LÜHR FILTER

Operating experiences gathered from fabric filters downstream incinerators for wood grade AI up to AIV

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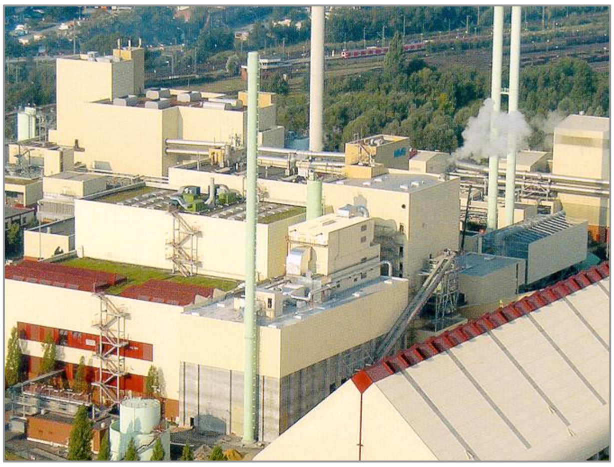


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1 Introduction

In most of the cases, single stage crude gas cleaning plants provided with fabric filters are installed downstream incinerators for waste wood of grade A I – A IV to observe the requested emission limit values. Beside the particle separation, all limit values for acid crude gas components, dioxins/furans, Hg and Hg-compounds as well as other heavy metals can reliably be observed in continuous operation by means of injection of additive powders in connection with a dry or conditioned dry sorption process. The selection of the additive powder and the adequate sorption process depends on the application, considering the investment and operating costs.

In the following some noteworthy aspects for the planning of fabric filters for applications with untreated wood are given. Subsequently different sorption procedures combined with fabric filters are presented with assessment of the corresponding advantages and disadvantages.

In this respect the focal point lies on the chemisorption of acid crude gases.
The reduction of other gas components such as e.g. NO_x, CO and TOCs is not subject of this lecture.

2 Requirements on fabric filters downstream biomass incinerators without additive powder injection

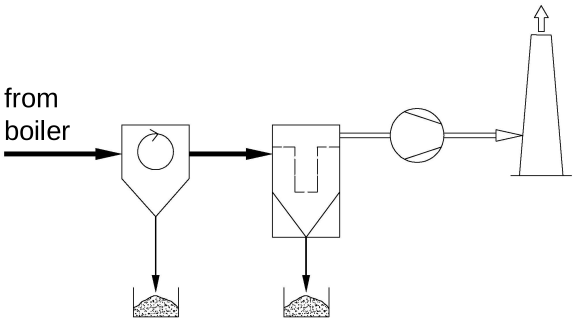
As far as the gaseous pollution lies below the requested limit values, the procedure can be realised without an additive powder injection. In these cases the gas cleaning comprises a fabric filter with – in most of the cases – an upstream installed spark separator (cyclone, multiclone). The first plants downstream biomass incinerators have already been realised for more than ten years. When realising the experiences gathered during the first years of operation, these plants can be driven without any problems.

The following but not exhaustive list states some aspects to be considered:

- Wear protection near spark separator
- Limitation of C_xH_y content in the gas by means of controlled combustion
- Selection of a sufficiently low filtration velocity of max. approx. 1.0 m/min
- Selection of a suitable filter fabric considering the thermal and chemical constraints as well as the often very fine and hygroscopic fly ash particles
- Controlled start-up and shutdown of the complete plant even with regard to the requirements of the fabric filter, for example by injection of additive powder during these operating conditions

Illustration 1 shows as realised example a fabric filter downstream waste wood incinerator, taken into operation more than ten years ago.

- **Volume flow :**
  2x 30.000 Nm³/h humid
- **Temperature downstream boiler :**
  180 - 240 °C



- **Particle content downstream boiler :**
  3000 - 8000 mg/Nm³ humid
- **Guarantee :**
  Particles: < 20 mg/Nm³ dry

Illustration 1: Application example: Particle separation downstream incinerator for untreated wood

3 Sorption procedure

If due to the fuel composition an additional separation of gaseous compounds is required, adequate additive powders for the ab- and/or adsorption of gaseous compounds have to be added to the gas flow upstream fabric filter. Regarding the acid crude gas components, the main additive powders available are calcium hydroxide ($Ca(OH)_2$) and sodium hydrogen carbonate ($NaHCO_3$). For the separation of dioxins/furans as well as mercury and mercury compounds an additive powder with large specific surface such as activated coke or special clay is used.

Especially with regard to the acid crude gas components a large number of process variants is available. In the following the most used process variants are presented and assessed.

3.1 Sorption process with utilisation of $Ca(OH)_2$ as additive powder

3.1.1 Basis variant dry sorption process

The fundamental design of the dry sorption process with $Ca(OH)_2$ is shown in illustration 2. It mainly consists of the component parts fabric filter and additive powder injection device.

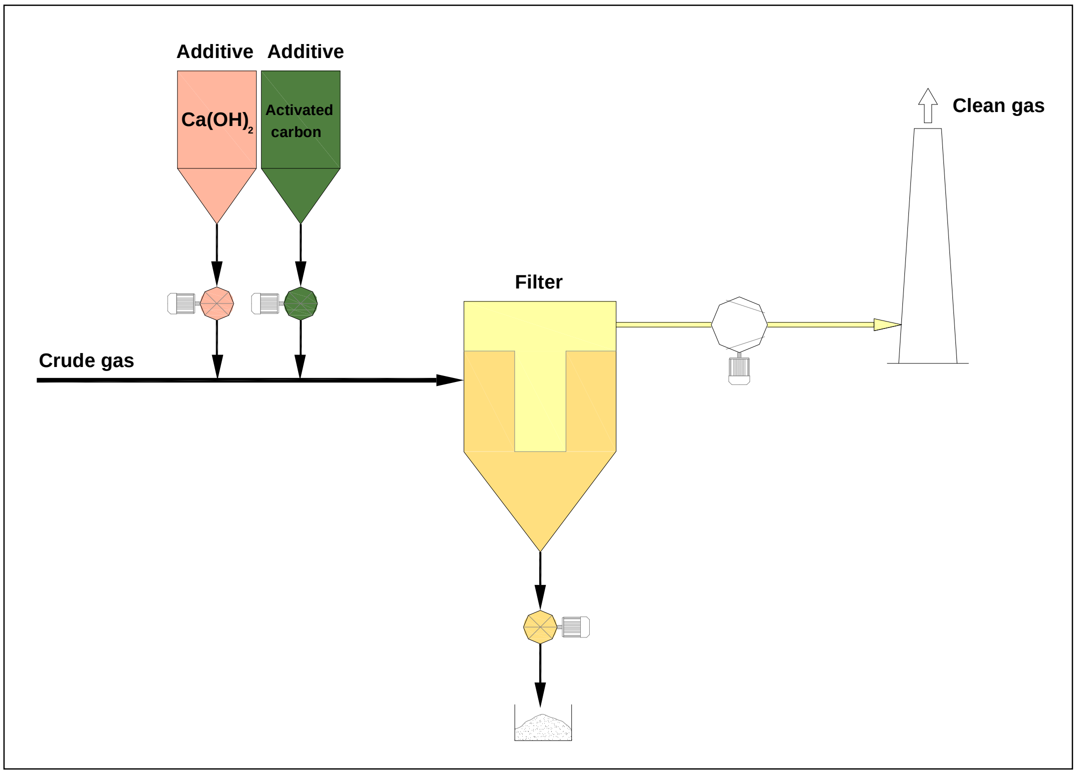


Illustration2: Dry sorption with $Ca(OH)_2$

Several qualities of $Ca(OH)_2$ with different reactivity are available as additive powder. In general, a high-reactive hydrated lime quality with a large surface (> 40 m²/g) and a high pore volume (> 0,2 cm³/g) will be necessary for this very simple process variant in order to achieve the reliable observance of the requested emission limit values.

The reaction equation as well as the injection and the remainder quantities at an additive powder efficiency of 100% are listed in table 1. In order to achieve the reliable compliance with the requested emission levels in the practice, the additive powder has to be injected above stoichiometry.

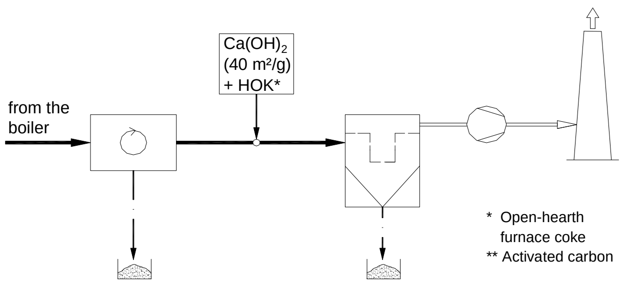
The advantages of this procedure are the favourable investment costs and the low maintenance works as a result of the simple plant design. The disadvantages are high additive powder purchase costs and a limited separation efficiency.

Equations of reaction	$Ca(OH)_2$ - injection quantity related to crude gas at 100% conversion (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: Injection and remainder quantities

In case of moderate crude gas contents downstream boiler, this process will also be suitable to observe the requested limit values of 17 BImSchV. with an acceptable additive powder consumption.

Illustration 3 shows a dry sorption plant downstream fluidised bed firing for waste wood of grades A I – A II. Due to the requested low degrees of separation for the acid crude gas components, this application requires a simple sorption process with low investment costs. The higher additive powder costs for the high-reactive hydrated lime are sufficiently compensated by the savings regarding the investment costs.



Volume flow:
85.000 Nm³/h humid

Temperature downstream boiler:
150 °C

Crude gas values downstream boiler:

Particles	:	**≤ 8.000**	**mg/Nm³ dry**
HCl	:	**≤ 105**	**mg/Nm³ dry**
HF	:	**≤ 10**	**mg/Nm³ dry**
SO_2	:	**≤ 480**	**mg/Nm³ dry**
PCDD/PCDF	:	**≤ 1**	**ng/Nm³ dry**

Guarantee:

Particles	:	**≤ 10**	**mg/Nm³ dry**
HCl	:	**≤ 30**	**mg/Nm³ dry**
HF	:	**≤ 3**	**mg/Nm³ dry**
SO_2	:	**≤ 350**	**mg/Nm³ dry**
PCDD/PCDF	:	**≤ 0,1**	**ng/Nm³ dry**

Additive powder consumption:

$Ca(OH)_2$	:	**i ≤ 1 related to input**
HOK* / AK**	:	**≤ 5 kg/h**

Illustration 3: Application example: Dry sorption with $Ca(OH)_2$ downstream waste wood incinerator with stationary fluidised bed firing

3.1.2 Particle re-circulation and particle conditioning

In order to increase the efficiency and to reduce the additive powder costs, the fundamental process design is often extended by units such as reactor with particle re-circulation and evaporative cooler (illustration 4).

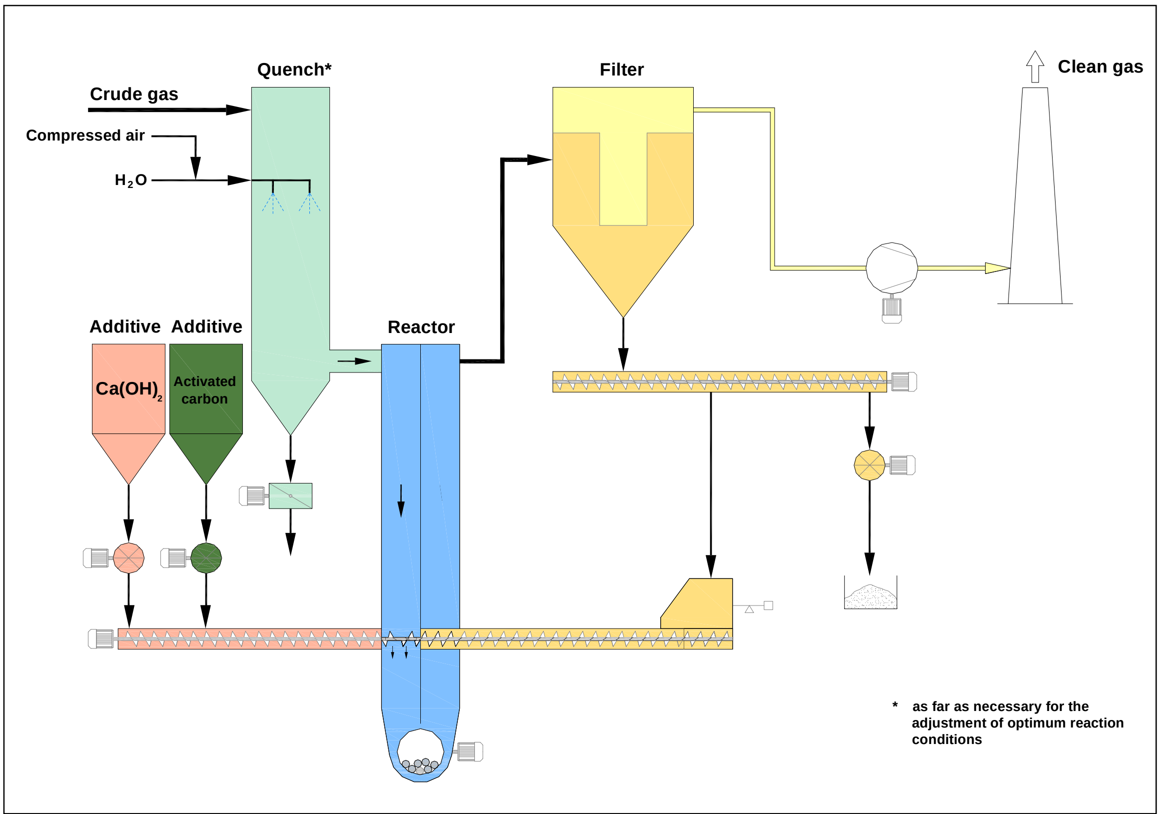


Illustration 4: Chemisorption with particle re-circulation and gas conditioning

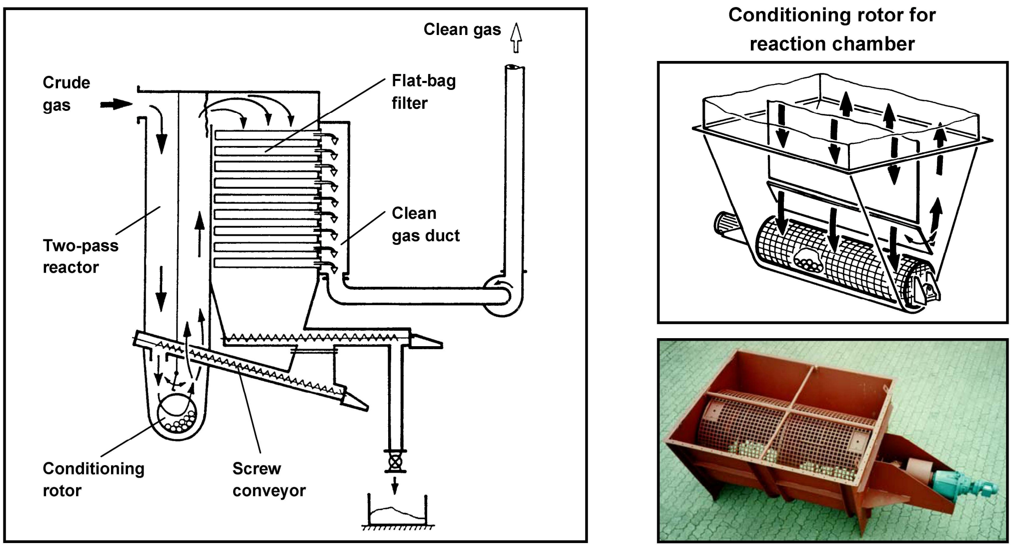
- **Particle re-circulation**

It is provable that especially in case of high additive powder recycle rates, the particle re-circulation 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
- Near reactor upstream filter there is a higher additive particle density (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.

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 becomes necessary which can reliably handle considerable recycling quantities – even if larger quantities of difficult particles, such as $CaCl_2$, are present in the particle spectrum.

Illustration 5 shows a technology which has been applied successfully for many years for various fields of application. It is characterised by high reliability and homogeneous distribution of the re-circulated particulate in the crude gas flow upstream filter. Conveying with pneumatic methods, which is prone to frequent breakdowns, is not used.



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 approx. 200 g/m³)**
- **disintegration of larger particle agglomerates**

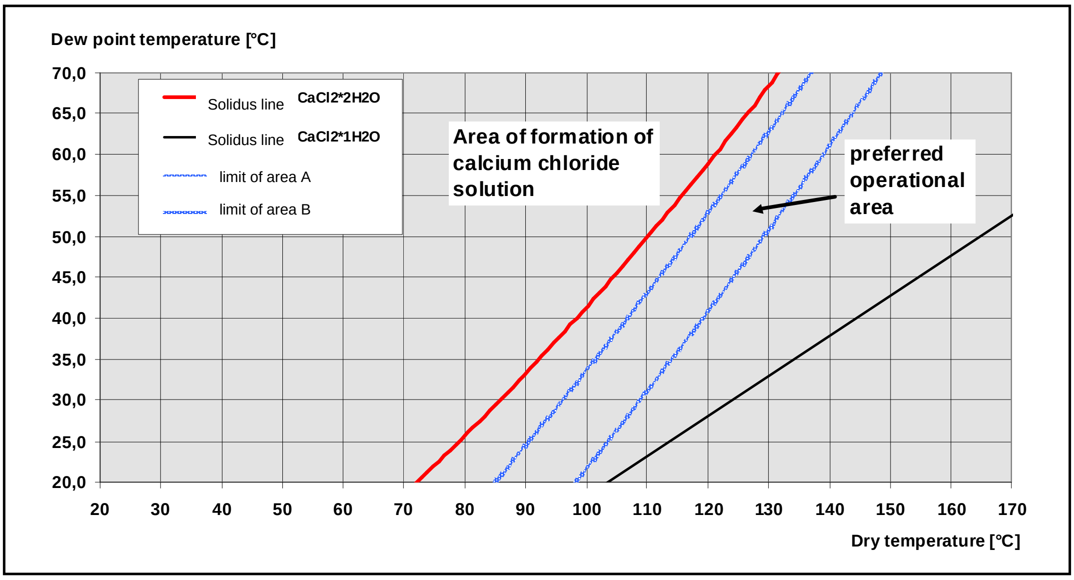
Illustration 5: Conditioning Rotor – Recycle Process (KUV)

- **Evaporative cooler**

Regarding the temperature range between 100 and 220°C which is typical for fabric filters, the following order of reaction results:

SO_3 > HF >> HCl >>> SO_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 that way, that adhesion and blockages especially due to the hygroscopic characteristics 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 $CaCl_2 \bullet x\ H_2O$

The application example described in illustration 7 clearly shows the evaporative cooler, installed upstream filter. Based on the chosen process technology, a commercially available $Ca(OH)_2$ with low purchase costs can be used for this plant. The particle re-circulation has an additional positive effect on the consumption rates for open-hearth furnace coke, which is injected for the separation of dioxins/furans and Hg as well as Hg-compounds.

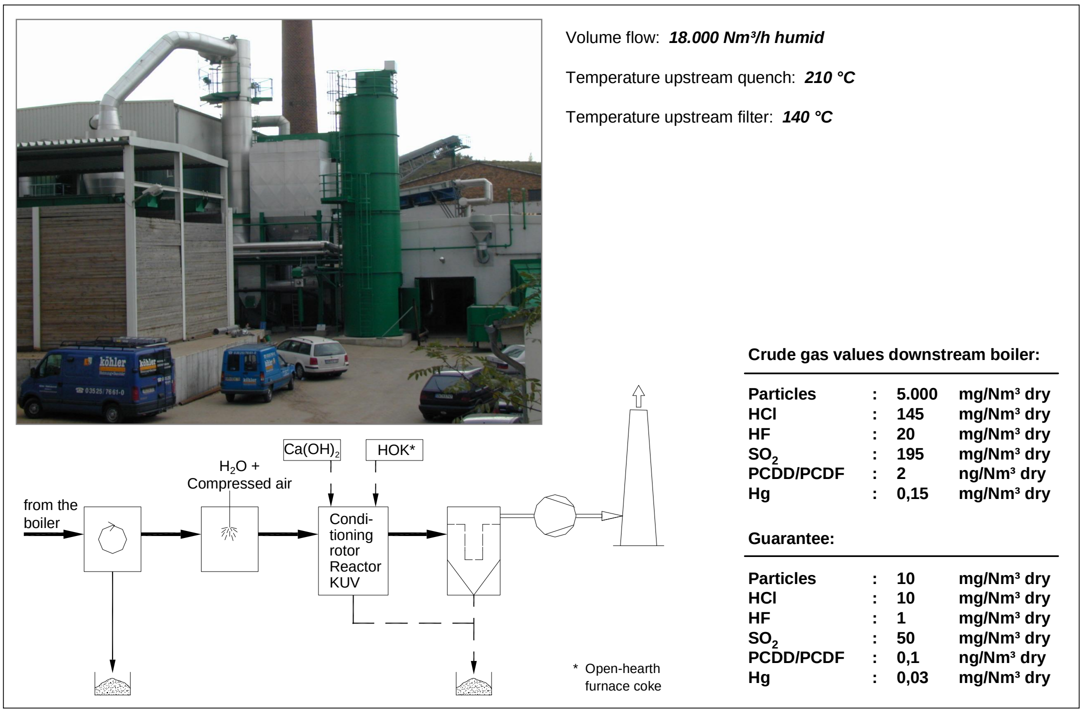


Illustration 7: Application example: Chemisorption with gas conditioning and particle re-circulation downstream waste wood incinerator with grate bar firing

The low additive powder purchase costs are up against higher investment costs as well as additional operating costs for compressed air, necessary for the water spraying in the evaporative cooler. Compared to the fundamental design, this variant requires a larger complexity of equipment.

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 8).

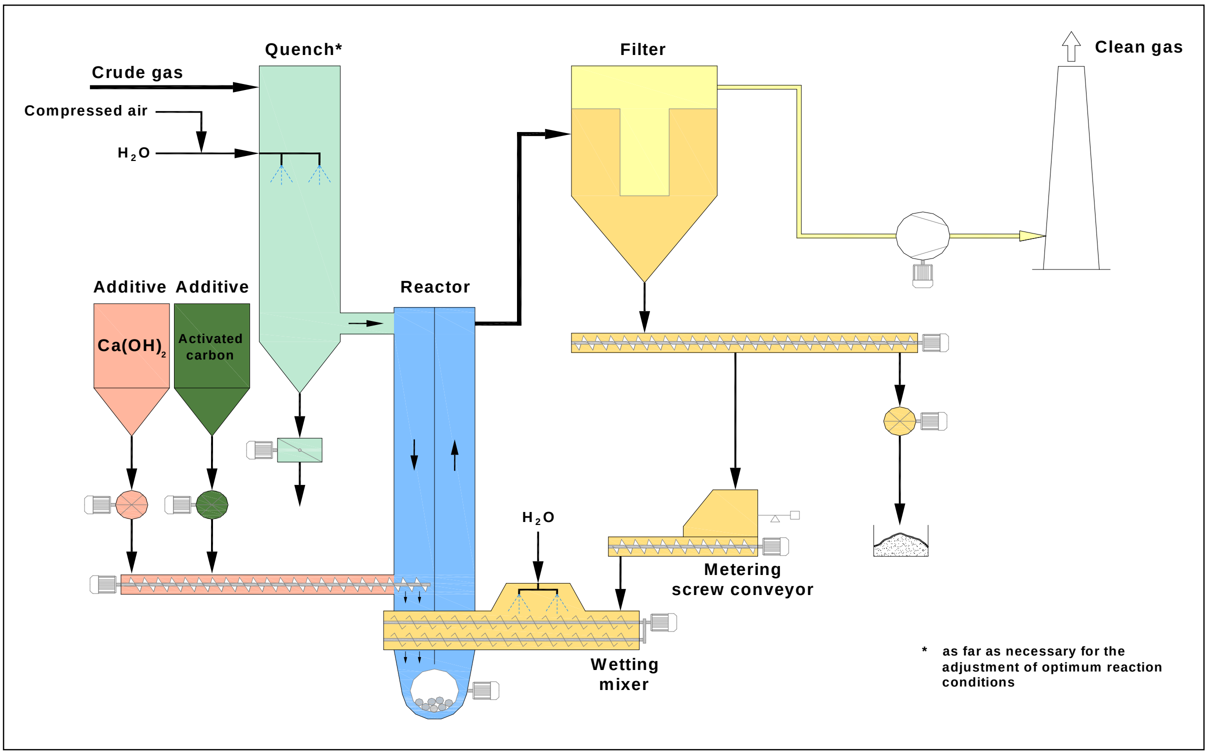


Illustration 8: Chemisorption with particle and gas conditioning

Regarding this type of process, the recycled particulate is wettened prior to reintroduction 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 in comparison to the acid crude gas components.

The used additive powder quality is commercially available $Ca(OH)_2$.

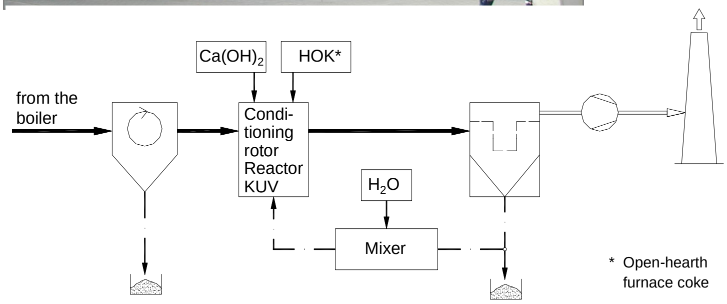
Due to the limited proportional wetting of the recycled particulate and depending on the gas temperature upstream reactor, it might be useful to install an upstream located evaporation cooler for the adjustment of optimum reaction conditions.

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, in comparison with other procedures, the higher investment costs and the larger expenditure of equipment have to be taken into account.

Illustration 9 shows a process variant with circulating fluidised bed firing for the combustion of waste wood, grades A I – A IV, with a downstream installed particle conditioning. The requested high separation efficiency for SO_2 in connection with an unfavourable relation of HCl / SO_2 requires the utilisation of the particle conditioning. Due to the fact that the crude gas temperature downstream boiler is < 150°C, the use of an upstream installed evaporative cooler can be left out.

Volume flow: ***128.000 Nm³/h humid***

Temperature downstream boiler: ≤ ***150 °C***



* Open-hearth furnace coke

Crude gas values downstream boiler:

Particles	:	**< 10.000**	**mg/Nm³ dry**
HCl	:	**< 250**	**mg/Nm³ dry**
HF	:	**< 40**	**mg/Nm³ dry**
SO_2	:	**< 700**	**mg/Nm³ dry**
PCDD/PCDF	:	**< 2**	**ng/Nm³ dry**
Hg	:	**< 0,16**	**mg/Nm³ dry**

Guarantee:

Particles	:	**< 7**	**mg/Nm³ dry**
HCl	:	**< 10**	**mg/Nm³ dry**
HF	:	**< 1**	**mg/Nm³ dry**
SO_2	:	**< 50**	**mg/Nm³ dry**
PCDD/PCDF	:	**< 0,1**	**ng/Nm³ dry**
Hg	:	**< 0,03**	**mg/Nm³ dry**

Additive powder consumption:

$Ca(OH)_2$	:	**i ≤ 2,0**
HOK*	:	**≤ 0,1 g/Nm³ dry**

Illustration 9: Application example: Conditioned dry sorption downstream waste wood incinerator with circulating fluidised bed firing

The application example described in illustration 10 shows that due to a gas temperature downstream boiler of 200°C, it will be useful to decide in favour of a process variant with gas and particle conditioning. The temperature upstream reactor is adjusted to approx. 150°C by means of an evaporative cooler. As a result of the injection of wettened particles into the gas flow upstream filter, the gas temperature is again reduced by approx. 10 Kelvin. The particle recycle quantity in this case totals to approx. 150 g/Nm³ humid. In case the optimum reaction temperature upstream filter of approx. 140°C has to be adjusted exclusively by the particle conditioning, the necessary specific recycle quantity would have to be > 600 g/Nm³ humid.

Volume flow: ***76.000 Nm³/h humid***

Temperature downstream boiler: ***200 °C***

Temperatur upstream filter: ***140 °C***

Crude gas values downstream boiler:

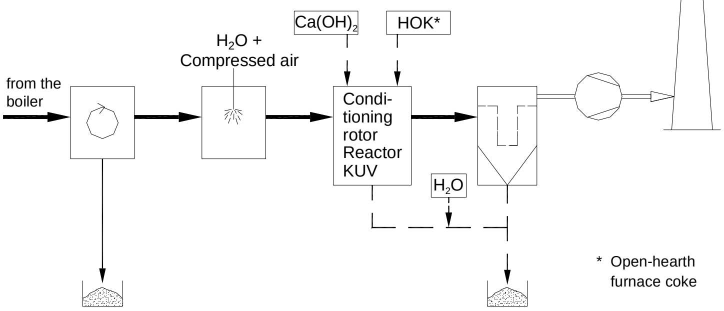
Particles	**:**	**2.500**	**mg/Nm³ dry**
HCl	**:**	**370**	**mg/Nm³ dry**
HF	**:**	**20**	**mg/Nm³ dry**
SO_2	**:**	**440**	**mg/Nm³ dry**
PCDD/PCDF	**:**	**4,0**	**ng/Nm³ dry**
Hg	**:**	**0,096**	**mg/Nm³ dry**

Guarantee:

Particles	**:**	**10**	**mg/Nm³ dry**
HCl	**:**	**10**	**mg/Nm³ dry**
HF	**:**	**1**	**mg/Nm³ dry**
SO_2	**:**	**50**	**mg/Nm³ dry**
PCDD/PCDF	**:**	**0,1**	**ng/Nm³ dry**
Hg	**:**	**0,03**	**mgN/m³ dry**

Additive powder consumption:

$Ca(OH)_2$	**:**	**i ≤ 2,0**
HOK*	**:**	**≤ 0,1 g/Nm³ dry**



* Open-hearth furnace coke

Illustration 10: Application example: Chemisorption with gas and particle conditioning downstream waste wood incinerator with grate bar firing

It may be remarked in addition, that the utilisation of the conditioned dry sorption process also proved to be successful for a range of other applications with requested high separation rates and low additive powder consumption. Application examples in this respect are sludge incinerators, domestic and industrial waste incinerators, incinerators for alternative fuels as well as industrial fields of use, such as the separation of SO_2 downstream sinter bands and glass tanks.

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

The process with a quite simple plant structure is shown in illustration 11.

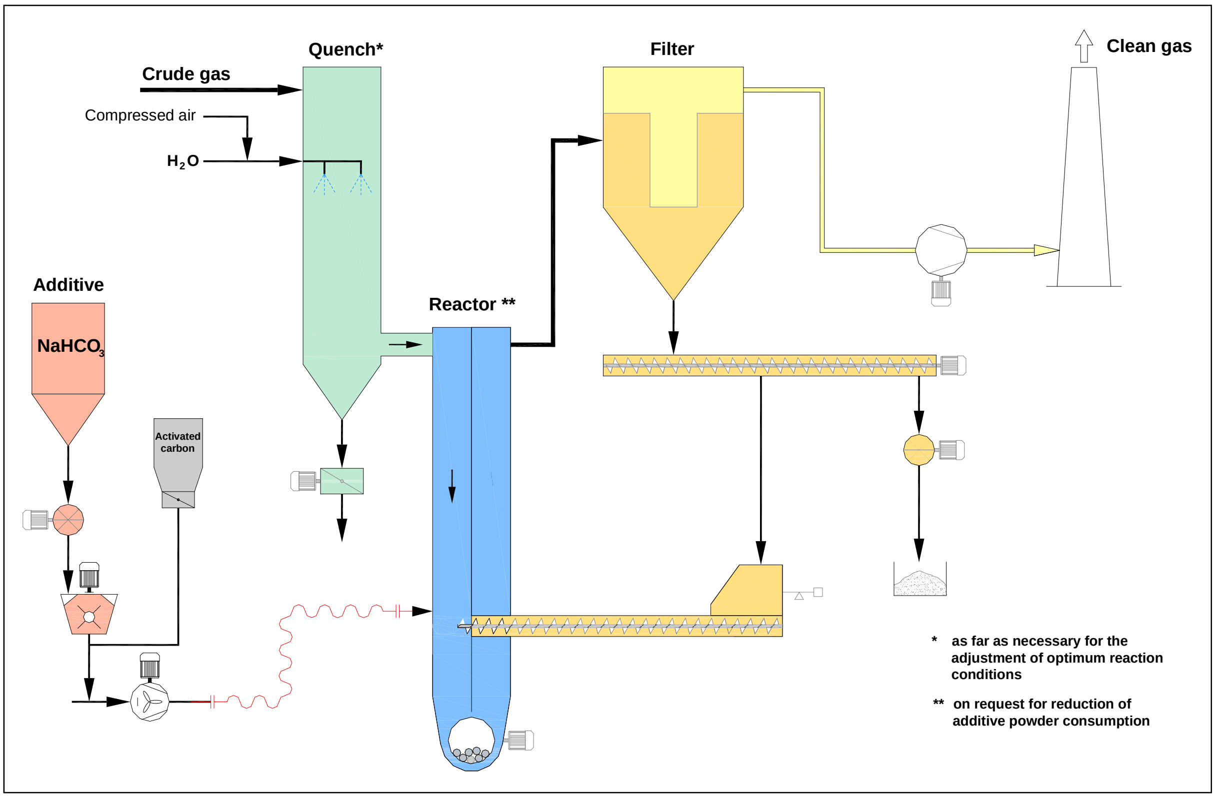


Illustration 11: Process scheme

The additive powder is injected into the crude gas flow upstream filter. In case of crude gas temperatures > 140°C, a thermal activation of sodium hydrogen carbonate will take place. The result is a high reactive sodium carbonate.

Table 2 states the chemical reaction equations as well as the injection and remainder quantities on the basis of an additive powder efficiency of 100%. Normally the required emission limit values are reliably achieved in continuous operation with the adequate plant design with an over stoichiometric factor of 1.2 – 1.4.

Equations of reaction	$NaHCO_3$ - injection quantity related to crude gas at 100% stoichiometry (i=1)	Resulting residual particle quantity related to crude gas
$HF + NaHCO_3 \rightarrow NaF + H_2O + CO_2$	**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 $NaHCO_3$:

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

Tab. 2 Injection and remainder quantities

The multiple re-circulation of the particulate separated in the filter into the crude gas flow upstream filter can be advantageous.

The main advantages of this technology are:

- high reactivity of additive powder
- simple plant design
- 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

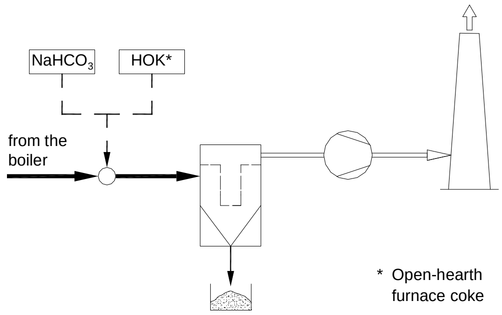
The disadvantages are:

- unfavourable mass ratio of additive powder to crude gas
- necessary pulverisation of the additive powder prior to the injection into the crude gas flow
- high specific purchase costs for the additive powder

An example for this type of process variant is shown in illustration 12.

Volume flow: ***120.000 Nm³/h humid***

Temperature downstream boiler: ≤ ***200 °C***



Crude gas values downstream boiler at 11 % O_2:

Particles	**:**	**3.000**	**mg/Nm³ dry**
HCl	**:**	**140**	**mg/Nm³ dry**
HF	**:**	**10**	**mg/Nm³ dry**
SO_2	**:**	**140**	**mg/Nm³ dry**
PCDD/PCDF	**:**	**4,0**	**ng/Nm³ dry**
Hg	**:**	**0,05**	**mg/Nm³ dry**

Guarantee DAV:

Particles	**:**	**8**	**mg/Nm³ dry**
HCl	**:**	**8**	**mg/Nm³ dry**
HF	**:**	**1**	**mg/Nm³ dry**
SO_2	**:**	**50**	**mg/Nm³ dry**
PCDD/PCDF	**:**	**0,1**	**ng/Nm³ dry**
Hg	**:**	**0,03**	**mg/Nm³ dry**

Illustration 12: Application example: Dry sorption with $NaHCO_3$ downstream waste wood incinerator with grate bar firing

In spite of the comparatively high crude gas temperature of up to 200°C, this variant does not comprise a temperature reduction, for example by means of an upstream installed evaporative cooler. The observance of all emission limit values, even for dioxins/furans as well as Hg and Hg-compounds could be proven.

The essential criteria of the plant operator when selecting the process technology were the simple plant design in connection with low maintenance and high plant availability, combined with the utilisation of a high-reactive additive powder.

4 Selection of process technology

The presented practical examples demonstrated that beside the particle separation, fabric filters downstream waste wood incinerators are also able to meet the today‘s requirements regarding the sorption of acid crude gas components. The current emission limit values are reliably kept in continuous operation. In addition to that it may be remarked that the injection of adequate additive powder qualities allows the reliable, simultaneous separation of dioxins/furans and mercury.

However, there is no most suited technology available for all fields of application. Each application has to be considered separately.

The criteria of choice for the assessment are:

- Required degrees of separation (average values and max. values as well as peaks)
- Emission limit values
- Investment costs
- Operating costs, such as additive powder supply and disposal as well as energy costs (current and compressed air)
- Plant availability and reliability of operation
- Partial load behaviour
- Flexibility with regard to changing crude gas values, emission limit values and specifitc operating costs

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