LUEHR FILTER

Separation of gaseous substances by means of fabric filters

Author:
Rüdiger Margraf

Contents

1   Introduction

Fabric filters are generally only suitable for the separation of particles from gas. To allow the separation of gaseous components, these substances have to be converted into the particulate form by means of chemical reaction caused by the injection of additive powders (absorption) or have to be attached to the inner surface of adequate additive powders (adsorption).
Examples are:

> ➢ Absorption of acid crude gas components such as HF, HCl and SO_x by injection of additive powders based on Ca- or Na compounds
> ➢ Adsorption of dioxins / furans by injection of additive powders with large inner surface such as e. g. open-hearth furnace coke, activated carbon or special clay minerals
> ➢ Ab-/ Adsorption of gaseous heavy metal compounds (as e.g. Hg or As compounds) by means of one or several of the before-mentioned additive powder qualities.

These technologies are often integrated in one plant for the simultaneous separation of particles and gaseous substances. They make considerable demands on the design of fabric filters as well as on the knowledge about the significant criteria and separation procedures concerning the achievement of high degrees of separation with at the same time low additive powder consumption. This lecture presents remarkable aspects and discusses practical examples.

2 Frequently used additive powder qualities
2.1 Absorption
2.1.1 Ca(OH)$_2$

In general commercially available hydrated lime Ca(OH)$_2$ with a specific surface of approx. 18 – 20 m²/g is used as additive powder for the injection into the gas flow upstream filter. In special cases, Ca(OH)$_2$ qualities of up to 40 m²/g with at the same time high pore volume (> 0,2 cm²/g) are used. The reaction equations as well as the injection and remainder quantities at an additive powder efficiency of 100% are listed in table 1.

To grant the reliable observance of the requested emission levels in the practise, the additive powder has to be injected above-stoichiometric (usually 1.5 – 3fold).

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

Tab. 1: Ca(OH)$_2$ injection and remainder quantities

2.1.2 NaHCO$_3$

The additive powder is injected into the gas flow upstream filter. In case of gas temperatures > 140°C, a thermal activation of the sodium bicarbonate will take place and results in the formation of a high-reactive sodium carbonate. The optimum reaction temperature lies in a range of 180°C up to 240°C.

Table 2 show the chemical reaction equations as well as the injection and remainder quantities at an additive powder efficiency of 100%. As a general rule and in case of an adequate plant design, the requested emission levels can reliably be kept in continuous operation with an above-stoichiometric factor of 1.2 – 1.5.

HAUS DER TECHNIK e.V.
2nd symposium: "Filtration technology – filtering and electrostatic particle separation"
29. – 30.05.2008 in Essen

4

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$_3$ NaF + H$_2$O + CO$_2$	4,2 kg/kg	2,1 kg/kg
HCl + NaHCO$_3$ NaCl + H$_2$O + CO$_2$	2,3 kg/kg	1,6 kg/kg
SO$_3$ + 2NaHCO$_3$ Na$_2$SO$_4$ + H$_2$O + 2CO$_2$	2,1 kg/kg	1,77 kg/kg
SO$_2$ + 2NaHCO$_3$ Na$_2$SO$_3$ + H$_2$O + 2CO$_2$	2,63 kg/kg	2,22 kg/kg

Thermal activation of NaHCO$_3$:

$$2NaHCO_3 \xrightarrow{\ T \geq 140\ °C\ } Na_2CO_3 + CO_2 + H_2O$$

high-reactive, porous
crystal structure

Tab. 2: NaHCO$_3$ injection and remainder quantities

To improve the activity, the additive powder is usually ground up in a classifier prior to injection into the gas flow.

2.2 Adsorption

For this type of chemical process, additive powders with a large specific surface are used. A selection of commercially available qualities, especially suitable for the separation of dioxins / furans as well as Hg and Hg compounds, is shown in illustration 1.
As far as carbonaceous products are used and subject to the application, additional measures have to be taken for the prevention and fighting of smoulders and, in case of need, some additional measures concerning the explosion prevention. Referring to this, illustration 2 shows some corresponding information.
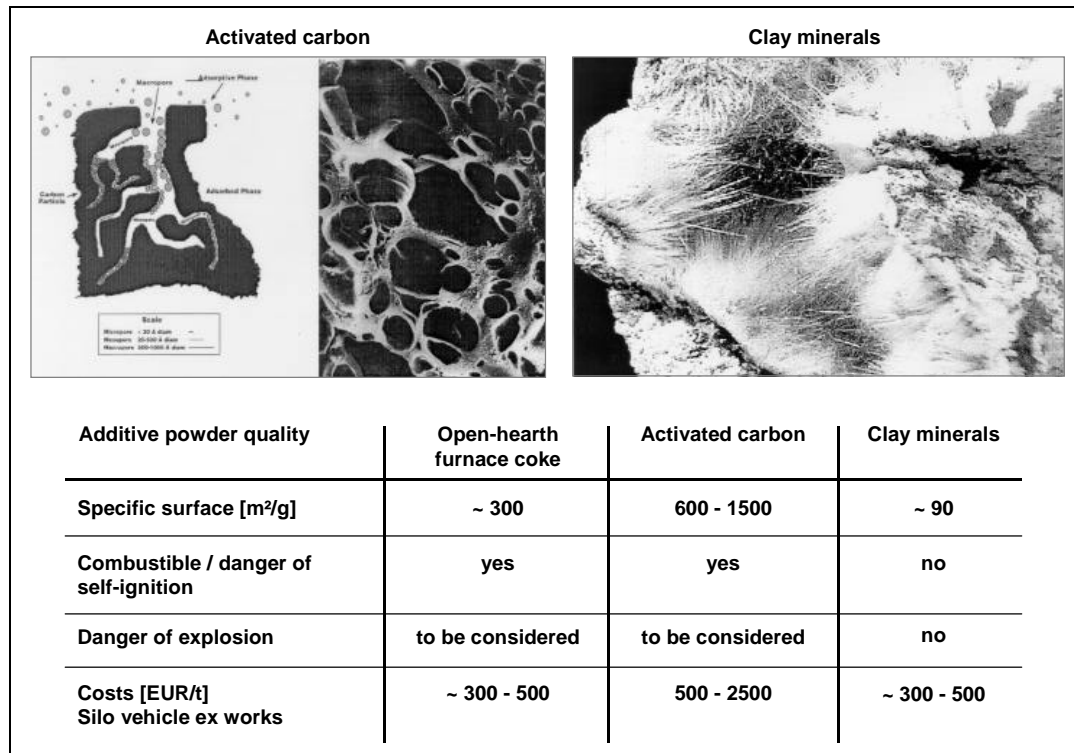
HAUS DER TECHNIK e.V.
2nd symposium: "Filtration technology – filtering and electrostatic particle separation"
29. – 30.05.2008 in Essen   5

Additive powder quality	Open-hearth furnace coke	Activated carbon	Clay minerals
Specific surface [m²/g]	~ 300	600 - 1500	~ 90
Combustible / danger of self-ignition	yes	yes	no
Danger of explosion	to be considered	to be considered	no
Costs [EUR/t] Silo vehicle ex works	~ 300 - 500	500 - 2500	~ 300 - 500

Illustration 1: Commercially available additive powder qualities

Safety regulations

1. *Danger of explosion*

   C-concentration < 35 % : no demands (make sure there will be no separation)
   C-concentration > 35 % : protection against explosion is necessary

2. *Fire hazard*

   - avoid external ignition
   - self-ignition → Critical temperature according to diagram VDI 975 (1992)

2.1 *Precautions to avoid self-ignitions*

   - temperature < 150 °C if possible
   - avoidance of additional O_2-entry
   - avoidance of particle deposit
   - avoidance of pointwise heat input

2.2 *Precautions for recognition of pyrophoric layers*

   - level control in dust hopper
   - temperature measurements e. g. in dust hopper and silo
   - D CO-measurements (only in a few exceptional cases)

2.3 *Precautions for firefighting*

   - N_2-purging (approx. 3-times volume alternation)
   - compartmentalised filter

Source: VDI - Report 975 (1992)

Illustration 2: Safety requirements when using carbonaceous additive powder qualities

HAUS DER TECHNIK e.V.
2nd symposium: "Filtration technology – filtering and electrostatic particle separation"
29. – 30.05.2008 in Essen

6

2.3 Additional remarks

This lecture deliberately does without a discussion of the advantages and disadvantages of the separate additive powder qualities. Information in this respect can be taken e. g. from the literature available from other symposia of the HdT.

3 Measures for a reduction in the additive powder consumption

The objective of a project-related planning is to select the optimum process with regard to:

- ➢ the observance of the emission limit values
- ➢ the overall costs
- ➢ the availability and reliability
- ➢ the upkeep and maintenance

Apart from various additive powder qualities, plenty of different process variants are available especially for the absorption. In the following frequently used variants are presented. The listing makes no claim to be complete.

3.1 Sorption procedure when using $Ca(OH)_2$ as additive powder
3.1.1 Base variant dry sorption process

The schematic view of the base variant for the dry sorption process with $Ca(OH)_2$ is shown in illustration 3. It mainly comprises the units fabric filter as well as additive powder injection.
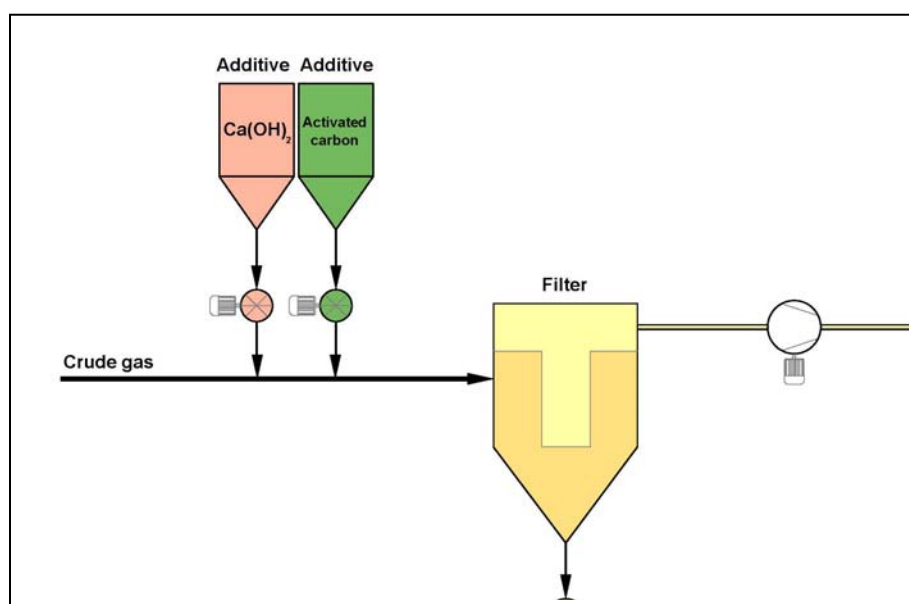

Illustration 3: Dry sorption with $Ca(OH)_2$

HAUS DER TECHNIK e.V.
2nd symposium: "Filtration technology – filtering and electrostatic particle separation"
29. – 30.05.2008 in Essen

7

3.1.2 Particle re-circulation and gas conditioning

To improve the separation capacity and to reduce the additive powder costs, the base variant is often completed by the component parts reactor with particle re-circulation as well as evaporative cooler (illustration 4).
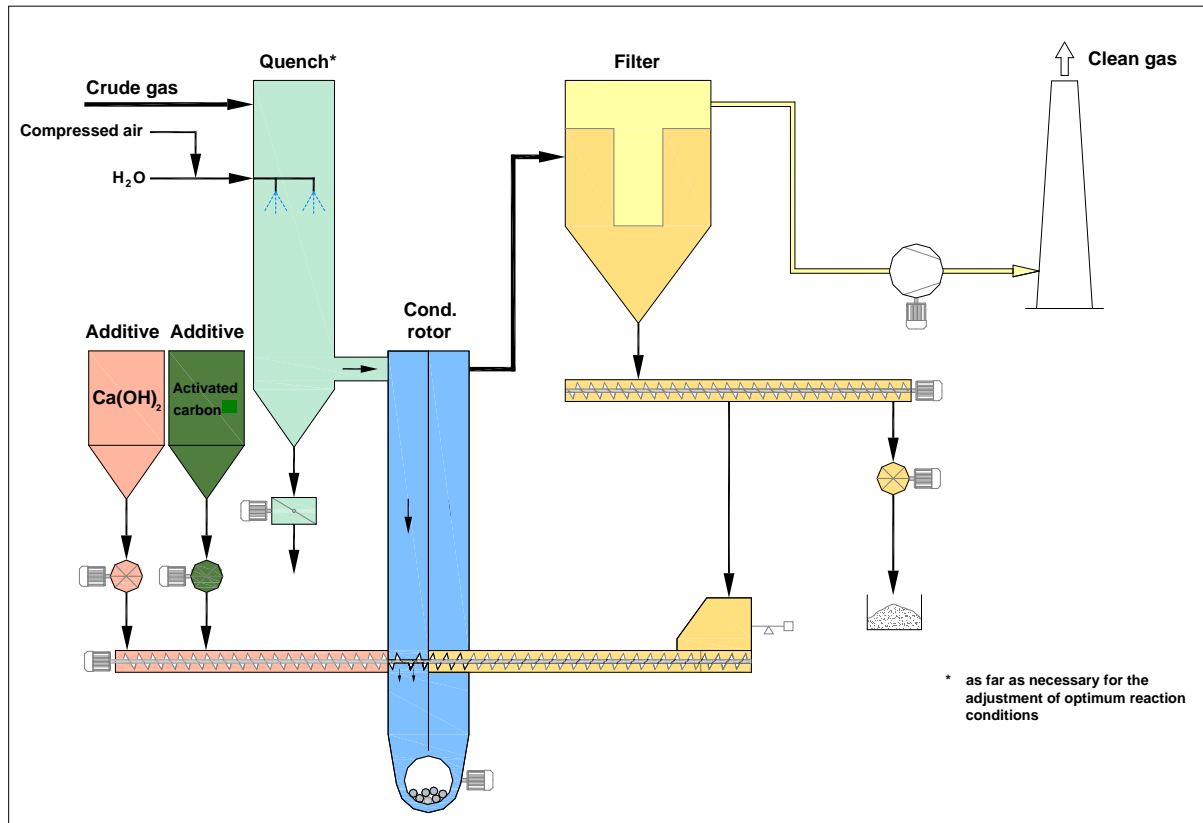

Illustration 4:   Chemisorption with particle re-circulation and gas conditioning

- **Particle re-circulation**

Especially in case of high additive powder recycle rates, the particle re-circulation demonstrably leads to a considerable improvement of the degree of separation regarding acid crude gas components and/or to a reduction in the additive powder injection quantity.

> ➤ The residence time of additive powder particles within the system is increased
> ➤ There is a higher additive powder density near the reactor upstream filter (reaction time within reactor up to > 2 sec).
> ➤ Achievement of a frequent spatial new orientation of the re-circulated additive powder particles with attachment to the filter fabric

Due to the requested, necessary high particle recycle rates and in order to grant an optimum additive powder efficiency, the utilisation of re-circulation systems with a reliable handling of large recycle quantities - even if problematic particles such as $CaCl_2$ form a larger part of the particle spectrum - will be necessary.

Illustration 5 shows a process which has been applied successfully for many years for different types of application. Besides the high reliability it is characterised by a homogeneous distribution of the re-circulated particles in the flue gas flow upstream filter. The process works completely without the use of pneumatic transport systems which are prone to frequent breakdown.
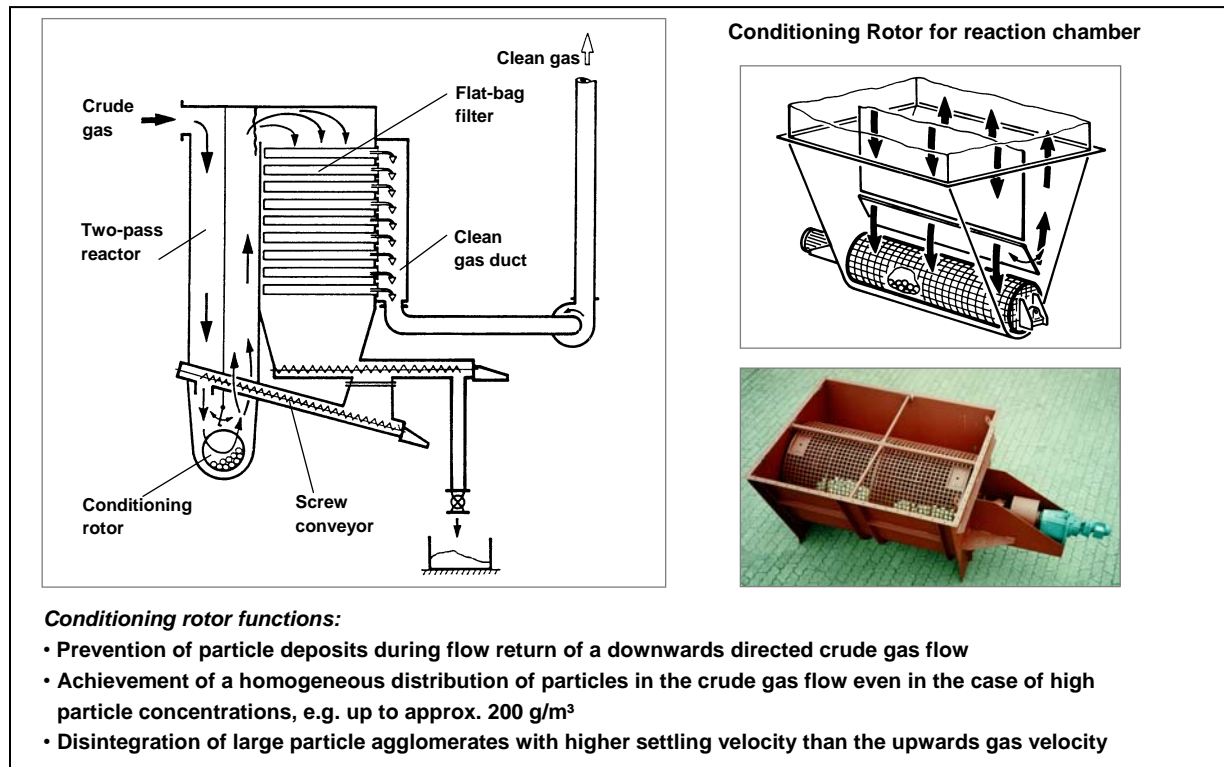

Conditioning rotor functions:
• **Prevention of particle deposits during flow return of a downwards directed crude gas flow**
• **Achievement of a homogeneous distribution of particles in the crude gas flow even in the case of high particle concentrations, e.g. up to approx. 200 g/m³**
• **Disintegration of large particle agglomerates with higher settling velocity than the upwards gas velocity**

Illustration 5:   Conditioning Rotor – Recycle Process (KUV)

The multiple particle re-circulation also has a positive effect on the additive powder consumption rates, which possibly have to be added e. g. for the separation of dioxins / furans or Hg compounds.

- **Evaporative cooler**

With regard to the temperature range of 100°C – 220°C customary for fabric filters, the following sequence of reaction results when using $Ca(OH)_2$ as additive powder:

$$SO_3 > HF \gg HCl \ggg SO_2 \gggg CO_2$$
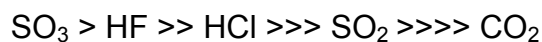
The dry temperature as well as the absolute and relative humidity have a decisive influence on the HCl and SO_2 separation, however, the separation of SO_3 and HF does not present any problems within the stated temperature range. In order to save additive powder, it is often useful to cool down the crude gas temperature upstream reactor to optimal operating temperatures by means of recuperative heat exchange or preferably by using an evaporative cooler. The min. admissible operating temperature has to be chosen in that way, that adhesion and blockages especially

due to the hygroscopic character of the CaCl$_2$ particles in the plant will be avoided. Illustration 6 shows the preferred temperature range, depending on the dew point temperature.
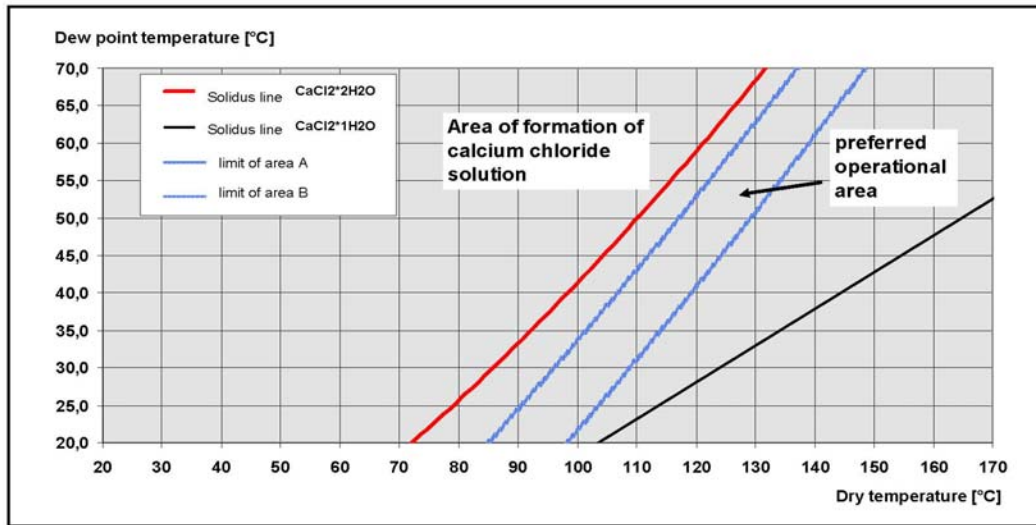
Reference: Dr. Mosch, Karpf

Illustration 6:   Phase diagram CaCl$_2$ • x H$_2$O

The low additive powder costs are confronted with higher investment costs as well as additional operating costs for the compressed air necessary for the water spraying in the evaporative cooler. Compared to the base variant, the expenditure of equipment is larger.

3.1.3 Chemisorption with particle conditioning

As described before and as a result of the increase in the absolute and relative humidity of the crude gas, the gas conditioning has a positive effect on the sorption output. However, a good additive powder efficiency, especially for the separation of SO$_2$, can only be achieved if the water steam partial pressure close to the recycled particulate lies at least for a short time in the range of the saturation steam pressure. This will be achieved by using the conditioned dry sorption (illustration 7).

Regarding this type of process, the recycled particulate is wetted prior being reintroduced into the reactor. The wetting causes an increase in the water steam content at the surface of the additive powder particles, thus improving the reactivity compared to the acid crude gas components.

Due to the limited proportional wetting of the recycled particulate and depending on the gas temperature upstream reactor, it might be useful to install an upstream located evaporation cooler for the adjustment of optimum reaction conditions.

Compared to the above-described variants, this highly efficient procedure is characterised by an excellent additive powder efficiency and the exceptionally reliable observance of the emission limit values even in case of higher crude gas

contents in the raw gas. A dependency of the separation efficiency on the ratio HCl / SO_2 does not exist.

However, compared to other procedures, the higher investment costs and the larger expenditure of equipment have to be taken into account.
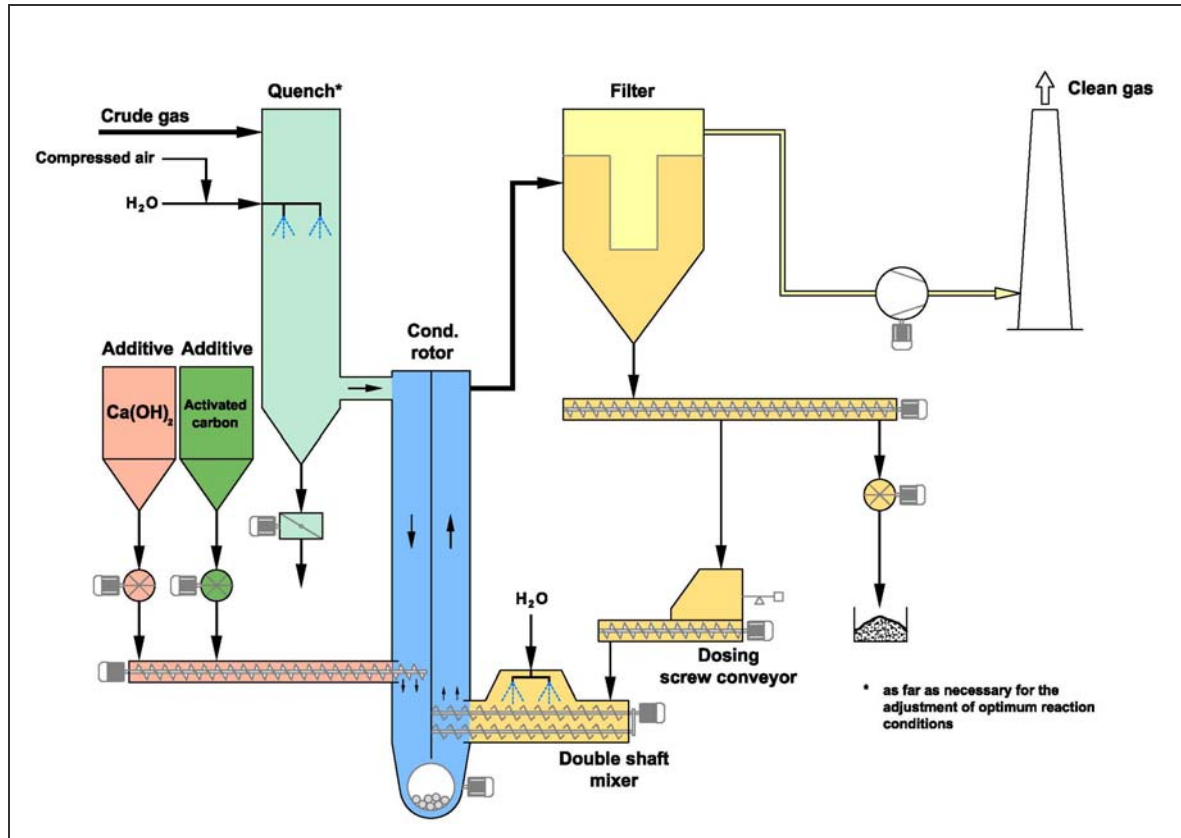

Illustration 7: Chemisorption with particle and gas conditioning

3.2 Sorption procedures with utilisation of $NaHCO_3$ as additive powder

This process with a quite simple plant structure is shown in illustration 8.

The multiple re-circulation of the particles separated in the filter into the crude gas flow upstream filter may be advantageous.
The installation of an evaporative cooler is only advisable if the temperature upstream filter is higher than the admissible continuous temperature (240°C) or if the simultaneous separation of other components such e.g. Hg compounds imperatively requires a temperature reduction.

The main advantages of this technology are:

➢ High reactivity of additive powder
➢ Simple plant structure

> ➤ The remainder quantity is reduced in contrast to the additive powder injection (advantage in case of high disposal costs)
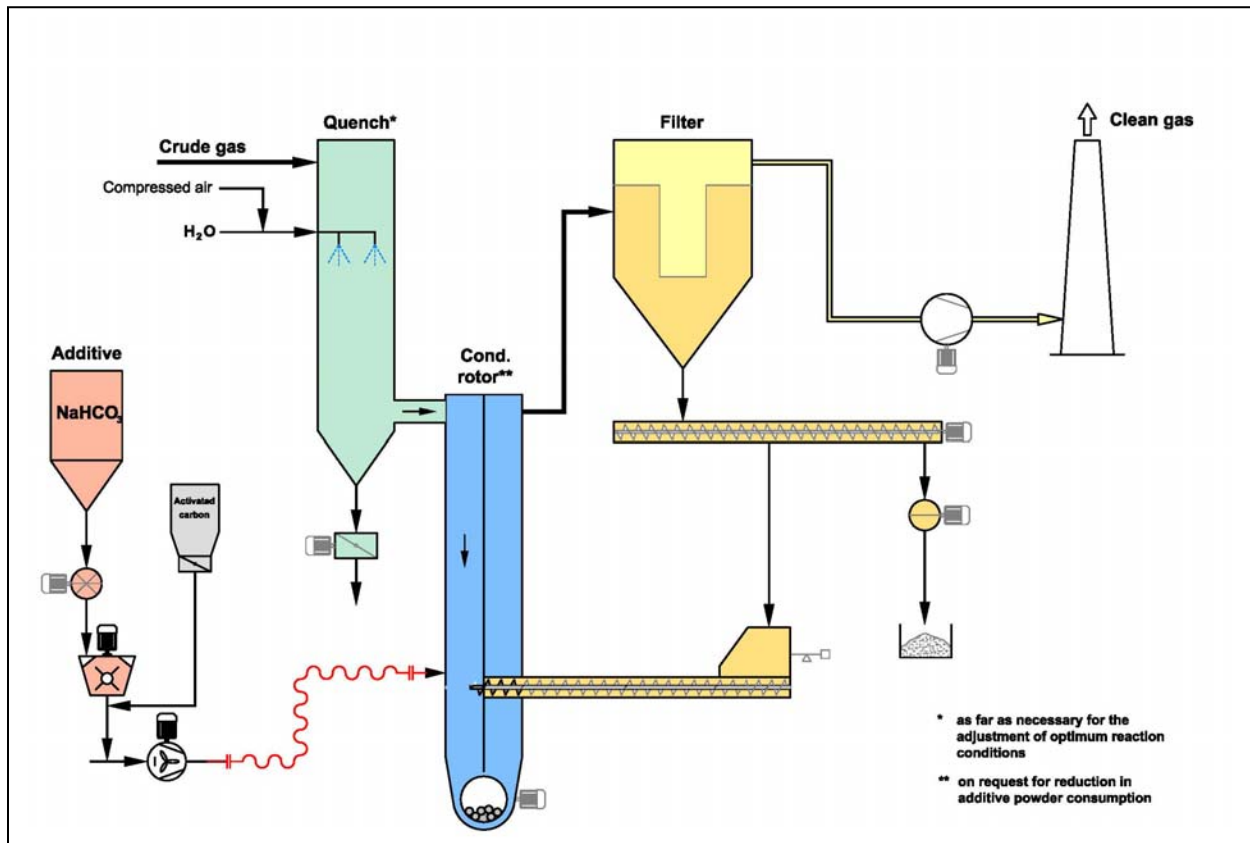> ➤ Lower hygroscopic nature of the resulting salts

Illustration 8:   Process scheme

The disadvantages are:

> ➤ Unfavourable mass ratio of additive powder to crude gas
> ➤ Necessary grinding of the additive powder prior to the injection into the crude gas flow
> ➤ High specific purchase costs of the additive powder

4   Resulting requirements on the used fabric filters, demonstrated by means of case studies

Ab- and adsorption are very demanding regarding the efficiency of fabric filters. Sufficient degrees of separation can only be achieved if

> ➤ a contact between the crude gas component and additive powder particle is granted (homogeneous particle distribution) and if

> ➢ the additive powder particles are to a great extent retained at the filter fabric and do not reach the clean gas side of filter.

In the following two different application examples are discussed.

- **Application example: dioxin separation**

The separation of dioxins / furans clearly shows the requirements on the construction of fabric filters. Illustration 9 exemplary shows a sinter plant fine cleaning stage. The dioxin / furan concentration in the gas upstream filter totals to approx. 5 – 10 ng/Nm³ , the requested emission level is < 0.4 ng/Nm³.
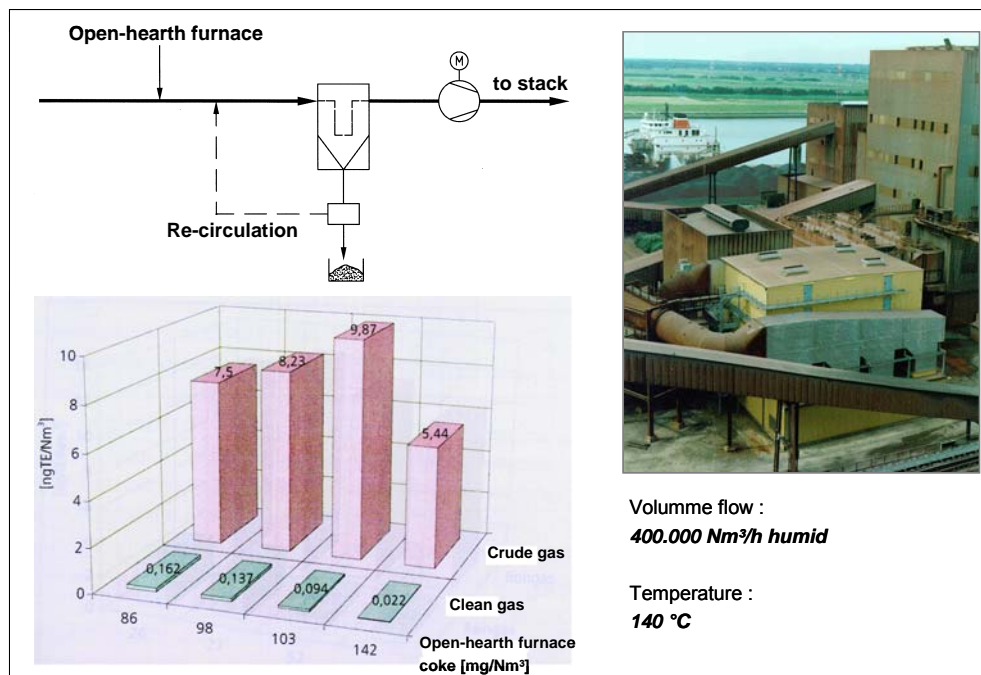

Illustration 9:   Application example: Dioxin / furan separation

Measurements have proven that for this type of application more than 95% of the dioxin / furan compounds are present in gaseous form and can only be separated by injecting an additive powder with large inner surface. During measurements, the residual particle content in the clean gas was ≤ 1 mg/Nm³.

Compared to the usual requirements on a fabric filter, the necessary degree of separation for dioxins / furans of 92% - 96% is comparatively low. However, considering the given concentrations of the dioxin / furan compounds to be separated, the difficulty of this type of application becomes obvious. The clean gas value of 0.4 ng/Nm³ corresponds to a value of 0.000 000 000 4 g/Nm³.
It stands to reason that a reduction in dioxins / furans to such a low value will only be possible if the additive powder particles are homogeneously distributed within the filter and if the residual particle content in the clean gas is considerably lower than the normally requested values. An additional particle re-circulation will help to support the separation in the fly stream upstream filter fabric by raising the particle density.

- **Application example: domestic waste incinerator**

The universal usability of a fabric filter for the separation of gaseous and particulate components from gases is exemplary shown by means of a gas cleaning system downstream grate bar firing with downstream installed boiler for the incineration of domestic waste. Illustration 10 shows the plant structure and table 3 the crude gas and clean gas values as well as the requested degrees of separation.
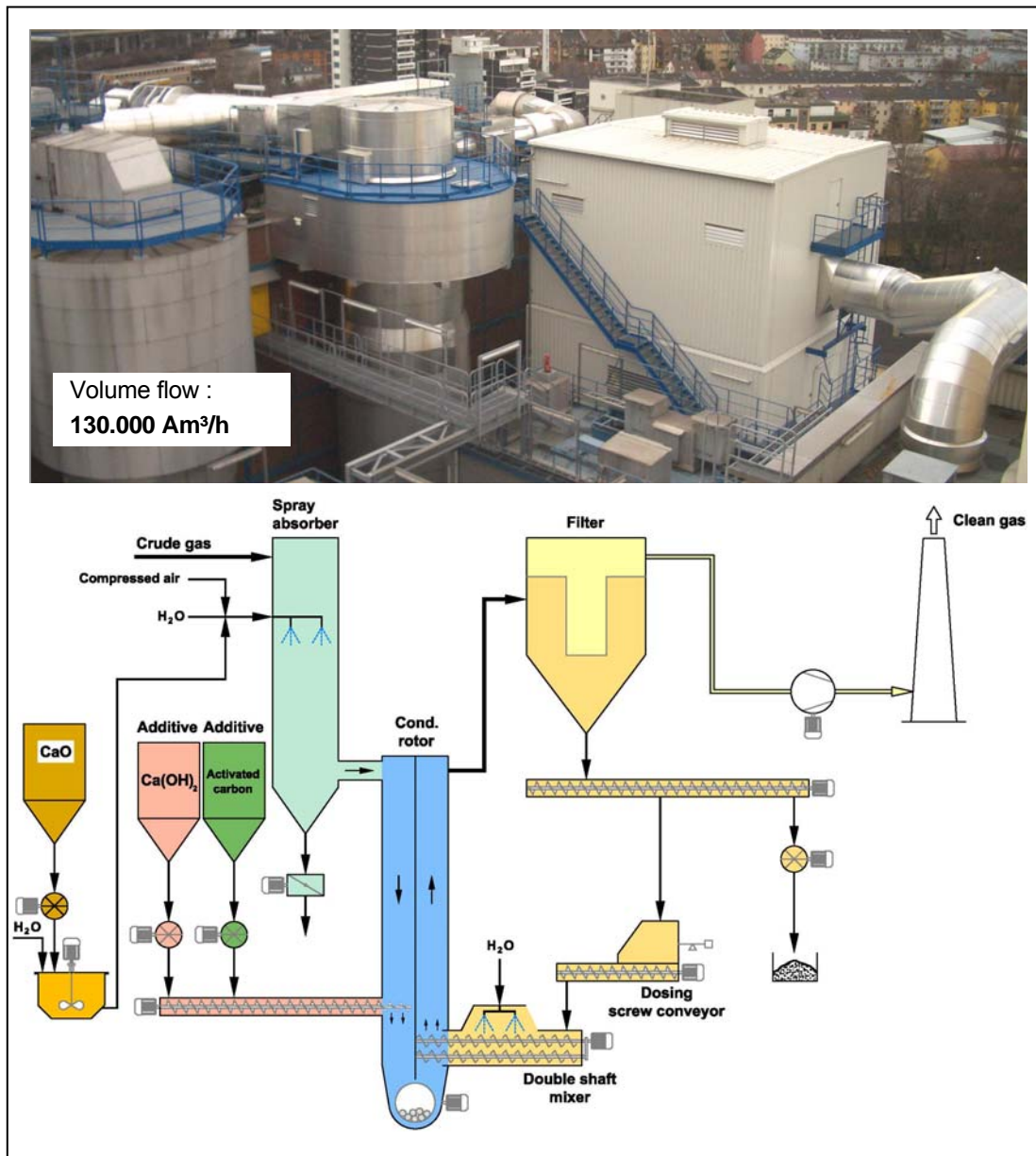

Illustration 10: Application example: domestic waste incinerator

It is worth mentioning that for an improvement of the separation efficiency of gaseous substances, the particles separated in the filter are repeatedly reintroduced into the gas flow upstream filter. As a result of this re-circulation, the particle content upstream filter totals to approx. 250 g/Nm³. The actually necessary degree of separation for the observance of the requested emission levels therefore results to > 99.996 %.

		Gas take-over		Emission limit values		Degree of separation [%]	
		DAV *	HAV **	DAV	HAV	DAV	HAV
Overall dust	[mg/Nm³ dry]	1.600	5.000	10	20	> 99,4	> 99,6
HCL	[mg/Nm³ dry]	1.000	2.000	10	60	> 99	> 97
HF	[mg/Nm³ dry]	15	30	1	4	> 93,3	> 86,7
SO₂	[mg/Nm³ dry]	400	600	25	150	> 93,8	> 75
Hg	[mg/Nm³ dry]	0,3	0,3	0,015	0,03	> 95	> 90
Cd + Tl	[mg/Nm³ dry]	1,0	3,0	0,05 ***		> 95	> 98,3
Σ (Sb, As, Pb,Cr, Mn, Ni, V, Sn)	[mg/Nm³ dry]	20	50	0,5 ***		> 97,5	> 99
Dioxin / Furan	[ngTE/Nm³ dry]	3,0	5,0	0,1 ***		> 96,7	> 98

* Daily average value   ** Half-hour average value   *** Average value over sample taking period

Tab. 3: Requirements on a fabric filter, exemplary shown by means of a domestic waste incinerator

For this type of application, the warranty concerning the service life of filter fabric and by this also for the observance of the emission limit values usually totals to 3 up to 5 years. Such warranty promises require a well proven and reasoned filter construction.

5   Assessment

In principle, fabric filters are suited to meet reliably in continuous operation the requirements of today and in the future concerning the requested degrees of separation not only for particles but also for other gaseous components. During construction of sorption plants, the following requirements have to be implemented consistently:

➢ Homogeneous distribution of injected additive powder in the gas flow (on request even with utilisation of a computer simulation)

➢ Homogeneous distribution of the additive powder particles on the filter fabric, e. g. by an upstream installed inlet chamber with internal attachments for gas distribution

➢ Assurance of a largely homogeneous particle load on the filter fabric, realised by an intelligent cleaning control

➢ Selection of a filter design, granting the long-lasting, reliable separation of high particle concentrations to low residual particle contents in the clean gas

➢ Project-related selection of an additive powder quality and a sorption system, considering at least the following criteria:

    o   Reliable observance of the emission values

    o   Investment and operating costs

    o   Availability and reliability

The experiences gathered from a large number of realised plants demonstrate that fabric filters including the belonging upstream installed components parts such as reactor and/or evaporative cooler are currently able to realise the simultaneous separation of particulate and gaseous substances in a single stage plant. Today, cost-intensive multistage procedures, for example with utilisation of wet scrubbers, are no longer necessary.
Even with regard to the separation of gaseous substances from gases, fabric filters belong to the today's state of the art.