of particle conditioning. Prior to water injection into the humidifying mixer and in spite of a particle re-circulation rate of approx. 150 g/Nm³ the achieved degrees of separation only were in a range of 5 up to max. 10%. Only after moistening of the re-circulated particulate with an at the same time acceptable additive powder consumption the requested emission levels of < 500 mg/Nm³ dry could reliably be observed in continuous operation.

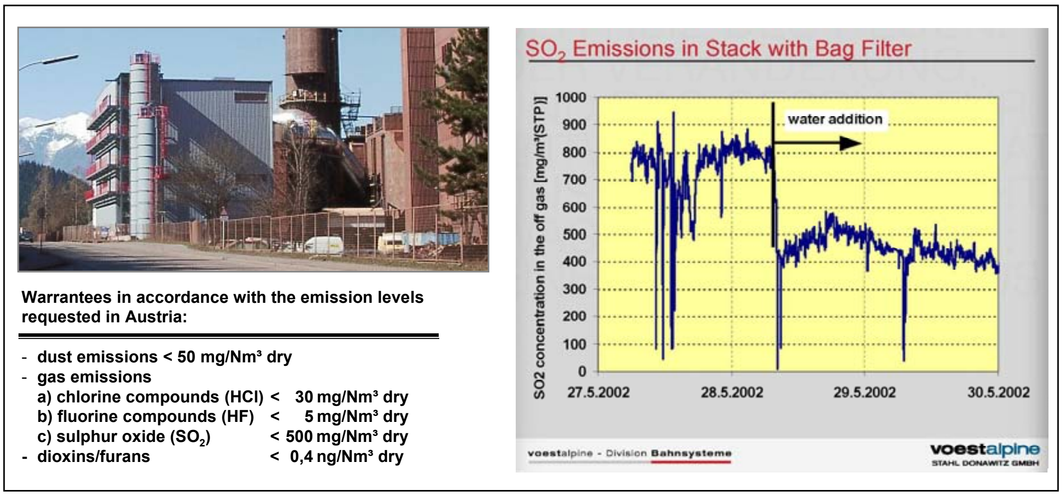

Figure 8: SO2 concentration with and without particle conditioning

The reason for the successful separation of SO_2 with the Conditioning Rotor – Recycle Process with particle conditioning is that the required reacting parties – SO_2

– molecule, additive powder particles and water - are directly brought together in the reactor. During injection into the reactor the water is already adsorbed at the additive powder and not injected separately as e.g. in case of other procedures. Another advantage of this process is that high degrees of separation can be achieved even in case of comparatively low gas temperatures as e.g. 110°C.
For clarification of the efficiency of the process it may be remarked that regarding the project DSC in Taiwan which is at present in process of erection, a degree of separation for SO_2 of > 80% has been granted.

2.3.2 Comparison to alternative additive powder qualities

In principle, sodium bicarbonate $NaHCO_3$ can also be used as alternative to $Ca(OH)_2$ for the separation of acid crude gas components. After injection of this additive powder quality into the gas flow with temperatures > 140°C a thermal activation of the $NaHCO_3$ will take place. The result hereof is high reactive sodium carbonate. Table 2 shows the chemical reaction equations as well as the injection and remainder quantities in case of an additive powder efficiency of 100%. As a general rule, the requested emission limit values can be kept in continuous operation with an above average stoichiometric factor of 1.2 – 1.5, referred to the separated quantity. A multiple re-circulation of the particles separated in the filter into the gas flow upstream filter may be advantageous. Due to the high reactivity of the additive powder, the process can work without the particle conditioning for the separation of SO_2.

Table 2: Reaction equations for NaHCO3

Equations of reaction	$NaHCO_3$ - injection quantity related to crude gas at 100% stoichiometry (i=1)	Resulting residual particle quantity related to crude gas
$HF + NaHCO_3 \rightarrow NaF + H_2O + CO_2$	4,2 kg/kg	2,1 kg/kg
$HCl + NaHCO_3 \rightarrow NaCl + H_2O + CO_2$	2,3 kg/kg	1,6 kg/kg
$SO_3 + 2NaHCO_3 \rightarrow Na_2SO_4 + H_2O + 2CO_2$	2,1 kg/kg	1,77 kg/kg
$SO_2 + 2NaHCO_3 \rightarrow Na_2SO_3 + H_2O + 2CO_2$	2,63 kg/kg	2,22 kg/kg

Thermal activation of $NaHCO_3$:

$$2NaHCO_3 \xrightarrow{T \langle \; 140\,°C} \underbrace{Na_2CO_3}_{\text{high-reactive, porous crystal structure}} + CO_2 + H_2O$$

However, this process offers considerable disadvantages:
- Unfavourable mass ratio of additive powder to crude gas
- Grinding of additive powder prior to injection into the gas flow necessary
- Compared to $Ca(OH)_2$ high specific purchase costs for the additive powder
- Provision with additive powder not assured all over the country
- The gas temperature should be > 140°C.

From the point of view of the author and based on the before-mentioned disadvantages, this process cannot be applied without reservations for the fine cleaning downstream sinter plants.

3 INTEGRATION OF FINE CLEANING STAGE NTO OVERALL PLANT

In principle there are three different ways to integrate the fine cleaning stage into the overall plant. Picture 9 shows a schematic view of the three variants. In the following the advantages and disadvantages of the separate solutions are explained.

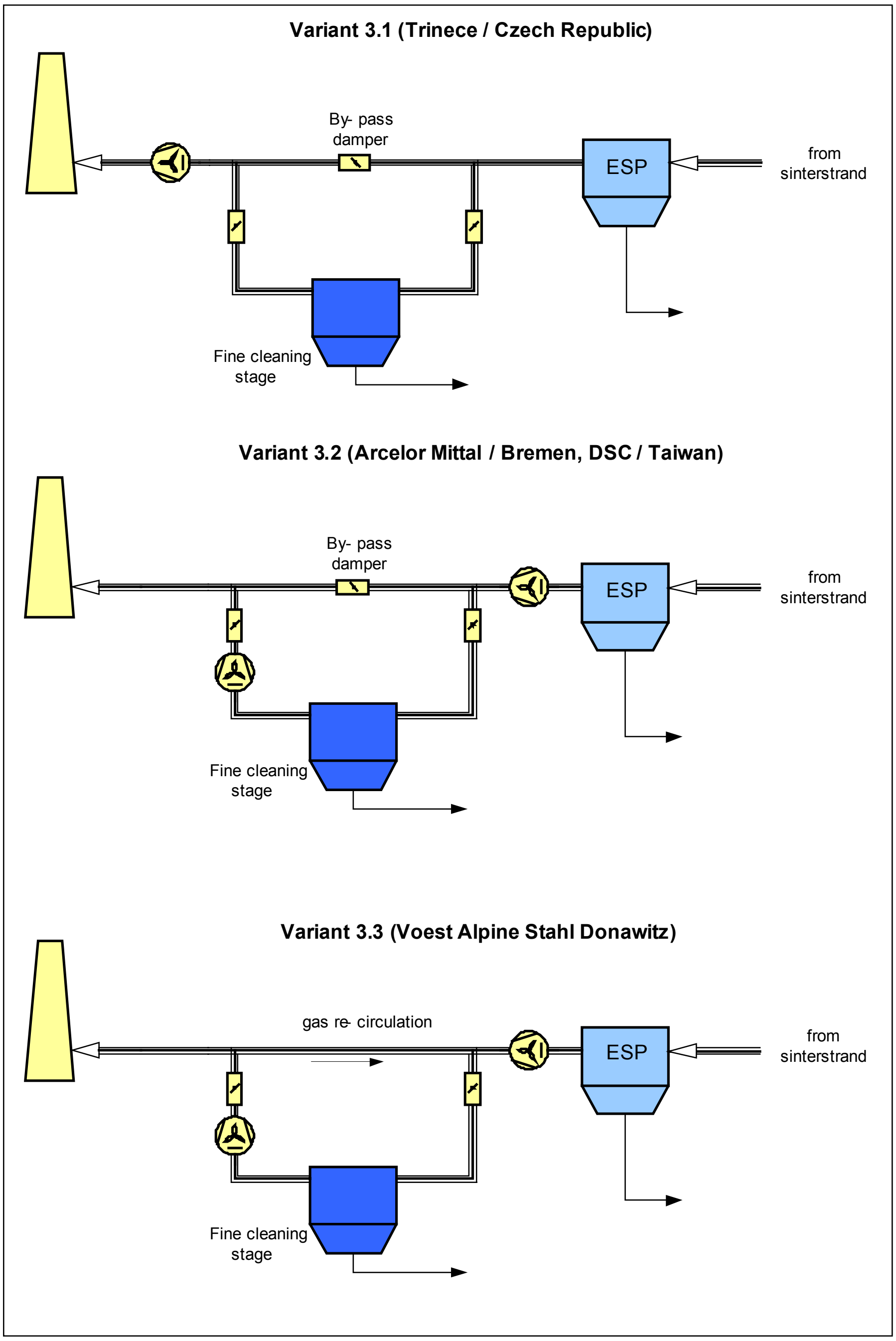

Figure 9: Integration of fine cleaning stage into the overall plant

3.1 Arrangement between ESP and main fan

3.1.1 Advantages

- No second fan necessary
- Protection of main fan from wear due to good particle separation

3.1.2 Disadvantages

- Constructive design of fine cleaning stage taking under consideration the max. negative pressure of main fan
- As a result of the high negative pressure increase in operating volume flow, thus causing the installation of a larger filter surface
- Execution of by-pass dampers with a tightness of 100%
- On-line maintenance due to the high negative pressure difficult
- The missing increase in temperature due to the main fan may lead to problems with the dew point and condensation in the fine cleaning stage in case of too cold gas
- In case of integration into existing systems it has to be checked to what extent the additional differential pressure will lead to losses in efficiency

3.2 Arrangement between main fan and stack with closed by-pass

3.2.1 Advantages

- Nearly atmospheric pressure at the take-over point (low expenditure regarding the reinforcement of component parts as well as smaller filter surface compared to variant 3.1)
- Increase in temperature in case of passing through the upstream installed main fan might be helpful to avoid dew point problems and condensation within filter
- On-line maintenance without any problems possible
- Compared to variant 3.1 quite simple integration into existing systems

3.2.2 Disadvantages

- No wear protection of main fan
- Execution of by-pass with a tightness of 100%
- Second fan necessary

3.3 Arrangement Between Main Fan and Stack with Gas Re-circulation Line

3.3.1 Advantages

- Extremely high flexibility with different operating conditions, among others even during start-up and shutdown of sinter plant
- Nearly atmospheric pressure at the take-over point (low expenditure regarding the reinforcement of component parts as well as smaller filter surface compared to variant 3.1)
- No by-pass dampers necessary
- Increase in temperature in case of passing through the upstream installed main fan might be helpful to avoid dew point problems and condensation within filter
- On-line maintenance without any problems possible
- Simple integration into existing systems

3.3.2 Disadvantages

- Total gas volume approx. 5% higher than for variant 3.2
- No wear protection of main fan
- Second fan necessary

3.4 Assessment

Based on the operating experiences gathered so far, the author's recommendation is variant 3.3. The important advantage of this variant is the high flexibility with control of all possible operating modes. The fine cleaning stage can be driven completely independent of the overall plant. This will definitely offset the disadvantages resulting from the slightly higher gas volume.

4 SUMMARY

For more than 15 years we have gathered operating experiences from plants provided with the Conditioning Rotor – Recycle Process as fine cleaning stage downstream sinter plants. The process allows the simultaneous separation of particles / alkali, acid crude gas components such as HF, HCl and SO_x as well as heavy metals and dioxins/furans in one stage.

The plants installed so far are characterised by

- a very high efficiency regarding the separation of the separate gas components
- a high availability combined with low maintenance
- low operating costs by using low-priced additive powder qualities and good additive powder efficiency
- an waste water-free operation