LÜHR FILTER

Draft of lecture
HVG-Colloquium
„Crude gas cleaning by means of fabric filters“

Experiential level of knowledge November 2007

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HVG-Continuation course „Emissions of glass melting furnaces“

18.10.2007 on November 19-20, 2007

German Leather Museum, Offenbach / Main

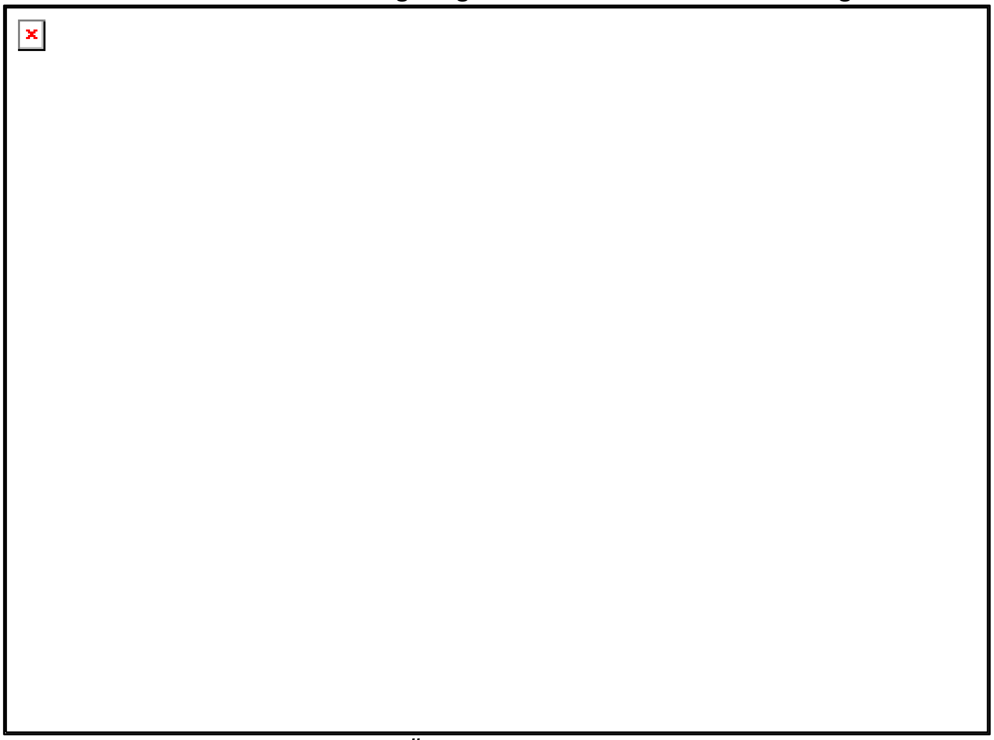
Contents

1 Introduction

This lecture is concerned with the particle and crude gas separation of flue gases extracted from glass tanks by means of fabric filters. The explanations are based on operating experiences gathered by LÜHR FILTER since the mid seventies until today from the realisation of more than 100 flat-bag filters downstream glass tanks for different products (picture 1).
Modern plants are characterised among other things by:

- Reliable observance of the requested emission limit values in the clean gas
    - particles
    - heavy metals (Pb, Se, . . .)
    - carcinogenic substances (As, Cd, . . .)
    - gaseous, inorganic substances (HF, HCl, SO_x)
- Assurance of the extraction capacity in continuous operation without pressure fluctuations in the tank
- Low operating costs, among others
    - several years‘ service lives of the filter fabric
    - good additive powder efficiency
- High availability
- Low maintenance

The aforementioned positive operating experiences can only be achieved if the specific features of the application with regard to the process technology as well as the characteristics of the particles to be separated, which differ considerably from many other applications, are taken into consideration. This lecture states the relevant aspects to be considered when designing fabric filters downstream glass tanks.

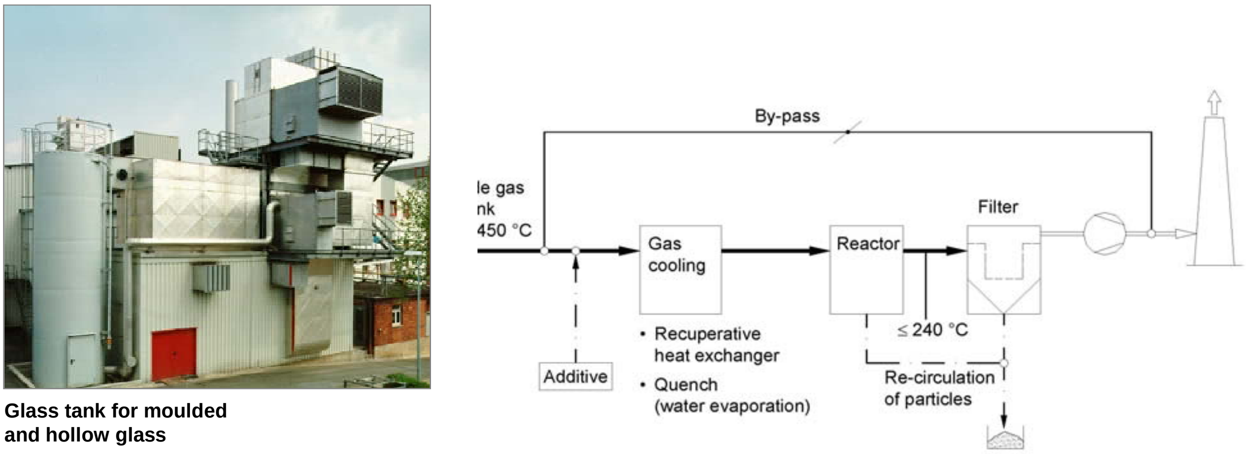


Pic 1:Application examples for LÜHR flat-bag filters in the glass industry

2 Process structure and description of components

2.1 Basic process structure

The basic structure of a flue gas cleaning system downstream glass tank is shown in picture 2.



Pic 2: Basic structure of a flue gas cleaning plant with fabric filter downstream glass tank

Fabric filters are working at flue gas temperatures of up to max. 240°C. Therefore it will often be necessary to install a cooling stage upstream fabric filter. The additive powder injection serves – as far as necessary – for the separation of acid crude gas components (HF, HCl, SO_x) and for the corrosion protection.

The separate components are described in the following:

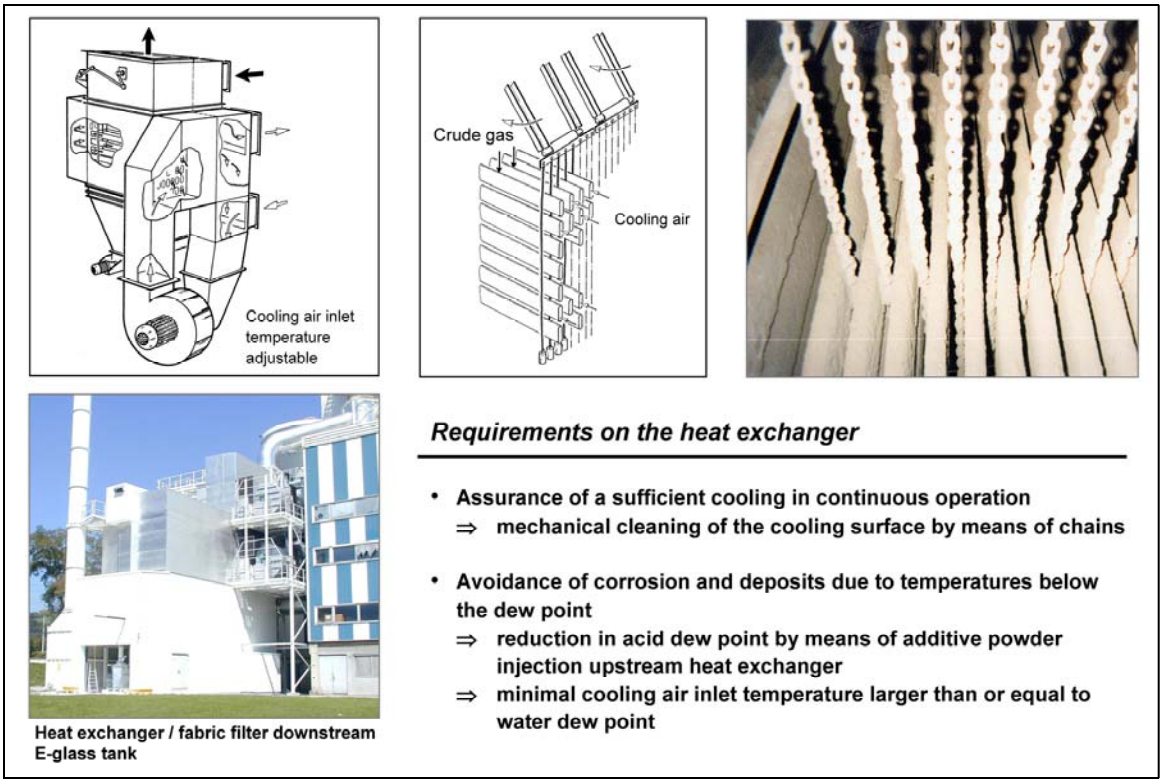
2.2 Flue gas cooling

In principle two proven variants for the flue gas cooling are available:

- Recuperative heat exchange
- Evaporative cooler (Quench)

2.2.1 Recuperative heat exchange

Picture 3 shows a schematic view of a gas / air heat exchanger. The cooling is effected by means of indirect heat exchange between the gas to be cooled and the ambient air taken in near the cooler. The flue gas to be cooled flows downwards and upwards between the horizontally located flat sided cooling tubes. A part of the heat is transferred through the external walls of the flat-tubes to the cooling air passing through the inside of the flat-tubes.



Pic 3: Recuperative heat exchanger exemplary shown by means of LÜHR flat-tube heat exchanger

The re-circulation of a part of the cooling air and the possible additional additive powder injection into the flue gas flow help to make sure that the temperature near the external walls of cooling tubes does not fall below the water or acid dew point. Corrosion and particle deposits will be avoided. This aspect gains special importance in case of using fuel burners (higher crude gas concentration and higher dew point) or if the flue gas has to be cooled down to temperatures of e.g. < 100°C for the separation of heavy metals.

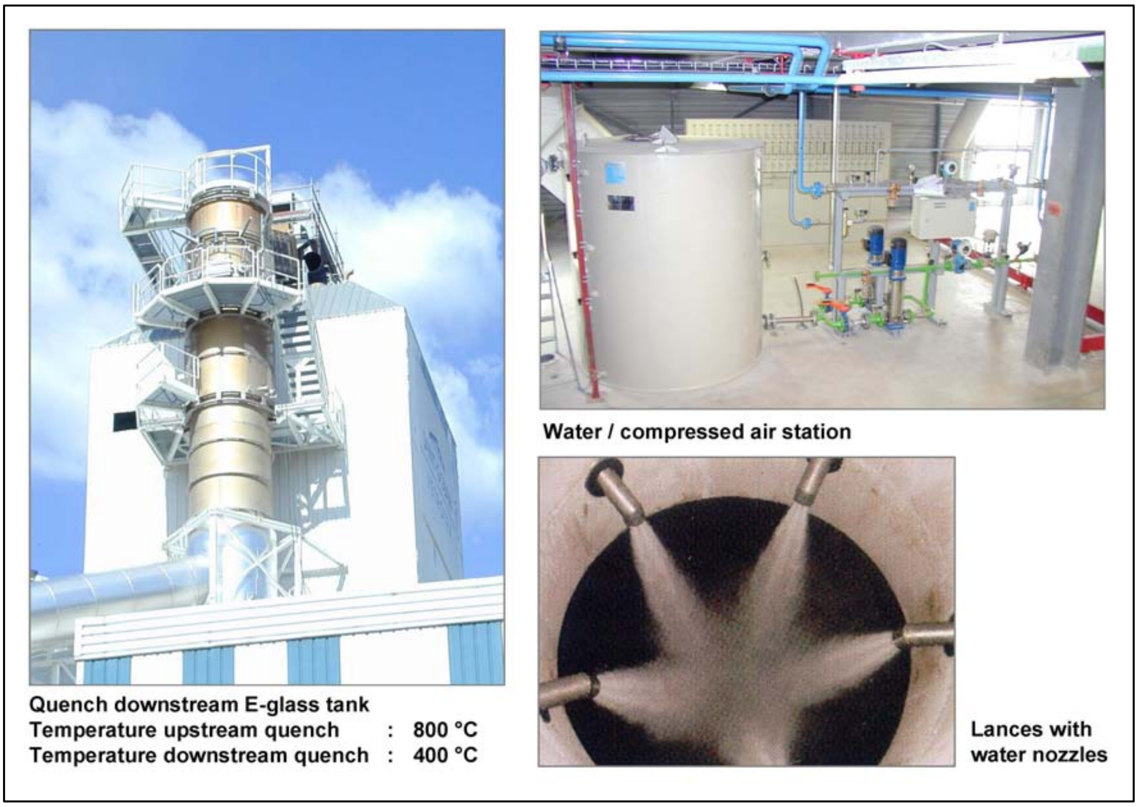
In general the working life of flat-tubes is well above 5 years.

Due to the strongly adhesive character of the particles existing in the gas flow downstream glass tanks, an automatically working cleaning device has to be installed. Chains are moving slowly to and fro the cooling tube rows, thus serving for the limitation of particle layer on the cooling tubes.

The integration of a heat recovery will e.g. be possible in form of a hot water generator.

2.2.2 Evaporative cooler

During the evaporative cooling, droplets of a fluid are dispersed over the flue gas flow by means of a spraying device, thus extracting heat from the flue gas to be cooled during evaporation (picture 4).



Pic 4: Flue gas cooling by means of water evaporation (Quench)

A safe operating mode of the cooler requires the complete evaporation of the droplets at low temperature fluctuations at the cooler outlet. Important aspects for the reliable design of an evaporative cooler are:

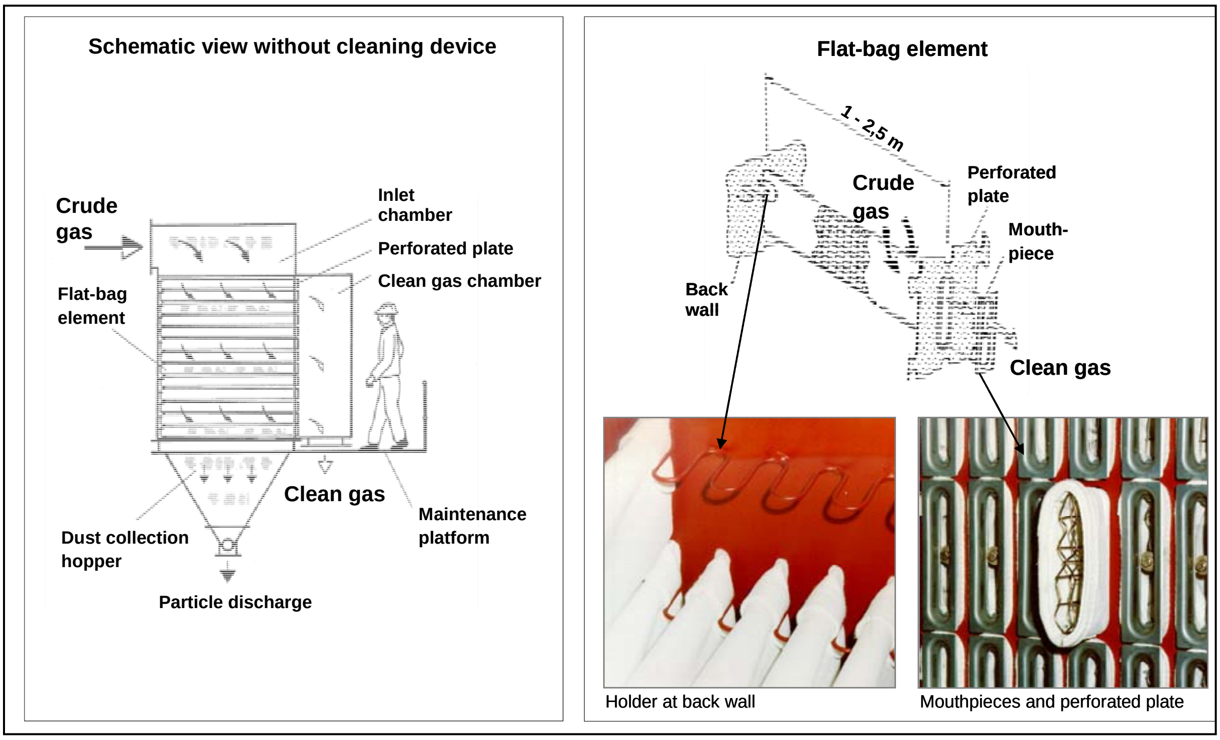
- procedure of spraying
- constant flue gas flow through the evaporation system
- control technique

In most of the cases two-media nozzles (water and compressed air) are used for the spraying.

2.3 Fabric filters

2.3.1 Basic design exemplary shown by means of a LÜHR flat-bag filter

The basic design of a fabric filter is shown in picture 5, representing a LÜHR flat-bag filter with horizontally installed filter elements.



Pic 5: Fabric filter exemplary shown by means of LÜHR flat-bag-filter

The filter housing is divided into a crude gas and a clean gas chamber by means of perforated plates.

The filter elements are horizontally installed flat-bags, mounted on support cages. The filter elements are inserted into the filter housing from the clean gas side. They are held in fixed positions in the filter housing, fitted precisely in the holes in the perforated plate, secured without the use of screws thus providing a perfect seal against dust leaks.
The gas flow passes the textile filter fabric from the outside to the inside, the particles being retained on the outer surface of the filter elements.

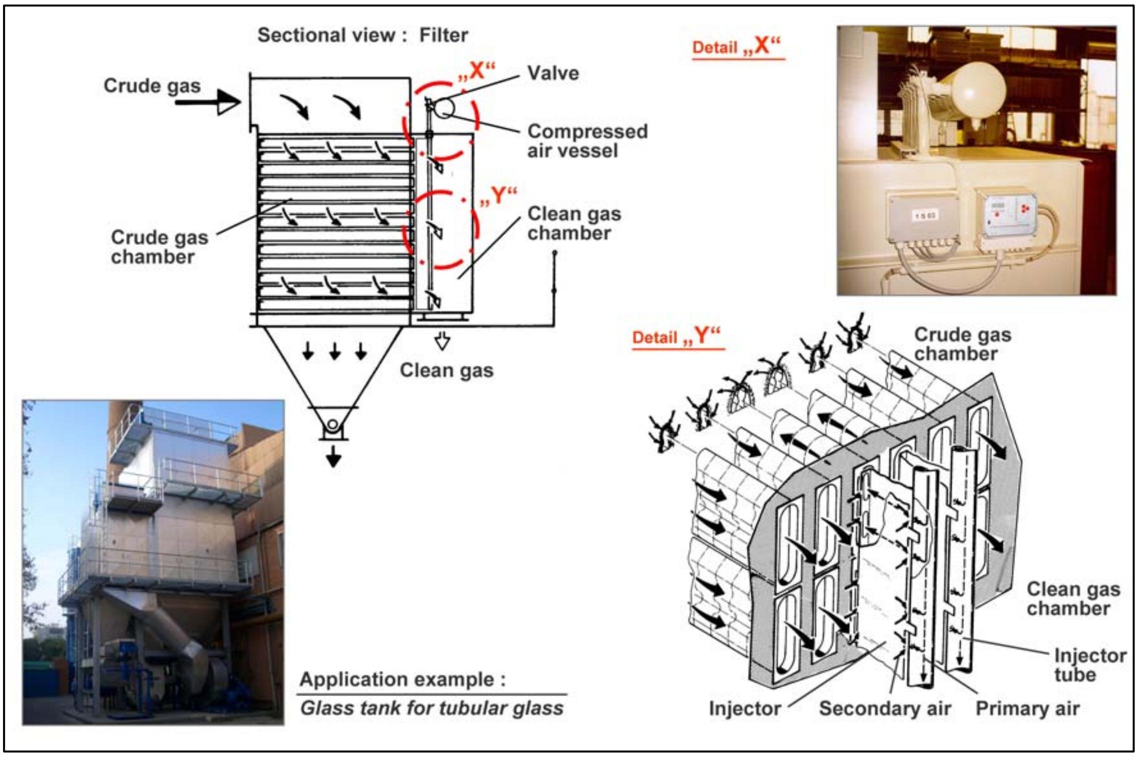
It may be remarked in addition, that alternatively a model with vertically installed flat-bag elements is available. Even regarding this type, the flat-bags are fitted precisely in the housing, however, the advantages of a filter with horizontally installed flat-bags cannot be used consistently in every respect.

2.3.2 Cleaning systems

Different cleaning systems are available for the removal of the particles adsorbed at the filter fabric and/or penetrated in the filter fabric. Four cleaning systems frequently used for flat-bag filters are described in the following, without assessment of their corresponding advantages and disadvantages.

2.3.2.1 Compressed air – on line – cleaning (pic. 6)

Easy to remove, vertically arranged injector tubes are installed in the clean gas chamber in front of all flat-bag rows. Compressed air and clean gas as secondary gas are injected one after the other into two adjacent bag rows simultaneously by means of high efficiency aerodynamic injectors. The bag rows are cleaned in pairs with a short, severe cleaning air pulse contrary to the sense of filtration, thus removing the particle cake from the flat-bags.



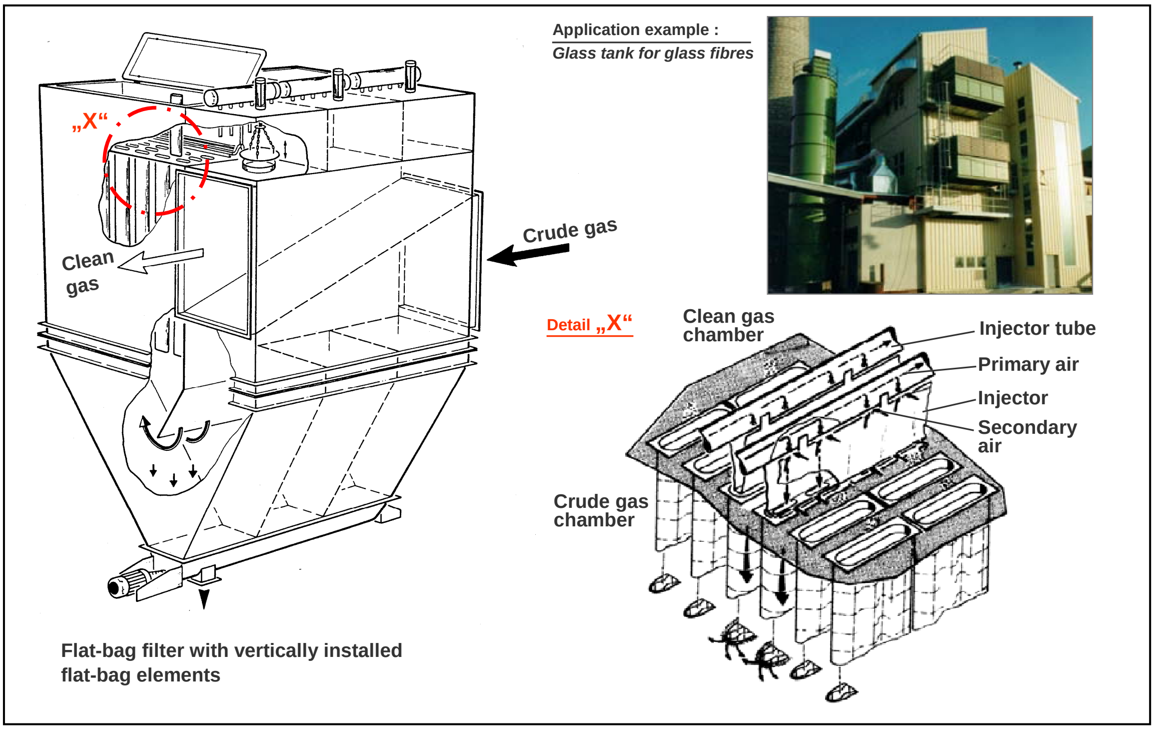
Pic 6: Compressed air – on line - cleaning

2.3.2.2 Compartmentalised compressed air – off line – cleaning

The fundamental design of this cleaning system is shown in picture 7, representing a flat-bag filter with vertically installed flat-bags.

The clean gas channel of the filter housing is divided into several compartments. Each of them is connected to the clean gas channel and can be isolated.

Prior to the cleaning of a compartment, the corresponding isolation damper is closed on the clean gas side. Once the compartment has been isolated from filtration, the flat-bags are cleaned by means of compressed air as described before.

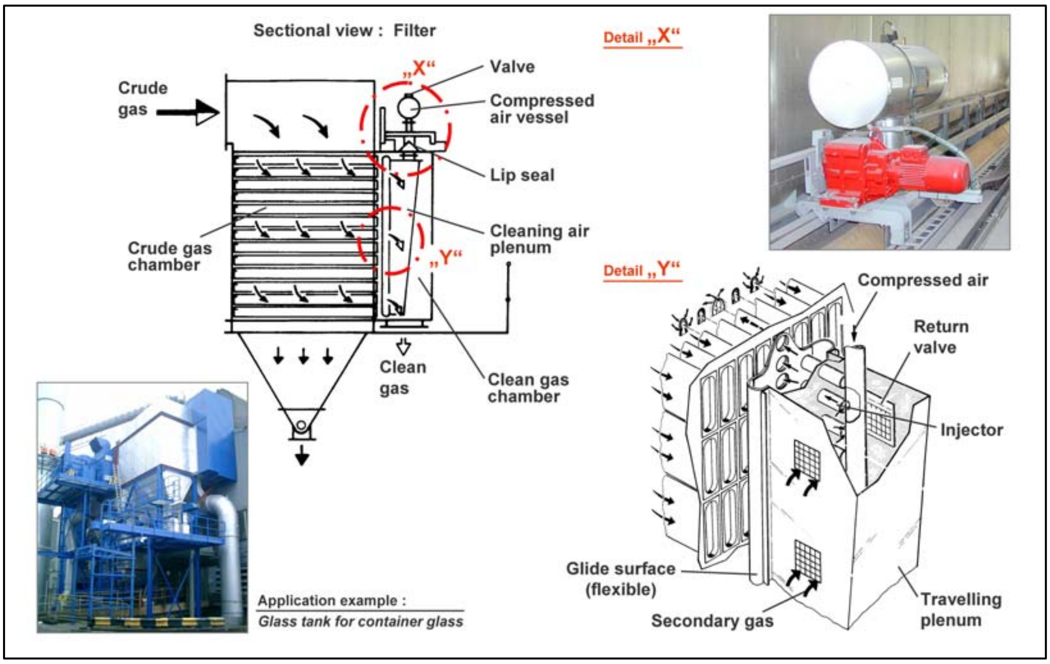


Pic 7: Compartmentalised compressed air – off line - cleaning

On request, the complete crude gas chamber of the filter housing can also be compartmentalised to allow the isolation of separate compartments for inspections or maintenance works, whilst the remaining compartments are still charged by the crude gas. In principle this will also be possible when using a compressed air –on line– cleaning system.

2.3.2.3 Travelling compressed air – off line – cleaning (pic. 8)

Sequential cleaning of the flat-bag rows by means of a cleaning air plenum travelling in the clean gas chamber, provided with compressed air supply and injectors. The plenum covers three vertical filter element rows, injecting a brief (approx. 0.5 sec.) pulse of compressed air and clean gas as secondary gas into the centre row. A well proven lip seal provides a reliable sealing along the cleaning air carriage travel.

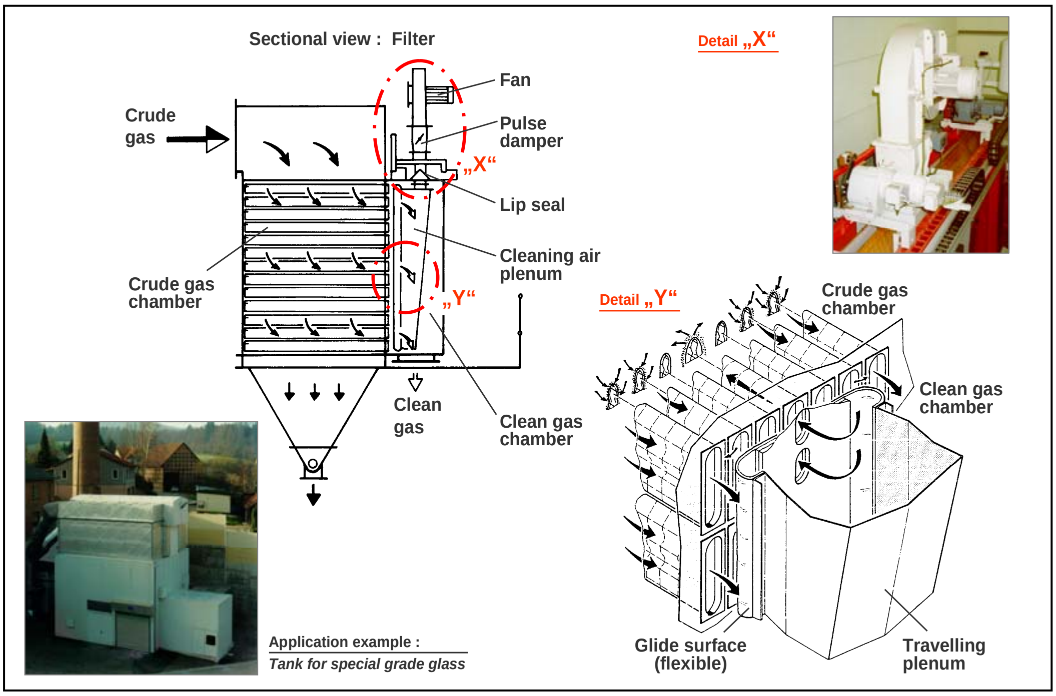


Pic 8: Travelling compressed air – off line - cleaning

2.3.2.4 Travelling medium pressure – off line – cleaning (pic. 9)

Sequential cleaning of the flat-bag rows by means of a cleaning air plenum, travelling in the clean gas chamber. Cleaning air is injected into one flat-bag row by means of a medium pressure fan, whilst the adjacent flat-bag rows are not charged by the crude gas. A well proven lip seal provides a reliable sealing along the cleaning air carriage travel.

Compressed air is not required for this type of cleaning system.

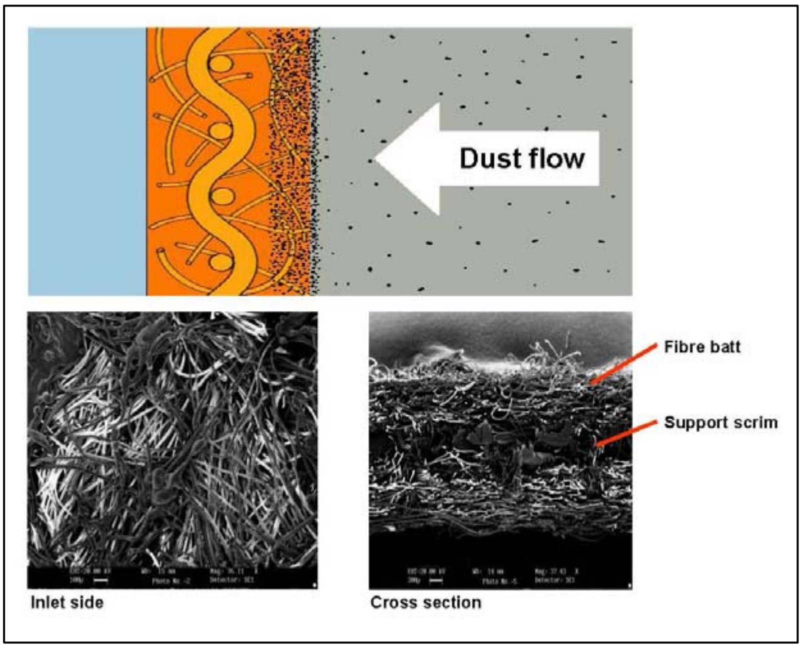


Pic 9: Travelling medium pressure – off line - cleaning

All of the four presented cleaning systems are used in the glass industry. In order to achieve long filter fabric service lives, the adequate system has to be chosen in accordance with the application.

2.3.3 Filter fabrics

The basic structure of the needle felts used as filter fabric is shown in picture 10. It consists of a support scrim with a fibre batt.



Pic 10: Structure of a needle felt without surface treatment

A large number of different needle felt qualities is available. Picture 11 shows a table with the qualities preferably used for filters downstream glass tanks and informs about the relation between needle felt purchase costs and the admissible operating temperatures.

Continuous operating temperature based on practical experience	Needle felt		Costs, referred to polyacryl-nitrile needle felt
	Fibre batt	Support scrim	
125°C	Polyacryl, e.g. Dolanie*)	Polyacryl, e.g. Dolanie*)	1,0
≤ 160°C depending on H_2O content	Aromatic Polyamide e.g. Nomex*)	Aromatic Polyamide e.g. Nomex*)	2,6
≤ 170°C in limits depending on H_2O content	Aromatic Polyamide e.g. Nomex*)	PTFE e.g. Profilen*), Rastex*)	5,0
≤ 220°C	PTFE, Polyimid P84*)	PTFE	8,0
≤ 250°C	PTFE e.g. Teflon*), Profilen*)	PTFE, Rastex*), Profilen*)	10,0

*) Trade name

Pic 11: Selection of filter fabric

The selection of a filter fabric quality and by this the setting of the flue gas temperature within the filter is subject to the requirements of the corresponding application. It is influenced among other things by:

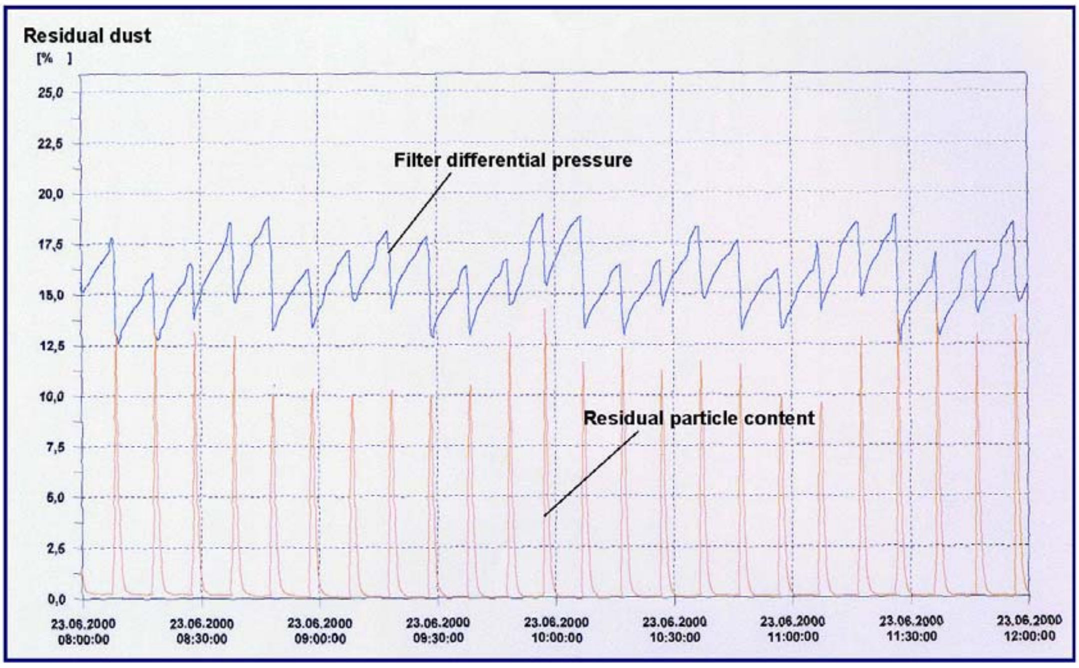
- gas composition
- separation of heavy metals
- separation of acid crude gas components
- acid and water dew point
- investment and operating costs

The service lives of the filter bags installed in fabric filters downstream glass tanks total to at least two and well above five years. Condition for this is the selection of a filter type with gentle treatment of the filter fabric.

2.3.3.1 Aspects concerning the gentle treatment of filter fabric to grant several years' operating lives of the filter fabric with observance of the requested emission levels in the clean gas

2.3.3.2 Cleaning systems

The application of a compressed air –on line– cleaning system implies a serious disadvantage due to the extremely short flow reversal in the filter fabric during the cleaning. Re-deposits of separated particles are unavoidable and uncontrolled.
The re-deposit takes place when the filter fabric impacts against the support cage after the cleaning pulse. The fine dust is literally catapulted through the fabric towards the clean gas side of the filter („Carpet wrapping effect“). The impact of filter fabric to the support cage causes an increase in the residual particle content on the clean gas side and represents at the same time a comparatively high stress to the filter fabric.



Pic 12: Influence of the cleaning cycle on the residual particle content in the clean gas

Picture 12 illustrates the influence of the cleaning system on the residual particle content in the clean gas. It shows the continuously measured residual particle content in the clean gas as well as the filter differential pressure over the time. The data have been collected at a filter with a comparatively small filter surface.

It is clearly visible that each -on line- cleaning procedure causes an increased particle passage which comparatively quickly drops to a lower level again.

The above described disadvantages can be avoided by using -off line- cleaning devices. This type of cleaning system allows a gentle treatment of the filter fabric, there is no „Carpet wrapping effect“. In addition, the particles have more time to fall down into the collection hopper after the cleaning procedure. Especially the travelling compressed air -off line- cleaning system is nowadays often used for flat-bag filters downstream glass tanks because of the high efficiency in connection with low mechanical stress to the filter fabric.

The main advantage in contrast to the travelling medium pressure -off line- cleaning system is the avoidance of temperatures below the dew point near the flat-bags during or shortly after the cleaning process.

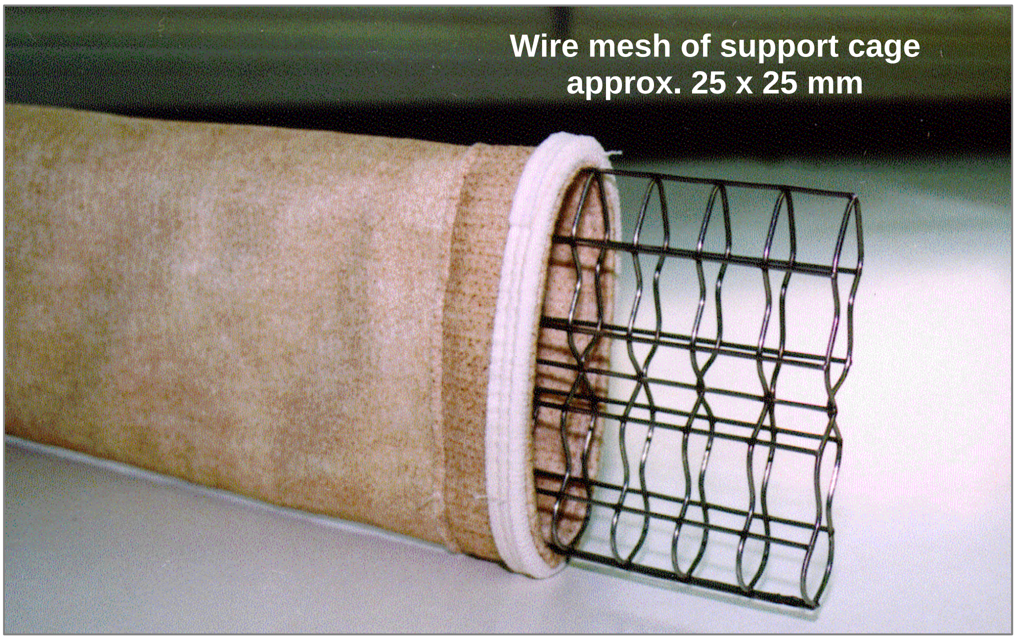
With regard to the costs, compartmentalised -off line- cleaning systems should only be used if a partition of the crude gas side for repair and/or maintenance works in continuous operation is requested. However, as a result of the proven high availability of fabric filters, this can in most of the cases be omitted.

2.3.3.3 Support cages (pic. 13)

Preferably support cages with a small wire mesh (in case of a flat-bag filter e.g. 25 x 25 mm) should be used, thus allowing a homogeneous distribution of the forces acting upon the filter bags as a result of the filter differential pressure on the complete filter fabric.

The size distribution of the arising forces can be explained with the help of a simple example:

A filter differential pressure of 15 mbar (equivalent to 150 mm water gauge) corresponds to a load of 1,500 N/m². These surface forces have to be transferred from the filter fabric to the wires of the support cage. The narrower the wire mesh, the lower is the stress to the textile filter material near the wires.



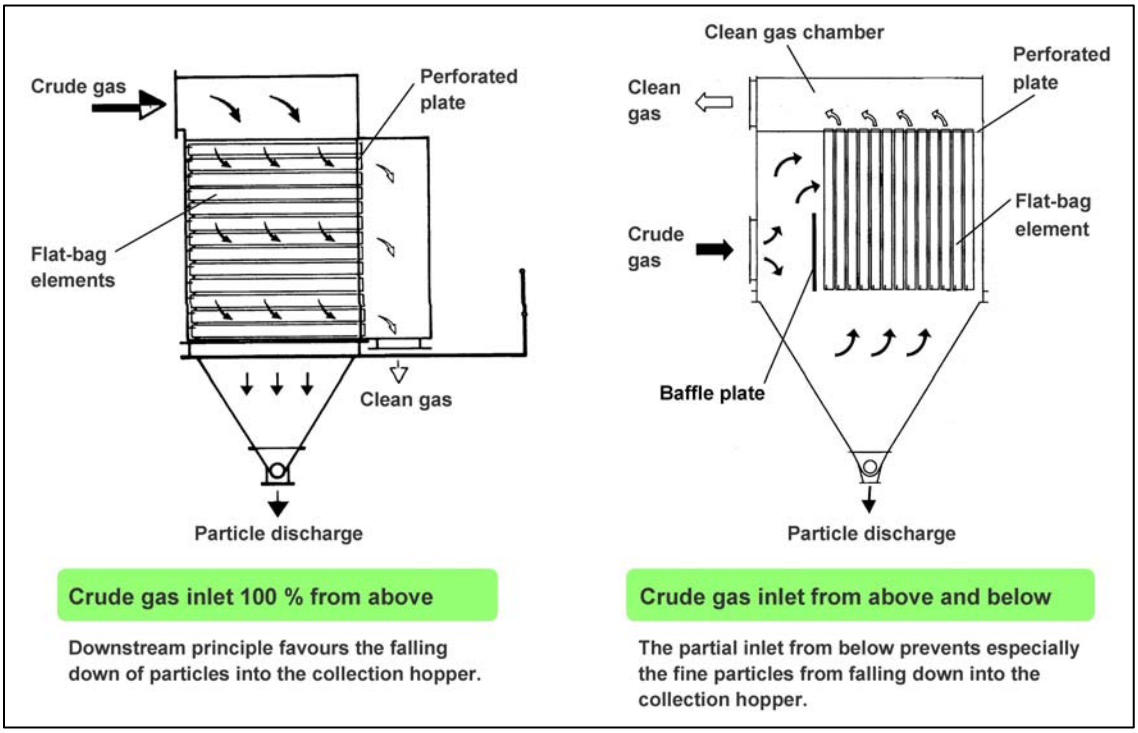
Pic 13: Support cage of the flat-bag filter element

2.3.3.4 Filter inlet flow to the filter elements (pic. 14)

An important precondition for the achievement of long cleaning cycles and by this low mechanical stress to the filter fabric is an undisturbed falling down of separated particles in the filter housing.

As far as one compartment filters are used, a flow inlet from above should be preferred.

In case of an inlet from below or diagonally from below at one compartment filters, the particles separated at the filter elements can only fall down, if the descend velocity is larger than the counteracting inlet gas flow. As the descend velocity of particle agglomerates of 200 µm is only approx. 1 m/sec, the top entry flow distribution in one compartment filters is the only way to minimise new undesired, uncontrolled particle deposits especially of finest particles.



Pic 14: Different types of crude gas inlet to the flat-bag elements

2.3.3.5 Air-to-cloth ratio

In case of flat-bag filters installed downstream glass tanks, the inlet velocity just in front of the filter fabric usually lies between approx. 1.0 m/min and max. 1.2 m/min.

When combining a partial re-circulation of the separated particles into the flue gas flow upstream filter (see chapter 3) with the pre-mentioned air-to-cloth ratio, cleaning cycles of 30 min. up to definitely > 60 min. connected with a filter differential pressure of 10 mbar up to max. 15 mbar in continuous operation will be achieved; presupposition for low residual emission levels in the clean gas with at the same time low mechanical stress of the filter fabric and as a result of this, long operating lives of the filter fabric.

2.3.3.6 Thermal and chemical stress on the filter fabric

A further precondition for the achievement of long filter fabric service lives beside the above-mentioned measures for the avoidance of high mechanical stress is the consideration of the following aspects regarding thermal and chemical stress:

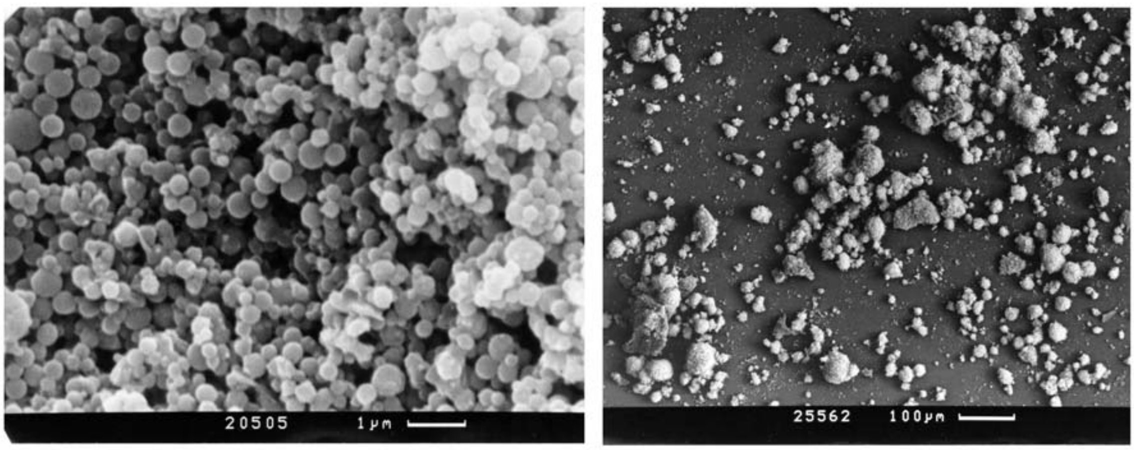
- Selection of a filtration temperature of filter fabric definitely below the max. admissible values, defined by the fibre manufacturers (see pic. 11).

- In case of acid formers, injection of neutralising additive powders (e.g. $Ca(OH)_2$), thus avoiding a condensation of acids in all areas of the flue gas treatment plant
- Selection of a filter fabric considering both the temperatures in question and the water steam and oxygen content in the clean gas.
- Avoidance of temperatures leading to irrevocable deposits within the filter fabric, formed by certain particles existing in the particle spectrum. In this connection it may be remarked that even in case of fabric filters downstream pot furnaces with comparatively low operating temperatures so far no serious problems due to temperatures below the dew point have occurred.

3 Particle re-circulation

3.1 Particle features

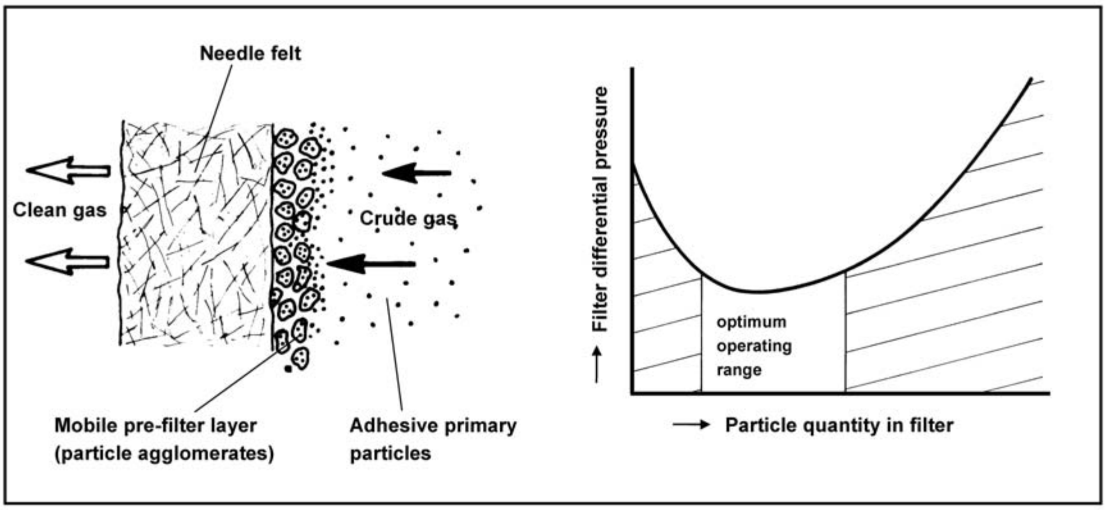
The particles existing in the flue gas downstream glass tanks are adhesive and extremely fine (particle size about 1µm or even smaller). Picture 15 shows the fineness of such particles and also their tendency to agglomeration.
Fabric filters are suitable to separate these particles, which have arisen after resublimation from the gas phase and due to their tendency to adhesion and agglomeration, with exceptionally high degrees of separation. However, in spite of the low crude gas particle contents < 1 g/m³, the removal of particles separated at the filter fabric proves to be difficult.



Pic 15: Microscopic photos of adhesive particles

The adhesive forces of the particles adhering to the fibres of the filter fabric are at least for some time (mostly several hours) definitely stronger than the forces that can be generated by means of up-to-date cleaning devices of filters. This leads to undesired high flow resistances or forces to the installation of large filter surfaces.

The necessary, frequent cleaning procedures will increase the energy consumption and reduce the filter fabric service lives.
The continuous operating behaviour of fabric filters for this type of application can definitely be improved by advantageous manipulation of the adhesive forces of the particles to be removed. This will be achieved by a multiple, volume-controlled particle re-circulation (pic. 16). The ratio between primary particles and re-circulated particles totals to approx. 1 : 50.

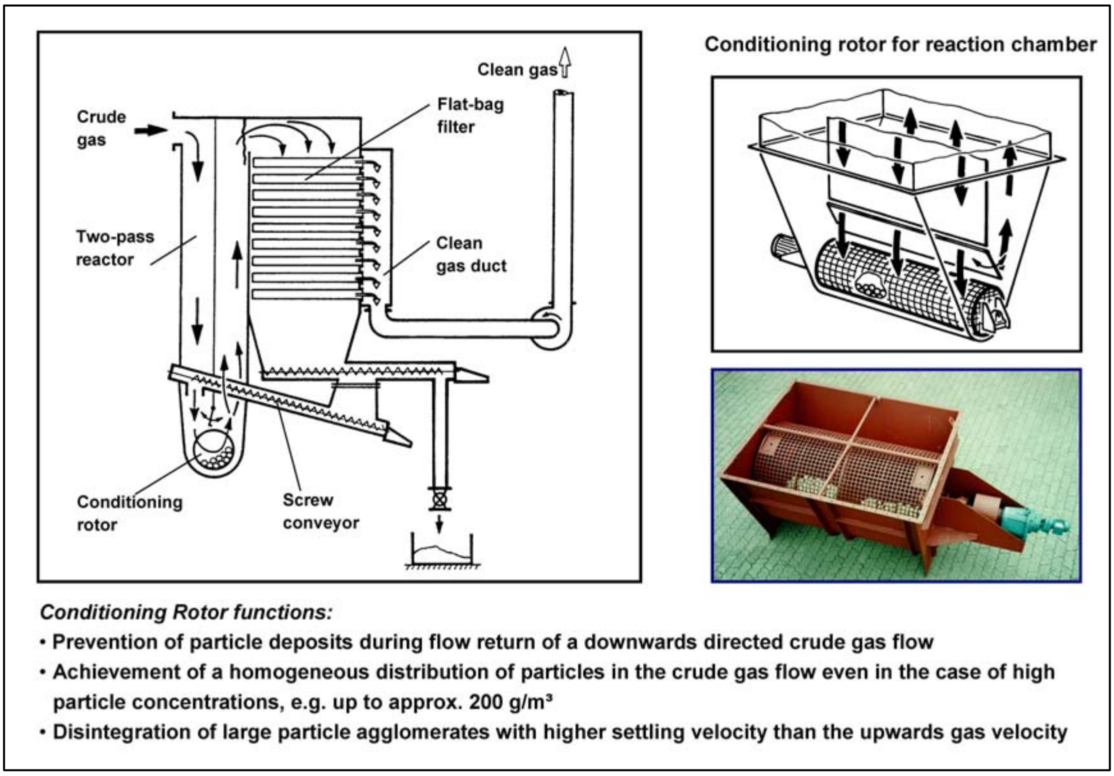


Pic 16: Mobile pre-filter layer fort h eseparation of fine adhesive particles

The agglomerates formed by re-circulated particles adsorb at the filter fabric. The adhesive particles are separated at this mobile pre-filter layer. Due to the fact that the adhesive forces of the agglomerates formed by older particles are weaker, these agglomerates can easily be removed from the filter fabric by means of the filter cleaning device.

3.2 Conditioning Rotor – Recycle Process

For many types of applications, the Conditioning Rotor – Recycle Process (pic. 17) proved to be suitable for the reliable realisation of the re-circulation of particles separated in the filter into the flue gas flow upstream filter.
The conditioning rotor is a hollow cylinder, manufactured of a perforated plate with openings of approx. 30 x 30 mm. Up to 10% 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 around within the rotor. The crude gas flow passes the rotor axis at first in downward direction and then in upward direction.



Pic 17: Conditioning Rotor – Recycle Process

The main functions of a conditioning rotor are:

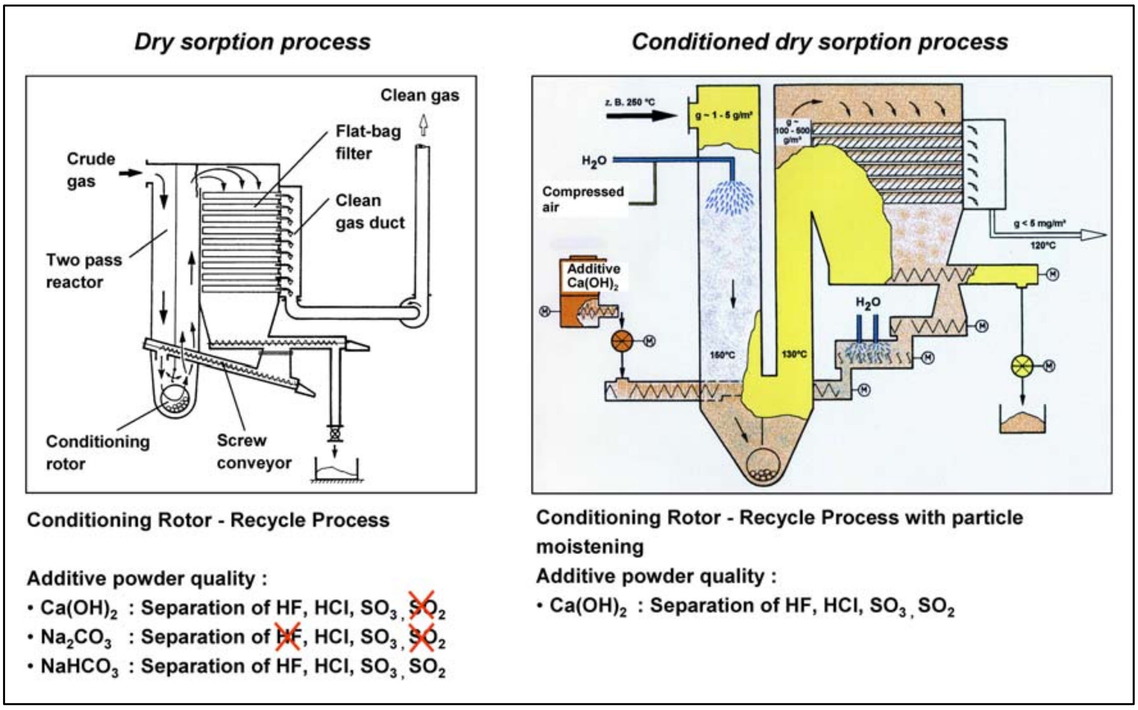
- prevention of particle deposits when reversing a particle-laden crude gas flow
- achievement of a homogeneous distribution of particles in the crude gas flow even in case of a high particle concentration (e.g. up to approx. 50 g/m³)
- disintegration of larger particle agglomerates

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 and can be controlled, e.g. 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 possibly interim storage of the recycled particulate is not necessary
- a homogeneous distribution of the reintroduced, recycled particulate in the crude gas flow
- no increase in O_2 content in the flue gas due to conveying air inlet

4 Crude gas sorption

Besides the achievement of low clean gas / residual particle contents, fabric filters also offer the reliable observance of the required emission levels for acid gas components by means of an acceptable additive powder consumption in continuous operation. The used additive powder qualities are $Ca(OH)_2$, $NaCO_3$ or $NaHCO_3$ (pic. 18).
Dry sorption procedures are exclusively used for the separation of HF and HCl. When separating SO_2 with $Ca(OH)_2$ even conditioned dry processes (pic. 18 - right hand view) are successfully used downstream glass tanks.

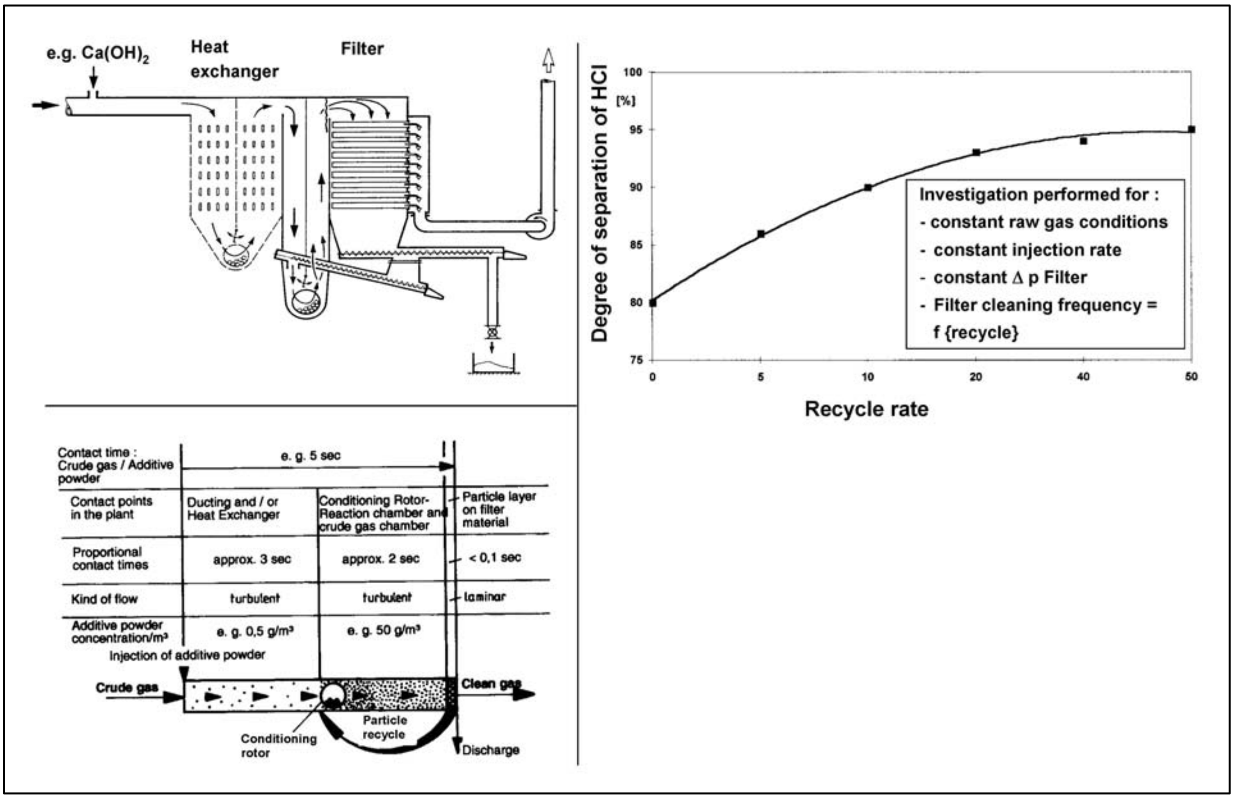


Pic 18: Crude gas sorption

A multiple re-circulation of the partly saturated additive powder particles, e.g. by means of Conditioning Rotor – Recycle Process, has a positive effect on the additive powder efficiency.

Generally, the time available within the plant for the sorption totals to 2 up to 10 sec. and corresponds to the residence time of the gas in the system after the first additive powder injection. The proportionally resulting time for the passage of the particle layer formed on the filter fabric is very short and lies below 0.1 sec.

As a result of examinations and measurements at plants in continuous operation it turned out that the additive powder consumption could be reduced by the particle recycle. Picture 19 shows the improved reaction conditions in the reactor area.
As expected, the reduction in the additive powder consumption with observance of given emission levels in the clean gas shows a flattened tendency after an approx. 40-times particle recycle.



Pic 19: Limits for contacts of crude gas molecules and additive powder in a system with fabric filter

The achievable degrees of additive powder efficiency lie above 50%.

The selection of additive powder quality and process variant depends on the application in question, considering the following aspects:

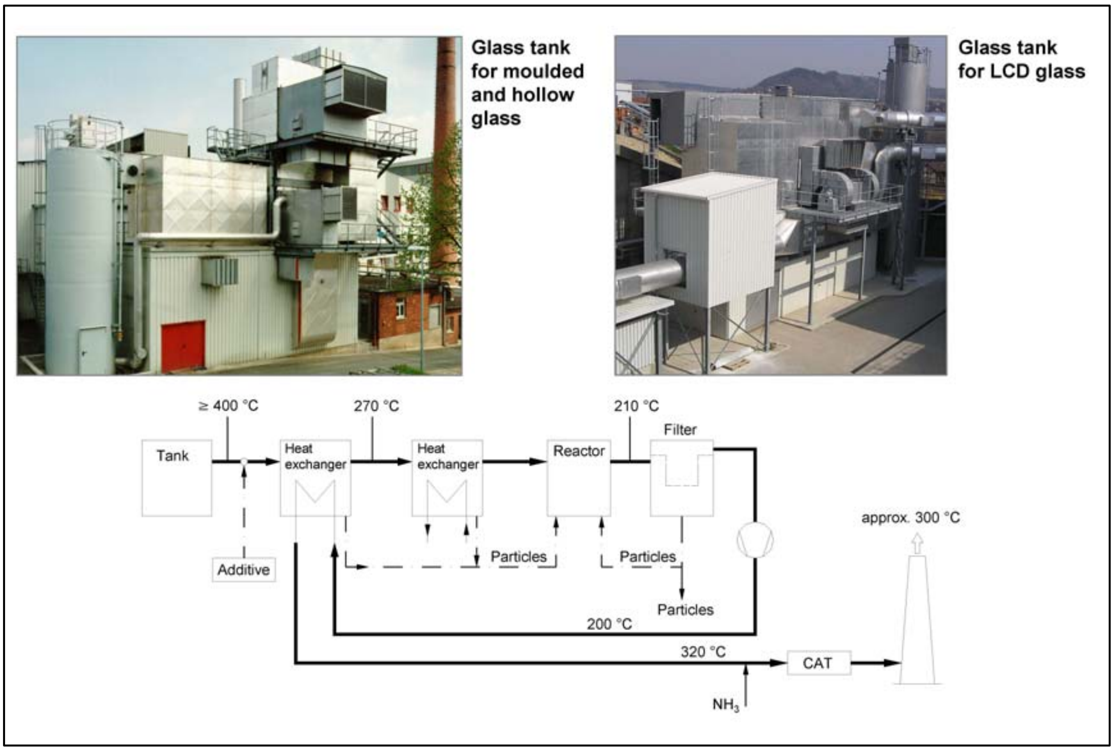
- components to be separated
- degree of separation
- re-circulation of separated particles into the gas flow
- investment and operating costs

5 Combination of fabric filter with catalyst

Catalysts for the NO_x reduction have to be operated at a higher temperature than the max. flow temperature of the filter. When combining a fabric filter with a NO_x catalyst, a reheating of gas downstream filter will be necessary. In these cases it will be useful to reuse the gas cleaned in the filter for heating in a heat exchanger crude gas / clean gas.

A corresponding process scheme is shown in pic. 20. As far as the flue gas temperature upstream heat exchanger does not fall below 400°C in continuous

operation, a reheating of clean gas to approx. 320°C can be achieved with acceptable investment costs.
The low residual particle content in the clean gas downstream fabric filter has an advantageous effect on the continuous operating behaviour of the catalyst.



Pic 20: Combination of fabric filter with catalyst fort he reduction of NO_x (SCR)

6 Summary

Fabric filters with particle re-circulation are suitable for the flue gas cleaning downstream glass tanks.

- All requested emission limit values for particles, heavy metals and acid crude gas components can reliably be kept in continuous operation.
- They can be used for different types of tanks and glass qualities.
- The correct dimensioning and design of plant allows several years‘ operating lives of filter fabrics with at the same time high reliability.

To what extent far fabric filters are the most suitable alternative for a given application has to be checked for each individual case, among others by means of the following criteria:

- Current emission limit values and those to be expected in the near future
- Investment and operating costs

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