Conditioning of filter bags with reactive CaO and $Ca(OH)_2$ dust in flue gas

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Abstract

Gas cleaning from reactive dusts is an issue for e.g. reactive flue gas cleaning processes. Changes in the specific dust volume due reactions are especially challenging for filter media, leading to possible pore clogging and filter media blinding. A conditioning period of 120h of two types of textile filter bags in a reactive atmosphere of artificial flue gas is simulated in an experimental setup at elevated temperature. The evolution of the filter cloth permeability and specific cake resistance are presented. In addition a novel method to determine apparent inhomogeneities of the filter media is applied. For all test series it is found that filtration is possible also in long-term. Although the final cloth permeability after the conditioning is lower for CaO dust than for $Ca(OH)_2$ it is higher than zero and semi-continuous filter operation is feasible with every investigated cloth – dust combination. Interestingly it is found that even an almost new filter cloth exhibits distinctive spatial differences in permeability. The decrease of the mean permeability value must be mainly attributed to a shift of this permeability profile, rather than a homogeneous filter blinding.

Keywords

Filter conditioning, Filter medium resistance, Pulse jet cleaning

1 Introduction

Filtration of reactive dusts is a demanding application for textile filter clothes. Reactive dust particles can deposit inside the filter cloth and onto its surface. A subsequent reaction of these particles, which is accompanied by e.g. an increase in specific volume, can deteriorate the achievable regeneration quality of the filter medium or even lead to full pore blockage, thus impeding further operation of the filter plant.

An example for such a filtration application is the removal of the solid sorbent in dry flue gas cleaning processes [1]. A calcium based sorbent is brought into contact with the flue gas and is eventually removed in a bag filter together with the fly ash. Acidic gas components, which are in most practical processes mainly SO_2 and HCl, react with the sorbent (and with the fly ash) and form a solid product. The residence time of the sorbent suspended in the gas is relatively short – usually in the order of some seconds. Then the solid dust is building up a filter cake on the filter media which is exposed to the gas stream until it is removed during filter cleaning. A typical cycle time for filter cleaning is in the order of 10 minutes [2]. The residence time on the filter cloth itself is relatively long. Thus this solid in the filter cake is exposed to the flue gas allowing the reaction to continue.

In industrial dry flue gas cleaning processes slacked lime $Ca(OH)_2$ is frequently used as solid sorbent. Slaked lime is produced from limestone $CaCO_3$ via burning and subsequent slaking. Slaked lime is relatively stable at atmospheric conditions and exhibits a good reactivity towards the acidic gas compounds compared to limestone. Quicklime CaO, which is the intermediate product of the $Ca(OH)_2$ production, is also reactive towards acidic gas compounds. Its production is cheaper than that of slaked lime, because the slaking step is not necessary. Since quicklime has the lowest molar weight of the three calcium sorbents, quicklime's capacity as a sorbent is maximal based on weight. Hence it might be economically advantageous to use quicklime instead of slaked lime as sorbent. However, quicklime is also highly reactive towards water vapor (slaking) and carbon dioxide (recarbonation). Flue gas is containing both, H_2O and CO_2, and thus quicklime is prone to react:

$$CaO + H_2O \rightarrow Ca(OH)_2 \qquad (1)$$

$$CaO + CO_2 \rightarrow CaCO_3 \qquad (2)$$

The products specific molar volume are for 0.037, 0.033 and 0.017 m^3/kmol for $CaCO_3$, $Ca(OH)_2$, and CaO, respectively. Thus a CaO particle that is fully converted to either of the products must be expected to grow up to a factor of two in volume. When particles are deposited inside the filter media such a severe change in dust volume is expected to have deteriorating effects on the filter media permeability.

This work comprises of the experimental study of the conditioning Optivel® TF and Microvel® needle felt filter clothes with quicklime and slaked lime in a laboratory scale hot gas filtration plant. The experimental data is evaluated to obtain the evolution of the mean filter media permeability and the specific cake resistance over the conditioning period. In addition a novel method is applied to the experimentally obtained pressure drop profiles, which captures the filtration behavior of the filter cloth – dust combination.

2 Experimental setup, procedure, and evaluation

In Figure 1 a flowsheet of the experimental facility is displayed. The artificial flue gas is generated by a commercial natural gas burner. A slipstream of its exhaust is used as sample gas. The sample dust is dosed in a screw conveyor and dispersed in the gas in a nozzle. The pressurized air in this nozzle is preheated to avoid local cold spots and thus possible condensation. The dust laden gas stream is entering the filter housing. Three filter bags are installed and dust is retained by these filter bags. For filter cleaning a jet pulse cleaning unit is installed. The gas is sucked through the filter by an induced draught fan. Online measurements are installed for several temperature measurements (not displayed), the pressure drop over the filter and the volume flow. The latter is measured via the pressure drop over an orifice plate. In addition the dispersion air pressure and the jet pulse tank pressure are recorded.

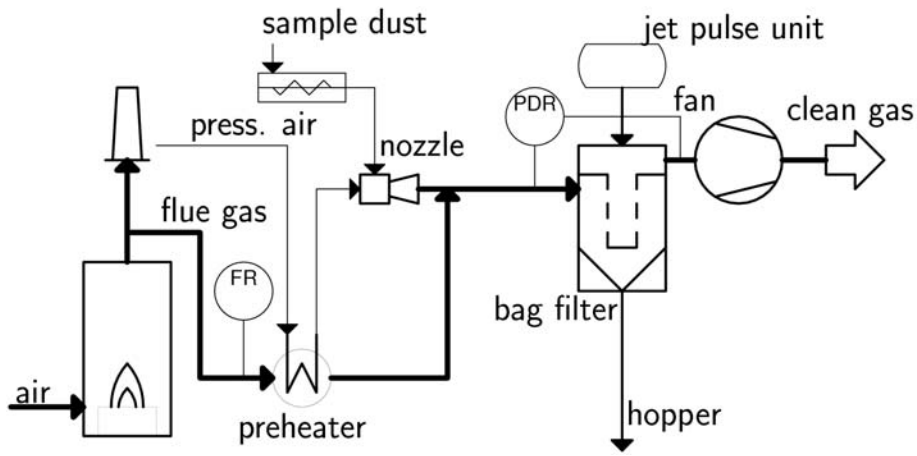

Figure 1: Flowsheet of the laboratory hot gas filtration plant

The characteristics of the plant specification is given in Table 1. The dynamic gas viscosity η_g is a calculated value for the operating temperature and the composition of the artificial flue gas. The last 5 columns in Table 1 are the plant specification and actual values are recorded by the online data acquisition. The filter housing is equipped with 3 filter bags that are 0.47m long and 0.12m in diameter mounted on wire cages. The bags are cleaned by jet pulses exerted in sequence. During normal operation one bag is pulsed after the preset cycle time t_{cycle} has elapsed. In addition a forced cleaning mode is implemented, i.e. the bags are pulsed in short succession to clean the entire filter. The entire plant is insulated and an electrical byheating is installed to keep the operation temperature at the desired level and to avoid local condensation.

A_{tot}	t_{cycle}	η_g	$\dot{V}_{tot}$	T_{op}	Δp - range	$\dot{m}_s$	p_{pulse}
m^2	s	Pa·s	m^3/h	°C	Pa	g/h	bar
0.53	300	$2.0 \cdot 10^{-5}$	35	135	100-600	80	3.0

Table 1: Experimental parameters – filter plant design data

Three experimental test series are carried out. One is carried out with the Microvel® PI + Antafin® cloth and quicklime as sample dust. The cloth is a singed polyimide needlefelt with a PTFE scrim. As in industrial applications the virgin filter clothes which are to be used with quicklime are pre-coated by a short filtration with slacked lime dust. This should fill some of the open pores and impede the subsequent intrusion of quicklime into these pores. Two more series are carried out with an Optivel® TF + Membratex® + Antafin® filter cloth. This cloth is a combined PTFE/PI needlefelt with PTFE scrim and has a PTFE membrane like coating. Again one run is performed using quicklime dust with slacked lime pre-coating. The other run is designed as reference run with slacked lime dust.

A filter cloth conditioning experiment lasts for approximately 120h of semi-continuous operation. Every day during that experimental period the filtration is interrupted to determine filter media permeability and filter cake resistance. Such a test is exemplarily displayed in Figure 2. Dust dosing is stopped and the filter is put into forced cleaning mode until no change in the residual pressure can be observed. Thereafter the filtration is started again by switching on the dust dosing. The subsequent pressure drop increase, termed pressure drop ramp test, is observed without cleaning the filter until a linear pressure drop profile is obtained. Then the dust dosing is stopped again and the filter cleaning control is switched to the forced cleaning mode until no change in the residual pressure drop can be observed. Afterwards the dust dosing is started again and the filter cleaning control is put into the semi-continuous operation mode with constant cycle time.

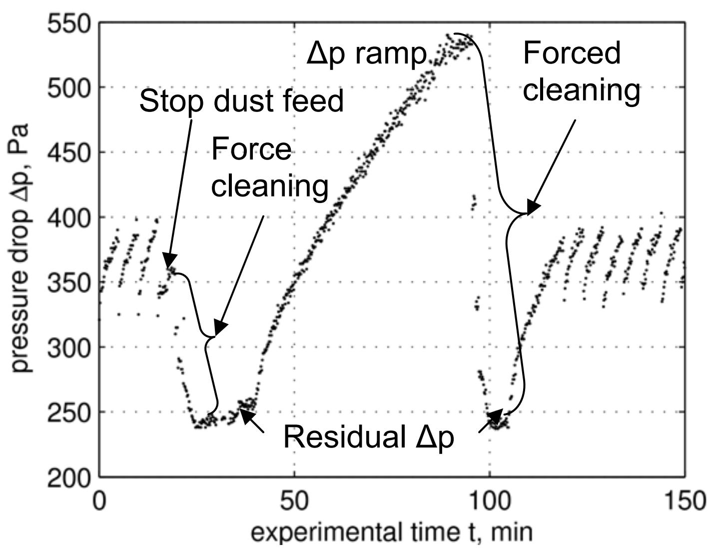

Figure 2: Filter media mean permeability and cake resistance test

The residual pressure drop value recorded during the ramp test can be directly used to determine the filter's residual mean permeability $\bar{k}_0$ in a state when the filter is excellently cleaned, i.e. no further cleaning impact can be achieved. Assuming laminar flow through the filter $\bar{k}_0$ can be calculated by equ. (3) directly from measured data [3].

$$\bar{k}_0 = \frac{\dot{V}_{tot} \cdot \eta_g}{\Delta p \cdot A_{tot}} \tag{3}$$

The linear part of the pressure drop ramp test can be used analogously to determine a specific cake resistance value based on cake mass:

$$\alpha_m = \frac{A_{tot}^2}{\dot{V}_{tot} \cdot \eta_g \cdot \dot{m}_s} \left(\frac{d(\Delta p)}{dt} \right)_{linear} \tag{4}$$

In addition to this analysis via classical cake filtration theory by e.g. [3] a new method to describe the filtration behavior is applied [4]. This method takes the shape of the pressure drop increase during filtration to determine a permeability distribution (PD) of the filter media. I.e. the PD-method accounts for areas on the filter media that have a relatively high permeability because of e.g. big open pores or only little dust cake mass. There can be other areas on the filter media that have a comparatively lower permeability because of e.g. clogged pores or deficient cleaning and thus a higher residual dust cake resistance. In the (integral) mean the PD of the filter medium equals, of course, the mean permeability $\bar{k}_0$. In the course of filtration the areas with relatively higher permeability will experience a correspondingly higher gas flow velocity. Thus cake is building up faster in these locations. The contrary occurs at areas having lower permeability. In the course of filtration the permeability profile will thereby be equalized. In the process of equalization a characteristic pressure drop profile over the filter evolves. By just using basic assumptions of classical filtration theory it can be shown that the pressure drop profile is unique for a certain initial distribution of the permeability, i.e. the pressure drop increase curve is a fingerprint of the permeability distribution of the filter media at the beginning of filtration.

3 Results and discussion

In Figure 3 the specific resistance values over the duration of the experiment in days are displayed, which are determined for the 3 test series. Some variation of the specific cake resistance value can be seen. However, a clear trend of the value over time cannot be observed. Given the fluctuation over time a comparison between the different test series does not show a significant trend. However averaged values on the same filter cloth (Optivel) suggest a slightly higher cake resistance value for slaked lime. Concerning properties of the dust, e.g. cohesiveness, experimentally slaked lime is found to be more difficult to handle.

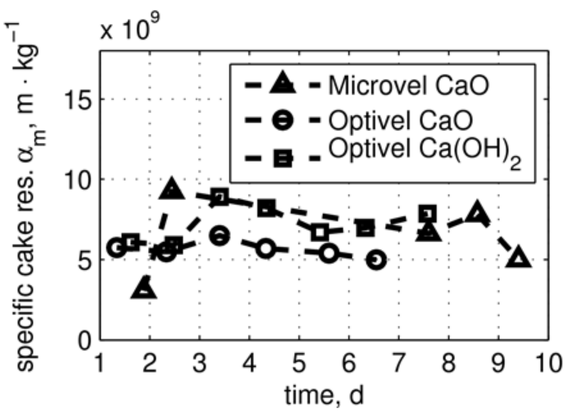

Figure 3: Specific cake resistance values vs. experimental time

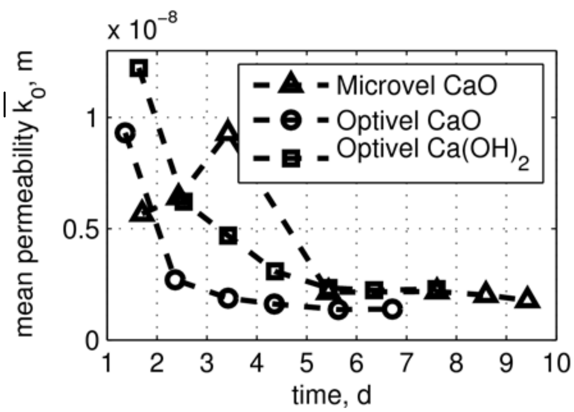

Figure 4: Integral mean permeability vs. experimental time

The evolution of integral mean permeability, in literature the reciprocal value is also referred to as cloth resistance, is displayed in Figure 4. At the beginning of the experiments a steady decrease of the mean permeability for the Optivel cloth is observed. This decrease is leveling out for both the slaked lime and quicklime series. In this series the mean permeability becomes lower when using quicklime which is in accordance with the expectation of a more problematic filtration behavior of quicklime. However, despite a decrease in permeability from the virgin cloth to about 15% a full clogging of the cloth is not observed. The mean permeability levels out at a value significantly above zero.

With quicklime the Microvel cloth does not show the same clear trend of a decreasing mean permeability at the beginning, which might be characteristic to the cloth itself. Chronologically the Microvel test series is conducted first. During initial operation of the test rig some difficulties are encountered, which also might account for the rather wide scattering of the data from the Microvel experiment. Nevertheless, a significant decrease of the mean permeability can also be observed here which is again leveling out at a value above zero.

The intercomparison of the Optivel and Microvel cloth with quicklime dust shows that the mean permeability remains higher for the Microvel cloth. Thus Microvel appears to be the favorable choice for the given application.

The evolutions of the permeability distributions (PD) for the Optivel cloth are displayed for the quicklime series in Figure 5. For the filtration with quicklime one obtains a stepped profile for the almost virgin, i.e. pre-coated, filter cloth (day 1), with a step at about halve of the filter area. This indicates that on pre-coated Optivel the quicklime dust can resolve some significant inhomogeneities on the filter cloth. In the course of the conditioning the permeability values which are found on the cloth do not change strongly, but already at the 2nd day the step in the area distribution is shifted significantly in a way that a much larger share of the total filter area is having the lower permeability value. This shift-trend continues, though not so articulately, throughout the conditioning period. Eventually a filter cloth with less than 8% area with is left high permeability.

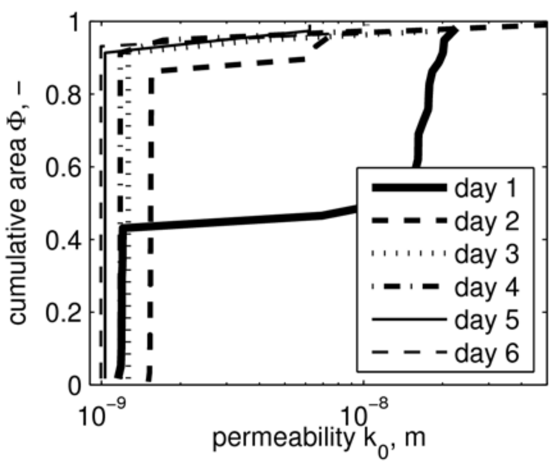

Figure 5: PDs for the Optivel cloth with CaO dust

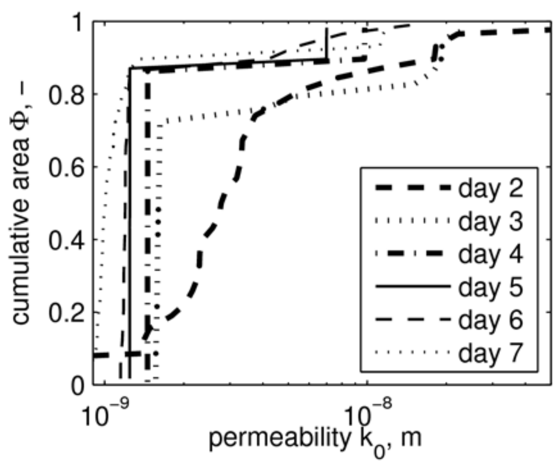

Figure 6: PDs for the Optivel cloth with $Ca(OH)_2$ dust

In Figure 6 for the situation for slaked lime is depicted. The first day of the slaked lime series is not directly comparable, to the 1st day of the CaO test run. The 1st day of the $Ca(OH)_2$ experiment included also the pre-coating period. Thereafter the picture is quite comparable with the situation for quicklime. However, the area of high permeability is only reduced to about 12% and the peak values of permeability observed are higher than in Figure 5. Thus the Optivel cloth is less prone of reducing the fraction of high permeability when $Ca(OH)_2$ is filtered than CaO which could be interpreted by more CaO embedded in the filter cloth or the harmful consequences of the highly reactive CaO dust.

Figure 7 shows the PDs for the Microvel cloth. Unfortunately the determination of a PD is not possible for all days due to experimental limitations. Again, an initially broader PD is converted to a distribution with a large area fraction with an almost constant permeability and only a small segment with a higher one. The remaining area fraction of high permeability is similar to the one observed in Figure 5. For the Microvel cloth the permeability values are higher than for the Optivel cloth, yielding a higher integral value despite that a similar area distribution is observed.

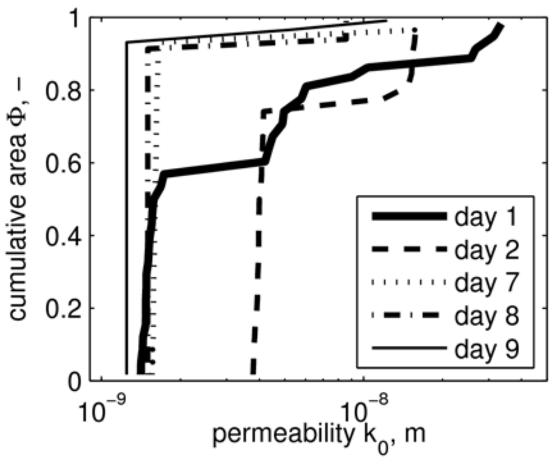

Figure 7 PDs for the Microvel cloth with CaO dust

4 Conclusions

Filtration tests with two different filter clothes and two different sample dusts are carried out at elevated temperature in an artificial flue gas atmosphere to study the filter cloth conditioning period. Specific cake resistance and permeability of the filter cloth are determined during the experiments. In addition the PD-method is applied to the pressure drop data and permeability distributions are determined.

The evolution of the integral permeability values shows a significant decrease during the conditioning. The mean permeability of the cloth operated only with slaked lime remains higher than when using quicklime. But for all experiments it is found that the mean permeability levels out at a value higher than zero. Thus filtration of both, CaO and $Ca(OH)_2$, is possible with the investigated filter cloth – dust combinations. No full filter blocking is observed, although CaO has a stronger tendency for filter blocking than $Ca(OH)_2$.

The investigation of the cake resistance does not reveal a clear trend over the conditioning period. In average a slightly higher cake resistance is found for the slaked lime cake than for the quicklime cake using the same cloth. This indicats more difficult dust properties of slaked lime compared to quicklime.

The PDs reveal additional information concerning these filter conditioning tests: The integral mean permeability is mainly decreasing because the area distribution is shifting. This leads not only to a change in the integral value, but also to a changing pressure drop curve shape from which the PD is determined. For the conditioning with slaked lime a wider span of the PD is found, that yields, despite a rather low integral value, a very sharp initial increase of pressure drop during filtration. This is due to the equalization of an inhomogeneous permeability. Thus in operation the pressure drop levels are higher for filtration of slaked lime also because of a more pronounced inhomogeneous PD than for quicklime.

The authors acknowledge the support of Austrian Energy & Environment AG and MGF Gutsche GmbH & Co. KG namely Mr. Ruoff.

Nomenclature

A_{tot}	total filtration area, m^2
k_0	permeability (cleaned cloth), m
$\bar{k}_0$	integral mean permeability (cleaned cloth), m
$\dot{m}_s$	solid mass flow to the filter, $g \cdot h^{-1}$
p_{pulse}	pressure pulse tank, bar
T_{op}	operation temperature, °C
t_{cycle}	filtration cycle time, s
$\dot{V}_{tot}$	total gas volume flow, $m^3 \cdot h^{-1}$
α_m	specific cake resistance mass based, $m \cdot kg^{-1}$
Δp	filter pressure drop, Pa
Φ	cumulative filter area, -
η_g	dynamic flue gas viscosity, Pa·s

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