DESIGN CRITERIA FOR HIGH TEMPERATURE FILTERS

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High temperature filtration is one of the most promising developments in particle collection technology to take place in the last couple of years. The long-term needs of power generation systems have driven this development but the focus has now shifted more and more to the chemical and process industry. In many processes, gases which are generated at high temperatures and/or pressures contain small particles and various harmful gaseous components. If these gas streams can be cleaned at elevated temperatures and pressures, processes can be made more efficient. In this context, high temperature begins above 250°C where conventional bag filters cannot be used because of the limited temperature resistance of synthetic filter media.

INTRODUCTION

In power generation systems, overall efficiency can be increased if the hot and eventually pressurised gases from a coal combustor or a gasifier are cleaned at high temperatures so that a gas turbine can be operated with the off-gases. Overall efficiencies might be increased from 38% to above 50 %. In numerous other applications in the metal, ceramic and process industries, hot gases also have to be cleaned. This is often done by quenching with conventional scrubbing or filter technology. In order to use the heat content efficiently, dust particles have to be separated at elevated temperatures with the additional advantage of avoiding possible corrosion and plugging due to cooling. At elevated temperatures, gaseous pollutants can be collected simultaneously together with particular matter in a high temperature dry scrubber or granular bed.

HIGH-TEMPERATURE FILTER MEDIA

Various filter elements are compared in Table 1. Porosities in a granular material are generally lower compared with a fibrous filter elements. Therefore granular material have higher weights and higher pressure drops. Since the size of the granules is considerably larger than the fibre diameters, which are often below 5Om the single collector efficiencies are smaller for granules compared with fibres. Therefore particles penetrate deeper into the granular material and may accumulate irreversibly in the depth of the media. Therefore, fibrous media are preferred where penetration of particles is limited to very thin layers near the surface of the media.

	Structure		
property	granular	woven	fleece
porosity	30 - 60%	35 - 55%	80 - 90%
permeability	low	medium	high
weight	high	low	low
pressure drop	>50 mbar	20 - 35 mbar	<30 mbar
separation efficiency	high	medium	high

Table 1: Comparison of various high temperature filter media

Both ceramic and metallic media can be used. Ceramic media are stable up to temperatures of 800 - 900°C. Porosities of these media are in the range of 60 - 90%. Pressure drops are often in the range below 20 - 30 mbar, seldom above 50 mbar. With granular media, pressure drops are often above 50 mbar. Metallic filter media have been mainly used in the pharmaceutical industry. Their application at elevated temperatures is now also being discussed in industry although chemical resistance has to be considered very carefully even when Inconel or Hastelloy qualities are used. Metallic fibrous media are available in a wide range from woven materials to sintered fleece structures.

CHEMICAL STABILITY

Chemical stability of filter elements in severe atmospheres at high temperatures is one of the basic and most difficult problems in high temperature filtration. Chemical stability is not clearly defined for any material. Normally, SO_2 and HCI are not problematic if condensation is avoided. HF is a problem since HF attacks also most ceramic materials including silica and SiC. Limits of concentration are not known and depend on gas atmosphere and temperature. For alumina silicate systems, alkali vapours may also be problematic.

For most of the media, collection efficiencies for particles down to submicron size range are very high so that emissions are often in the range of 1 mg/m^3 or below. Higher emissions are observed with woven materials.

In order to ensure a stable operation for a long period of time, filter elements have to be regenerated. This is one of the most challenging topics in high temperature filtration.

Either cold or alternatively preheated gases (air, N_2 or other process specific gases) can be used for regeneration. The danger of condensation can be avoided with preheated gases. Condensation as well as damage due to temperature shocks is more relevant for smaller filter elements since the mass of entrained air, and thus also the temperature of the jet, decreases with the smaller diameter of the filter element. Over-pressure inside a filter element translates into tensile stresses acting on the dust cake. These tensile stresses must overcome the adhesion forces between dust cake and filter media. The adhesion depends not only on temperature but also on properties of dust particles and filter medium. Very little quantitive data is available in this field. Therefore, filtration relevant dust properties are, besides stability of filter element, one of the most difficult questions for high temperature filters.

ESSENTIAL TESTING

Due to the difficulties experienced with chemical stability of filter elements in severe environments and due to the problem of mostly unknown particle properties, testing is often essential before a high-temperature filter is installed (see Table 2).

Selection and test of feasibility of a high temperature filter media for a given duty can be undertaken with a small coupon tester which allows a characterisation of the filter media under practical conditions. The test procedure is accepted as a general guideline in Germany (VDI 3926). The coupon tester also allows for the determination of separation efficiencies and the measurement of clean gas concentrations. When the test is being carried out in field, chemical stability of the filter media and cleanability of the medium can be verified in the real flue gas.

However, filter rates cannot be determined from the coupon tester. Experiments in pilot units are indispensable especially for filtration of fine dust particles. This touches on a fundamental difficulty of bag filter technology, filter rates can still only be determined on a purely empirical basis. Physical models are not available at all.

REGENERATION OF FILTER MEDIUM

Regeneration is accomplished in most industrial applications by pulse jet cleaning. Although this method is well-known, the fundamental mechanisms of dust cake removal are often poorly understood. In principle, three mechanisms for cake detachment can be defined.

- ❑ Cake removal by reverse air flow;
- ❑ Cake removal due to over pressure inside the filter element;
- ❑ Cake removal due to bag movement or by inertia of the dust cake during deceleration when the bag becomes taut.

test method		flow rate	result
media characterisation acc VDI 3926 coupon tester	in the lab	5Nm³/h	❑ separation efficiency, regeneration in dependence of temperature
	in the field		❑ chemical stability, separation efficiency, regeneration
filtration test in the lab		500 - 1000 Nm³/h	❑ filtration behaviour with synthetic flue gas ❑ test of components and filter media
filtration tests in the field		> 1000 Nm³/h	❑ filtration behaviour in the real flue gas

Table 2: Pilot tests at elevated temperature

For rigid media, only the two first mechanisms are of relevance. The pulse pressure inside the element is the most important parameter for regeneration of both rigid media and flexible media. The cleaning system must ensure a homogeneous distribution of pulse pressures along the candle length. Pulse pressure is affected by the blow tube or blow hole diameter, and the distance between the blow hole and filter element with fast piezo-electric pressure transducer in dependence of pressurised air consumption. Parameters are the blow hole diameter and the reservoir pressure. It can be clearly seen, that the consumption of pressurised air can be optimised by appropriate choice of blow hole diameter and reservoir pressure, respectively.

In the lab, the filtration behaviour of filter elements can be studied with various dusts under reproducible conditions. In addition, components like valves, various design parameters of tube sheet or discharge devices can be tested in the lab. Field tests are often necessary because the real gas atmosphere cannot be reproduced in the lab.

Fig 2 shows the schematic drawing of high-temperature pilot unit. The filter is designed for flow rates up to 800m³/h. Maximum temperature is 700°C. The system was designed to test various details of design. Filtration tests have been carried out with ceramic elements, metal bags as well as with woven high temperature filter media. Both hanging and standing configurations of filter elements have been tested. In order to allow comparisons between different filter media, inert quartz is used for all standard tests. Tests with dust relevant to specific applications are possible (eg., fly ash).

DESIGN OF THE BAGHOUSE

Baghouses for high-temperature applications can be designed up to temperatures of 800°C and/or for pressures ranging from vacuum to 60 bar. The baghouse is mostly round. Special care has to be given to the raw gas inlet and the distribution of air inside the baghouse. Various inlet configurations are available. An inlet into the hopper should be used only for coarse and heavy particles. For high temperature applications, down-

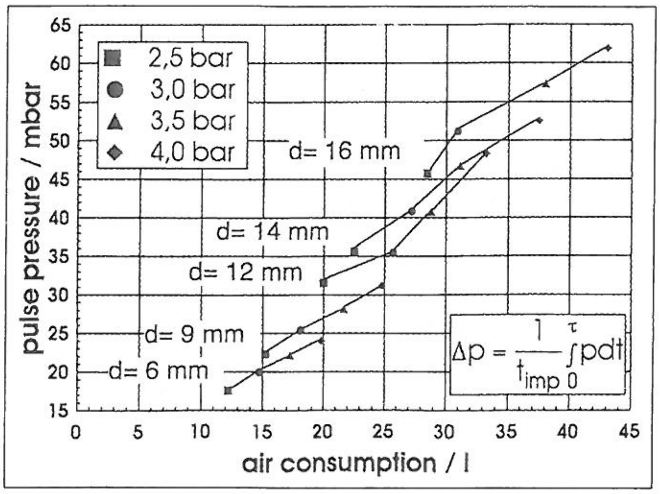

Fig 1: Measured pulse-pressure inside of a ceramic filter element (ambient conditions)

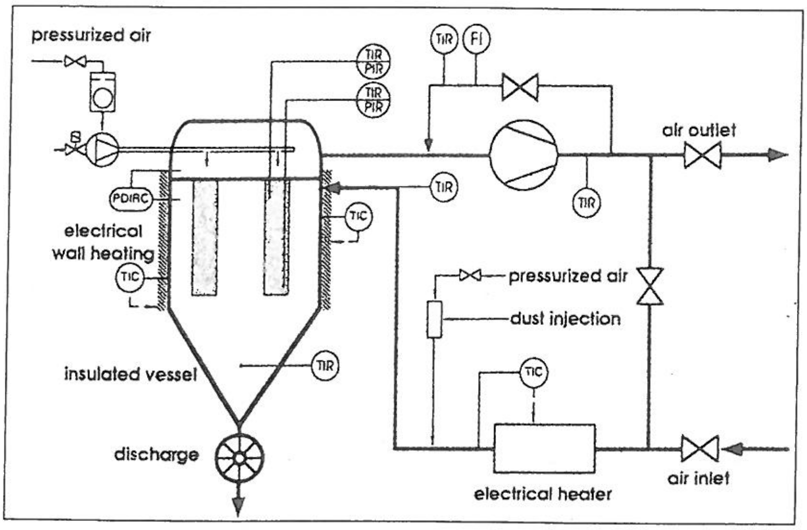

Fig 2: Experimental set-up for high-temperature filtration tests

flow configurations are highly recommended, ie, the gas velocity is directed downwards parallel to gravity. This enhances the transport of particles into the hopper.

Filter elements can be arranged in the well-known standard configuration with the tube sheet and hanging filter elements. This allows easy removal of filter elements from the clean-gas side. A twist-ring arrangement allows 100% dust tight mounting and sealing of filter elements. Special care has to be given to sealing between filter elements and tube sheet as well as between tube sheet and housing. Whereas tube sheets are used in filters for cleaning of several 100 000 m^3/h at temperatures below 250°C, the size of the tube sheets has to be limited at higher temperatures due to the decreasing stability with increasing temperature. For very large applications, therefore, the use of standing filter elements might be more economical since the filter elements can be arranged in 2 or more levels. In this case, detection and shut-off of failed elements is possible during operation.

An important question is the selection of materials of construction. High temperature corrosion, embrittlement and behaviour under long period stressing are most important in applications at elevated temperature. Resistance against high temperature oxidation depends on the formation of dense layers of oxides, especially of Cr-, Si- or Al. Temperature resistance increase with higher content of Cr, in high temperature resistant steels Cr-contents between 19 to 25% are used.

The hopper should be designed with a sufficient angle of inclination bearing in mind that the flowability of the dust at elevated temperature might be reduced. Additional aids for the discharge of dust like rapping devices or pneumatic guns are problematic at high temperature due to stability and due to cooling effects by injection of cold air. Preheating of air is possible. Discharge devices like air locks, double flap sluices or screw conveyors may be used depending on the dust properties and temperature.