Use of a Fabric Filter for the Sorption – What Has to be Considered? – Experiences and Solutions –

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In almost all flue gas cleaning systems installed at WtE-plants, the fabric filters are central components. A good example for this is the conditioned dry sorption process which is currently preferentially used in Europe. Within the filter not only the particles and the particulate heavy metals are separated from the gas flow, but also all reaction products resulting from the separation of gaseous pollutants such as HF, HCl, SO_2_, heavy metals and in this respect particularly Hg as well as PCDD/PCDF. In addition to this the fabric filter constitutes an excellent reaction chamber with high additive powder density in the filter cake.

High-efficient sorption technologies are often working with a high re-circulation rate of particles separated at the filter fabric and re-introduced in an upstream installed reactor. [2] Such procedures request a very high efficiency in the range of > 99.9 percent removal rate.

In the following the objectives of the fabric filter in WtE-plants are explained. Important aspects regarding design and construction of fabric filter will be considered.
1. Chemisorption and adsorption

1.1. Preliminary remark

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 (chemisorption) or have to be attached to the inner surface of adequate additive powders (adsorption).

Examples are:

- Chemisorption of acid crude gas components such as HF, HCl and SO\textsubscript{x} by injection of additive powders based on Ca- or Na-compounds.
- Adsorption of dioxins, furans as well as mercury (Hg) and Hg-compounds by means of injection of additive powders with large inner surface, such as e.g. activated coke, activated carbon or special clay minerals.

All reaction products will be separated from the gas flow in the fabric filter. A further separation of gaseous components particularly takes place in the particle layer built up on the filter fabric.

The separation of gaseous components makes considerable demands on the design of fabric filters as well as on the knowledge about the significant separation procedures concerning the achievement of high degrees of separation with at the same time low additive powder consumption.

1.2. Chemisorption of acid crude gas components

During chemisorption the acid crude gas components such as HF, HCl and SO\textsubscript{2}/SO\textsubscript{3} are reacting with a basic additive powder. As a result of reaction salts will be formed which will be separated from the gas flow in particulate form in a fabric filter.

The time span available for the reaction within plant normally only totals to 2 to 5 sec. and corresponds to the residence time of gas in the system, starting from the additive powder injection up to the passage through the filter fabric. The proportional time of approximately 0.5 sec. accounting in this connection for the flow through the particle layer formed on the filter fabric is comparatively short.

Figure 1 shows a schematic view of the contact time and contact opportunities between crude gas molecules and additive powder particles. Due to the high particle density, the best reaction conditions are surely given in the filter cake. The following aspects however, interfering the separation efficiency, have to be taken into account.

- The contact time is extremely short.
- The flow is laminar.
- Condition is a far-reaching homogeneous distribution of additive powder particles on the filter fabric.
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The schematic view in Figure 1 additionally shows the influence of the re-circulation of particles separated in the filter in a reactor installed upstream of filter. The contact opportunities are more or less linearly improved with the re-circulation factor in the time window starting from injection of re-circulated particles into the reactor up to the separation of particles on the filter fabric. They are furthermore improved by a turbulent flow in this plant section.

The increase in separation efficiency combined with additive powder savings in case of use of a particle re-circulation could be proven by means of examinations realised at a demonstration plant (Figure 2) [4]. In the scope of these examinations the particle re-circulation was varied at constant input conditions regarding crude gas concentrations, gas temperature, gas humidity and additive powder injection quantity.

Figure 1: Reaction time and particle density

Figure 2: Influence of particle re-circulation rate on the separation efficiency
The examinations were realised with approximately constant filter differential pressure. That means that at low re-circulation rate the filter was automatically driven with a prolonged cleaning cycle and that as a result of this the average particle layer on the filter fabric was kept nearly constant.

The results show that an improvement of crude gas separation up to an approximately 50-fold re-circulation rate can be achieved. With regard to the design of a sorption plant installed downstream of a waste and/or RDF combustion plant, this means that in case of an optimum operating mode the particle concentration in the reactor upstream filter totals to approximately 300 g/Nm³. The fabric filter integrated in the process has to be designed in accordance with this particle concentration. The specification of the particle concentration of 300 g/Nm³ is based on a fly ash concentration of 3 g/Nm³ and an additive powder injection in the same range (Figure 1).

The positive influence of the particle re-circulation could also be proven at large-scale plants. An example for this is the modification of the gas cleaning system installed at MHKW Rothensee from spray sorption without particle re-circulation to conditioned dry sorption with multiple particle re-circulation. [3]

1.3. Adsorption of dioxins/furans and mercury

As far as present in gaseous form, dioxins/furans and Hg as well as Hg-compounds will be separated from the gas flow by means of adsorption of pollutants in additive powders with large specific inner surface. The concentration of these pollutants in the gases downstream incinerators for waste and/or RDF is clearly lower than the one for the acid crude gas components. In case of Hg the factor totals to approximately 10⁻⁴, in case of dioxins/furans it totals to approximately 10⁻⁸. These factors approximately also apply to the typically stipulated clean gas concentrations. The figures above show that particularly with regard to the separation of dioxins/furans the focus of separation is on the filter cake, thus imposing high requirements on the fabric filter.

- Assurance of contact between crude gas molecule and additive powder particles in the filter cake.
- Observance of a low residual particle concentration in the clean gas in continuous operation.

With regard to the separation of dioxins/furans, a low residual particle concentration in the clean gas clearly < 5 mg/Nm³ is a condition for the reliable observance of the typically stipulated clean gas value < 0.1 ng/Nm³. During the measurement of dioxins/furans not only the molecules are measured which are passing the filter fabric in gaseous form, but also those that are adsorbed at those particles which have arrived on the clean gas side of filter because of an increased residual particle concentration.
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Sometimes, a single, well-considered decision is all it takes: for the benefit of your company, for the good of the environment.
2. Remarkable aspects when using fabric filters for the sorption

2.1. General design of a fabric filter

The general design of a fabric filter is shown in Figure 3.

![Schematic view of fabric filters with vertically and horizontally installed filter elements](image)

The filter housing is divided into crude gas and clean gas chamber by means of perforated plates. The flat-bag filter elements, each consisting of flat-bag and support cage, are mounted from the clean gas side. They are fitted in the holes of the perforated plate, providing a perfect seal against dust leaks. The crude gas flow through the textile filter material is from outside to inside. Particles are retained on the outside. Different design types are available on the market, differing with regard to flat-bag form and type of installation. Further details are among other things included in [7].

A compressed air on line-cleaning is normally used for the cleaning of filter elements. In this connection a group of filter bags is charged for a short time with compressed air and secondary air aspirated from the clean gas by means of injectors and contrary to the filtration flow. The particle cake is removed from the filter bags and falls at least partly into the filter collection hopper.

Alternatively a compartmentalised off line-cleaning device is available. With regard to this process, the clean gas area of filter housing is divided into several chambers. Each chamber is connected with the clean gas collective channel and can be isolated. At the beginning of the cleaning process in one chamber the corresponding isolation damper on the clean gas side will be closed. As described above the flat-bags are cleaned by means of compressed air during interrupted filtration process. This cleaning technology is more effective and means less mechanical stress for the filter bags. With regard to the separation of gaseous pollutants however, the process has considerable disadvantages as explained below.
2.2. Process-related requirements on a fabric filter used for sorption applications

2.2.1. Homogeneous particle layer on the filter bags

As explained in item 1, a preferably homogeneous particle layer on the filter bags is the condition for an effective separation of gaseous pollutants. The reasons for this are given below.

All filter bags mounted in the filter are located in parallel. However this does not involve that the volume flow passing the particle layer on the filter fabric is homogeneous. The gas flow through filter bags with a minor particle layer and by this an inferior flow resistance is better than the one compared to bags with a thicker layer. Due to the fact that the lack of an additive particle layer inevitable entails a poor separation of gaseous pollutants and that the flow through those bags is above-proportional, inhomogeneities will lead to a reduced separation efficiency.

Mainly the gas and particle inlet to the filter elements as well as the filter cleaning have a decisive influence on the homogeneity of particle layer.

Gas and particle inlet

Figure 4: Example of a computational fluid dynamics
The use of inlet chambers installed upstream of filter proved to be advantageous for achieving a homogeneous gas and particle inlet to the filter elements. An adequate homogeneous distribution can be achieved with the installation of guide plates. In case of a project-related construction of filtration plant, the arrangement of guide plates is often supported by a computational fluid dynamics (CFD) (Figure 4). Particles possibly discharged at this point will be re-introduced into the re-circulation via a discharge system.

**Filter cleaning**

The from time to time necessary cleaning of filter bag groups for the observance of a sufficiently low, constant filter differential pressure may lead to considerable inhomogeneities regarding the flow through the filter bags arranged in parallel. Figure 5 clearly shows the different flow velocities of separate filter bags during the filtration. Separate bags mounted in a demonstration filter with compressed air – on line – cleaning have been provided with Pitot tubes in the outlet area of mouthpieces for the measurement of the dynamic pressure.

Looking at the curve for one filter bag, the following coherences result:

- Increase in dynamic pressure directly after the cleaning,
- Decrease in dynamic pressure with increasing particle built-up on the bag,
- Together with the cleaning of next group of filter bags the dynamic pressure is further reduced and then remains on a comparatively low level until the next cleaning process of the flat-bag in question.

![Figure 5: Dynamic pressure as dimension for the flow velocity of separate filter bags](image-url)
The flow velocity fluctuates by factor 2, i.e. after the cleaning the velocity is twice as high as prior to the next cleaning procedure of the corresponding flat-bag group.

In case of filtration plants provided with a particle re-circulation, these inhomogeneities can quite quickly be compensated through new deposits of re-circulated particles on the cleaned filter bags. The cleaning cycle is surely clearly shorter but the particle layer on the bags is more homogeneous.

It stands to reason that the compartmentalised compressed air -off line- cleaning process mentioned in item 2.1. presents considerable disadvantages with regard to the assurance of a homogeneous particle distribution. During this cleaning process a larger group of filter bags is cleaned at the same time. In addition to this the cleaning is more effective, i.e. the filter cake is nearly completely removed. As a result of this the inhomogeneities regarding the particle layer become larger and the separation of gaseous pollutants gets worse. Due to this reason the off line-cleaning system is hardly used for sorption plants.

2.2.2. Assurance of a low residual particle concentration in the clean gas

A large number of examinations shows that the predominant part of particle emissions at fabric filters are generated during of shortly after the compressed air cleaning of filter bags [6]. This is impressively shown in Figure 6.

The examinations have been realised at a comparatively small demonstration filter. The measured value recording in Figure 6 clearly shows the correlation between cleaning impulse and emission value. During corresponding cleaning of one group of flat-bags

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Figure 6: Influence of cleaning cycle on the residual particle content in the clean gas
the differential pressure (blue curve) decreases and at the same time the dust emission escalates (red curve). After closing of cleaning valve and termination of cleaning process, the differential pressure of the total filter starts rising again. The particle emissions drop to values close to 0 percent of scale.

There are different approaches available to minimise the particle emissions

- Prolongation of pause interval and/or reduction of peaks resulting from the use of an off line-cleaning device. Based on the description given in item 2.2.1. this measure is not reasonable for sorption applications.
- Prolongation of pause interval between separate cleaning processes by means of reduction of air-to-cloth ratio. This involves higher investment costs and may at the same time increase the inhomogeneity of particle layer on the filter bags.
- Selection of a filter fabric which minimises the particle passage after the cleaning process. This can be achieved through the use of finest fibres on the inlet side of filter fabric or also through the use of surface treatments as e.g. shown in Figure 7.

![Dust flow](image)

Comparison of needle felt surface

- Needle felt singed
- Needle felt with membrantex coating

Figure 7:

Filter fabric with and without surface treatment on the inlet side

2.3. Remarkable constructive aspects when designing fabric filters for sorption plants

2.3.1. Plant availability

When using fabric filters for the gas cleaning downstream waste-/RDF incinerators, the operators have to provide a nearly 100 percent availability of plant. Listed below are the essential aspects which have to be taken into account to ensure high plant availability.
Avoidance of blockages within the filter area

When using Ca-based additive powder qualities, the reaction products resulting hereof also comprise hygroscopic salts in form of CaCl₂. To avoid problems caused by humidity inside of filter, the dry-bulb temperature of gas has to be adjusted subject to the gas humidity. The limits of temperature to be observed are listed in Figure 8 [5].

In case of operation of plant in the temperature range on the left of red solidus line, a bonding of filter bags may be possible, combined with an irreversible increase in differential pressure. There is also the risk of blocking of complete filter chamber. An operation of plant in the temperature range marked in blue on the right side of solidus line has to be aimed at.

![Figure 8: Phase diagram CaCl₂](image)

Furthermore a filter construction allowing the consequent avoidance of particle deposits has generally to be ensured.

- Steep collection hopper walls.
- No stiffeners inside of filter.
- Well-dimensioned discharge devices.
- Installation of discharge aids, such as pneumatic knockers.
- Consequent insulation of complete filter with avoidance of cold bridges.
- Heating of component parts with low heat input such as e.g. the filter collection hoppers and of complete discharge system.
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Design of filter as multi-chamber filter

The filter should be realised as multi-chamber filter. This design allows the isolation of separate filter chambers for maintenance and repair works without any interference of plant operation. The n-1 chamber operation has to be taken into account when defining the filter size.

Detection of defective flat-bags

Even in case of thorough design and realisation of fabric filter it cannot be excluded at 100 percent that in the course of the operating time separate filter bags will become defective and allow the passage of particles. Especially in case of high particle loads on the crude gas side totalling to several 100 g/Nm³, as in the case of the conditioned dry sorption, already small bag damages may quickly lead to an inadmissible increase of the particle content in the clean gas. Appearing damages have to be detected by the operating staff in a minimum of time and already whilst arising. In this respect the provision of each separate chamber with simple qualitative particle measuring devices proved to be successful.

2.3.2. Avoidance of corrosion

When using fabric filters downstream of waste- and/or RDF incinerators, there is a considerable risk of corrosion. In case of inconsequential observance of all necessary measures, particularly the clean gas chambers are liable to strong corrosion after a comparatively short operating time which may possibly lead to complete rust perforation.

Figure 9: Corrosion monitor
The risk of a corrosive attack in the wall area of flue gas treatment plants is demonstrated by the examinations realised at the MHKW Ludwigshafen, Germany, with a corrosion monitor (Figure 9) [1].

Due to the controlled cooling of such a corrosion monitor, the surface of probe presents a temperature profile by means of which the temperature range of an increased corrosion can be determined. Resulting from an internal cooling, the used corrosion monitors show different surface temperatures of the tube at different positions. A control of the cooling ensures a constant temperature profile over the duration of measurement, with detection of tube temperatures by means of temperature sensors.

At the plant in Ludwigshafen a corrosion monitor has been installed on the crude gas side near the collection hopper for a period of time of approximately 350 h. It may be remarked that at this point an adequate quantity of Ca(OH)$_2$ had already been available for the sorption. The results are shown in Figure 10.

![Operating hours: 350 hours](image)

**Figure 10:** Reduction in wall thickness due to corrosion

After an operating time of 350 h in a temperature range of approximately 80 °C the wearing off already totalled to more than 0.3 mm, corresponding to a wearing off rate of 0.94 mm/1,000 operating hours. Above a temperature of 100 °C the residual wall thickness totals to more than 2.8 mm, the wearing off rate thus totals to < 0.5 mm/1,000 operating hours. In case of a surface temperature above 110 °C, no wearing off could more or less not yet be detected.
Measures for the avoidance of corrosion are among others:

- Avoidance of cold bridges by means of consequent realisation of insulation. This also includes the isolation near steel construction. The penthouse may e.g. by no means be supported on the filter chambers above clean gas chambers. A separate steel construction is compulsory.
- Use of stainless steel where reasonable.
- Application of a special painting in high-risk areas, such as e.g. clean gas chambers.
- Consideration of acid dew point and solidus line.

On the occasion of annual downtime for maintenance works the filter should be inspected thoroughly with regard to corrosion. This also involves the removal of particle layer still existing on the walls after shutdown of plant to allow inspection of steel parts below. Corrective measures have to be taken immediately to ensure reliable avoidance of larger damages.

3. Assessment

Fabric filters are essential component parts for flue gas cleaning systems installed at WtE-plants. In the end all pollutants in form of fly ash, reaction products and free residual additive powders are separated in the filter. Here also takes place at least partly the separation of gaseous substances by means of chemisorption or adsorption.

With regard to the objectives above, fabric filters proved to be very reliable and efficient with at the same time high availability. A requirement for this is the observance of all process- and construction-related aspects which are not least based on the operating experiences gathered in the course of the last years. These are in particular:

- Compliance with design requirements to be derived from the corresponding applied sorption process.
- Process-related integration of fabric filter in the sorption process also as aggregate for the separation of gaseous substances.
- Consideration of process- and construction-related requirements discussed in chapter 2.

4. References


