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NEW DEVELOPMENTS FOR OPTIMAL SELECTION OF FILTER MEDIA IN FINE DUST BAG- HOUSE FILTRATION

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Abstract
Fine dust, especially those fractions below 10 and 2.5 microns can cause serious heart and respiratory disease and stringently requires effective pollutant standards and methods for their reduction. Therefore stricter emission European Union regulations [1, 2] were recently established, in order to improve the fine dust situation of the ambient air in Europe.
Nowadays among different technical separation devices, filtering, regenerate dust separators are the most suitable ones to meet very low dust emission concentrations of industrial exhaust gases. But the disadvantage of this separator is the relative high pressure drop and sometimes a premature filter media clogging, which requires its costly replacement. In order to minimise this disadvantage, suitable design and standard laboratory test methods are in use. E.g. in Europe a German guideline (VDI 3926) [2] exists, by which in laboratory test runs optimal filter media can be evaluated. The problem is that within these test methods a so called aging procedure is included. The clogging behaviour of the aging procedure was basically investigated in this paper and a new test procedure for comparing different filter media with respect to the aging was developed.

Keywords: Aging chamber, dust removal, filtering dust separator, residual pressure drop.

1. Introduction and problem description

Environmental aerosols and fine dust emissions with their related health impacts are strongly associated with their size distribution and concentrations. Especially fine dust particles below 10 microns are harmful, due to their possible deposition and passage in the thoracic part of human lung airways. Therefore the term PM10 has been used for describing dusty air quality in environment fields. PM10 refers to particles with an aerodynamic diameter smaller than 10 micron, at which value the dust sampler (e.g. impact or with a downstream filtering device) has a 50% sampling efficiency.
In 1999 an EU- Council Directive concerning PM10 [1] emission concentrations was established in Europe (Table 1). Further 2008 a stricter regulation concerning PM2.5 emission was fixed (Table 2) [2].
But up till now the PM10 limit values could not reached by many European countries. E.g Austria has reached the 35 exceedences of PM10 already within the first half of the year. Therefore within the Council Directive 2008/50 EC was also stated, that the fulfilling deadline of PM10 is extended until 1.6. 2011.

Table 1. EU-Council directive 99/30 EC, PM10

24 hour mean limit PM10	Step 1 : since 1.1.2005 50µg/m^3 35 exceedences possible per year	Step 2: since 1.1.2010 50µg/m^3 7 exceedences possible per year
Annual mean limit PM10	Step 1: 40µg/m^3	Step 2: 20µg/m^3

Table 2. EU-Council directive 2008/50 EC, PM2.5

Annual mean target PM2.5	Since 1.1. 2010 25µg/m^3	
Annual mean limit PM2.5	Step 1 since 1.1. 2015 25µg/m^3	Step 2 since 1.1.2020 20µg/m^3

Further more extensive activities have to be taken in reducing the concentrations from dust emission sources in order to fulfil the emission concentration limits.
Among the existing separation devises for dust emissions the filtering device shows the best separation efficiency (Figure 1) which are needed to reach the strict limits. But disadvantageous can be seen the relative high pressure drop and therefore a high energy consumption of this separation device. The reduction of latter is for further research.
Filtering devices used for waste gas cleaning have to deal with relatively high dust concentrations (in the range of 1 to 5 g/m^3) and will be executed by so called cleanable bag house filters (see Figure 2 and 3).

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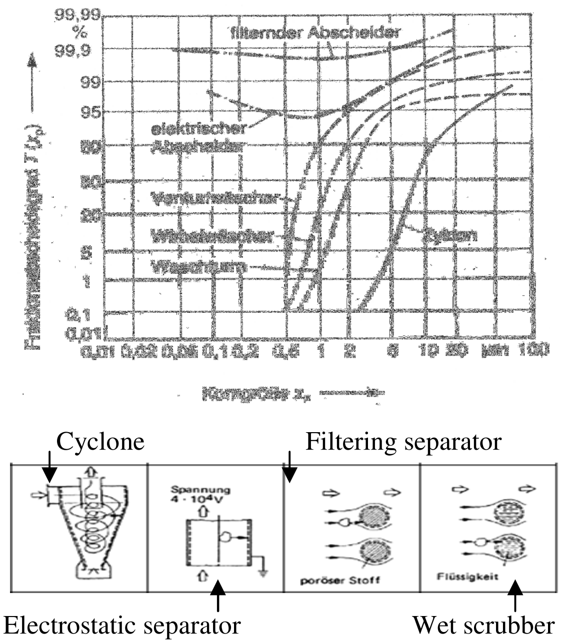

Figure 1. Fractional separation efficiency of different dust separators [3]

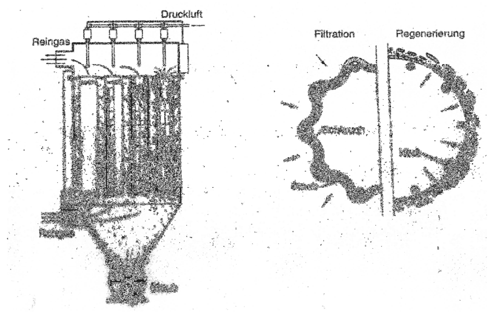

Figure 2. Cleanable bag house filter [3]

The pressure drop arising from the clogging of the filter medium and the back pulse air consumption, coming from a pressurised tank, are points which should be reduced concerning energy consumption [4].

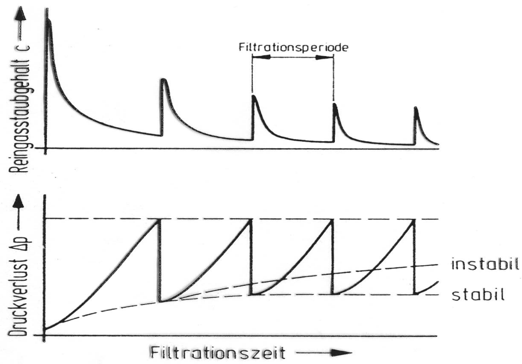

Figure 3. Pressure drop and concentration over time for a bag house filter [3]

In order to choose the right filter medium for a bag house filter in a large scale (filter medium area in the range of 1000m^2 or more), which should have a low pressure drop and therefore a low energy consumption, suitable measurement in a very small scale (filter area 0.02 m^2) are usually executed with standard test equipments (e.g: JIS Z 8909-1, Figure 4, VDI 3926, Figure.5, ASTM). Measuring parameters after a certain number of filtration cycles for comparing filter media are the residual pressure drop, the cycle time, the dust loading in the filter medium and the average clean gas concentration.

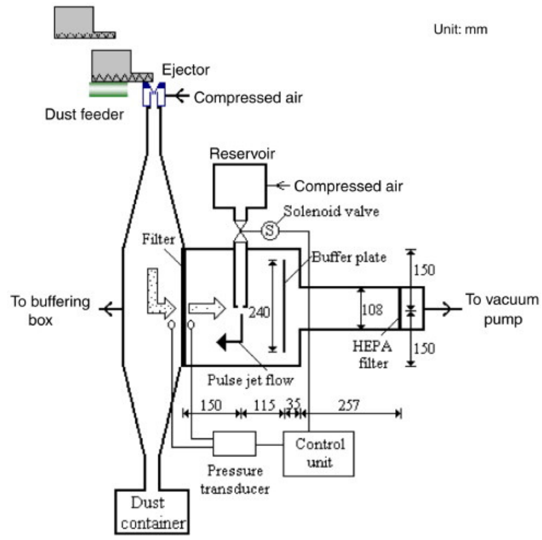

Figure 4. Japanese test standard JIS Z8909-1 [5]

Key operation of these tests is the aging of the filter medium. By the accelerated aging within the test procedure the filter medium is transferred in a short time into a state, which corresponds to a one or two years lasting industrial operation time. After this aging procedure the filtration behaviour of different filter media should be tested and compared.

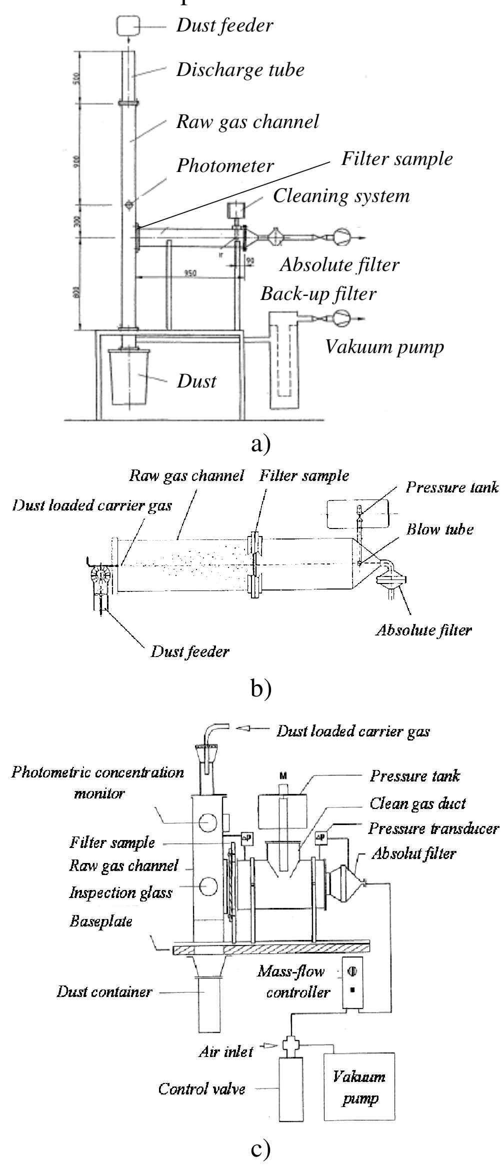

Figure 5. German test standard VDI 3926 [6]
a) Typ I, b) TypII, c) Typ III

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The problem up till now is to find a suitable aging procedure.
The first attempt was made by operating with very short and constant cycle times, e.g. 5 sec, and to operate up to 10.000 regeneration cycle number. With this procedure an industrial operation time of one or two years, which operates normally with a cycle times of 10 to 20 minutes, can be simulated in a short time [6]. Binning et al. found out, that 5 seconds is to short and should be longer, more than 15 seconds [7]. An ISO draft standard version (ISO/CD 11057, Table 3) with 20 seconds cycle time is at the moment under investigation [8].
Concerning the uncertainties about the aging behaviour the clogging mechanisms during the aging procedure were investigated in more detail [9]. For this purpose a new laboratory aging chamber was built by in cooperation with the company PALAS, Karlsruhe Germany (Figure 6).

2. Aging Chamber

The aging chamber consists of a vertical round flow duct of approx. 2 m length with a horizontal test filter holder which is situated approx. in the middle of the duct, and which holds a flat round (d=15 cm) filter sample.
The raw gas part is situated under the filter media and it is closed on the bottom by a dust collecting hopper. The dust injection probe and the opening for the air supply are situated above the dust collecting hopper. By means of a fan the dust containing gas is filtered through the filter, and the dust cake is formed on the raw gas side. The dust is dispersed by a dust dosing feeder into the injection probe. The dust dosing feeder is able to deliver a constant mass flow over long time periods. The necessary dust concentration of 5 g/m^3 will be determined and verified by differential weighing of the deposited dust and the measurement of the volume flow over the time.

As test dust Pural NF with a mean particle size of $d_{50,3}$= 4 µm is used. Above the filter medium a cleaning unit is situated which has been built according to VDI 3926 standard Typ 2 [6]. The cleaning unit consists of a pressure tank, a fast opening membrane valve with adjustable valve opening time and a blow pipe. The cleaning unit consists of a pressure tank, a fast opening membrane valve with adjustable valve opening time and a blow pipe. The only difference to the VDI Typ 2 clean gas part is the conception of the clean gas room, the room between the filter media sample and the absolute filter. The clean gas room is approx. 1,8 times larger, than that in the Typ 2 apparatus. The cleaning impuls is fixed by a certain valve opening time and tank pressure. The tank pressure can be varied from 0,4 to 0,6 MPa and the valve opening time can be varied from 50 to 150 ms.

The cleaning is done in a time controlled manner whereas cycle times from 5 s upwards can be adjusted. A mass flow controller is used for measuring and adjusting the volume flow, whereas velocities from 1 to 3 m/min can be adjusted. An absolute filter is built in between the Filter media and the fan in order to determine the mean clean gas concentration over the aging time. The pressure drop over the filter media and the volume flow are continuously measured and recorded.

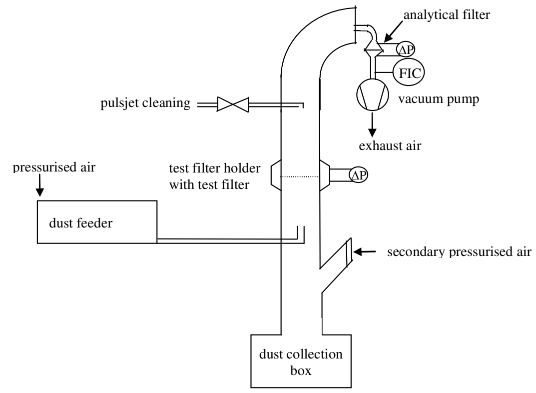

Figure 6. Aging chamber

Table 3. Sequence of test phases [6, 8]

Measuring phases	Conditions		
	VDI 3926 (1994)	VDI 3926 (2004)	ISO/CD 11057
Phase 1: Conditioning	no	30 loading cycles with differential pressure controlled pulse-jet cleaning (1000 Pa)	30 loading cycles with differential pressure controlled pulse-jet cleaning (1000 Pa)
Phase 2: Aging	no	**10000** pulse-jet cleaning cycles at an interval of 5 s each	**2500** pulse-jet cleaning cycles at an interval of 20 s each
Phase 3: Stabilizing	no	10 loading cycles with differential pressure controlled pulse-jet cleaning	10 loading cycles with differential pressure controlled pulse-jet cleaning
Phase 4: Measuring	Type 1: 100 loading cycles (1000 Pa) Type 2: 10 loading cycles (1200 Pa)	30 loading cycles minimum with differential pressure controlled pulse-jet cleaning, but at least 2 h	2 hour loading cycle with differential pressure controlled pulse-jet cleaning (1000 Pa; 1800 Pa)

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3. Aging tests

In order to accelerate the clogging behaviour and to see where the pressure drop development and the clogging finally leads, the face velocity was set to a relatively high value of 2.5 m/min and the cycle time was chosen of 100 s (Figure 7). As filter medium an industrial often used P84 needle felt was used. This test was done without a preconditioning phase.

It can be observed that the pressure drop limits (Pressure drop before cleaning, residual pressure drop) show a steep increase at the beginning, which is due to the embedding of dust inside the filter media because of depth filtration. Afterwards the pressure drop limits show a more moderate increase because the depth filtration is mostly replaced by surface- and cake-filtration, which has as consequence that the deposited dust is removed more efficiently by the cleaning pulse. After approx. 23 hours occurs a sudden increase in pressure drop which indicates a total filter media clogging. The upper and the bottom pressure drop limit show a s-shaped trend over the test time. In order to investigate the influence of the cycle time on the clogging behaviour of the filter medium, cycle times between 15 seconds and 280 seconds were tested (see Figure 8). The tests were executed with a filtration velocity of 2.5 m/min and as a filter medium an industrial often used P84 needle felt was used. The tests were done also without a preconditioning phase.

Due to the time controlled cleaning, which cleans the filter medium by back pulse after each fixed time interval, a pressure drop band between the maximum pressure drop and the residual pressure drop just after cleaning is visible in Figure 8 for each tested cycle time.

It can be seen for all tests, after a certain test time like in Figure 7 a total clogging respectively a very progressive pressure drop increase occur. For short cycle times this pressure drop increase occurs after a long test time and with increasing cycle time the corresponding test time gets shorter. Further the band width of the pressure drop band becomes broader with increasing cycle times.

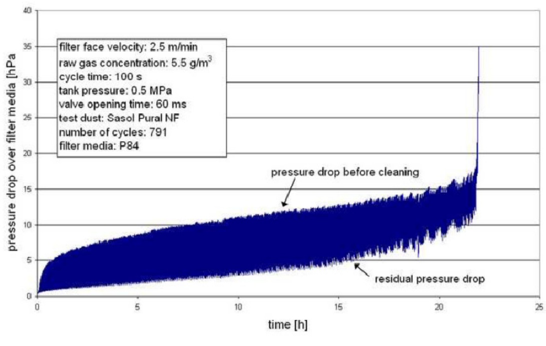

Figure 7. Pressure drop over time for an aging test (100s cycle time, 2.5 m/min filtration velocity)

Further tests were executed for a constant cycle time of 100 second and different filtration velocities and for two different valve opening times of the back pulse valve (Figure 9). For higher filtration velocities the progressive pressure drop increase is shifted to shorter filtration times and for higher valve opening times the progressive pressure drop increase is shifted to longer filtration times and higher pressure drops.

4. Physical mechanism during the aging procedure

If from the test run with 100 seconds cycle time, 2.5 filtration velocity and 60 ms valve opening time the pressure difference between the residual pressure drop and the maximum pressure drop is depicted over the time, it results Figure 10. This curve with a maximum represents the change of the cake pressure drop over the test time, which contains also a change of the separation mechanism.

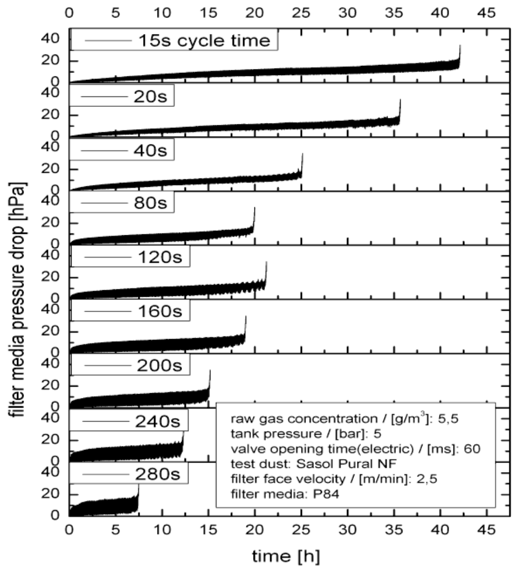

Figure 8. Pressure drop behaviour during the aging procedure for different cycle times [9]

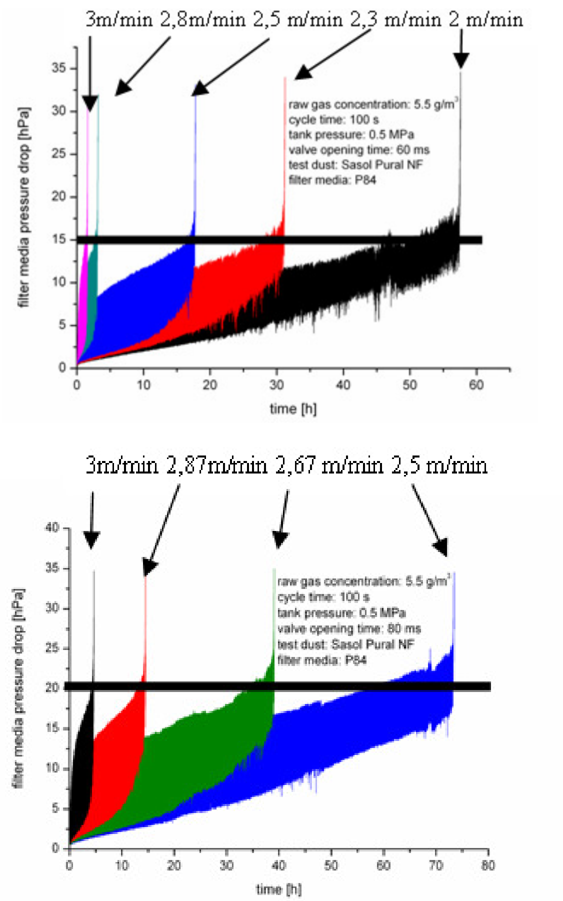

Figure 9. Aging test with different filtration velocities and two valve opening times

During the first filtration cycles most of the particles are separated due to depth filtration, which is indicated by a low, concave pressure drop increase over the whole cycle time of 100 seconds (see Figure 11a). With further test time e.g. during the 400th cycle the separation mechanism has changed to a so called "patchy cleaning"-mechanism (Figure 11b) inside the filter medium.

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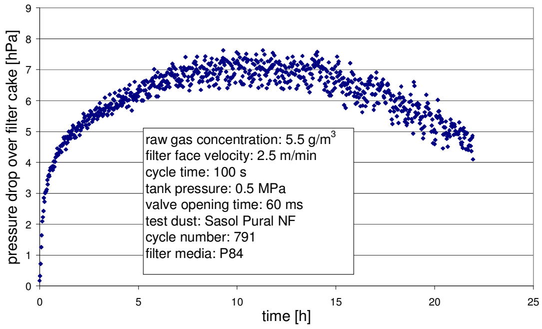


Figure 10. Cake pressure drop over the test time

By that way inhomogeneous dust depositions have been already developed inside the filter medium, which produces flow channels over the filter area, in which the gas flows through the filter medium with higher velocities. These flow channels will be preferably filled up with dust particles with an initially high pressure drop increase at the beginning of the cycle. After equalizing the dust mass over the filter area the pressure linearly increases with low increase. With further filtration cycles the channel like structure is becoming more homogeneous, so that a constant pressure drop slope over the whole cycle time creates a low total pressure drop over the cycle time again (750th cycle, Figure 11c).

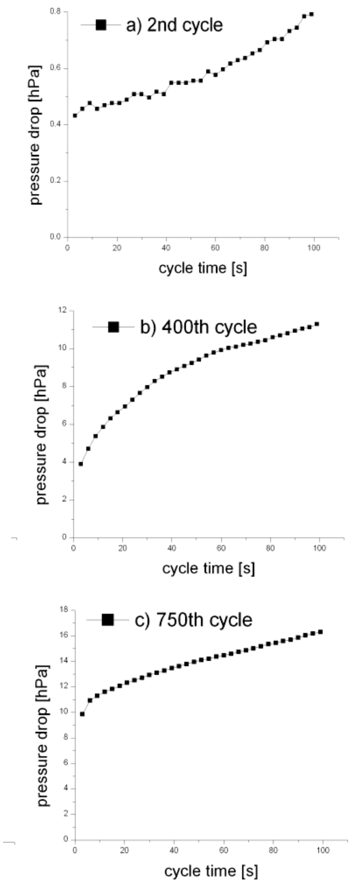
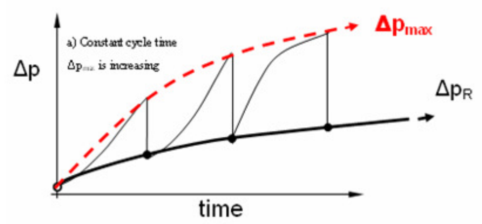
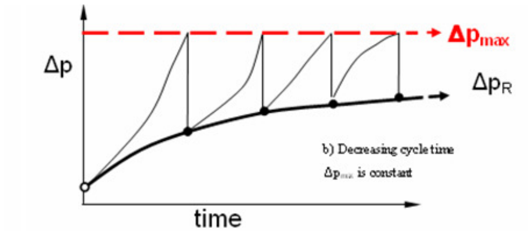


Figure 11. Pressure drop increase versus cycle time for an aging test with 2.5 m/min filtration velocity and 100 s cycle time
a) depth filtration phase,
b) “patchy cleaning” phase inside the filter medium,
c) phase with constant slope

Usually filter cleaning are pressure controlled executed (Figure 3 and Figure 12b). By that way if a certain maximum pressure drop Δp_{max} is reached, the cleaning by back pulse takes place and the pressure drop decreases to the residual pressure drop Δp_{res}, which increases with increasing number of filter cycles. This implies that the cycle time decreases with increasing cycle numbers. The aging tests are always executed with constant cycle times over the whole test time For constant cycle times the maximum pressure drop Δp_{max} will be not any more constant, but increases with further cycle numbers (Figure 12a).



a) Constant cycle time: Δp_{max} is increasing



b) Decreasing cycle time: Δp_{max} is constant

Figure 12. Pressure drop development over time
a) time controlled cleaning,
b) pressure controlled cleaning

The vacuum pump, which has to overcome this increasing maximum pressure drop by constant gas flow, produces accordingly to the increasing maximum pressure drop an increasing vacuum at the clean gas side. As counterpart to this development the back pulse cleaning nozzle injects a nearly constant pressure pulse volume, which changes the under pressure at the clean gas side for a short time to an over pressure (Figure 13). This over pressure is responsible that the cake will be thrown away from the filter medium. As Figure.13 shows, with increasing under pressure, respectively maximum pressure drop, this over pressure becomes smaller with increasing test time, until no overpressure can be created any more. This is then the time point, where the filter cake can not be detached from the filter medium any more, and a progressive pressure drop increase occurs.

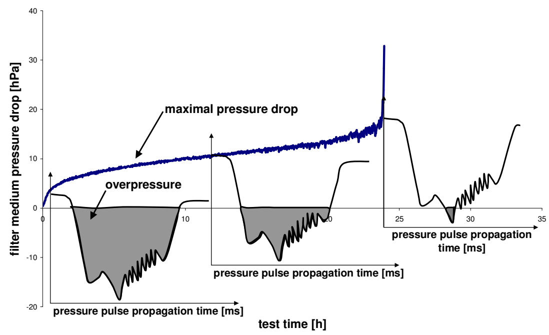


Figure 13. Pressure drop during cleaning by back pulse at different test times

5. New method for comparing the filtration behaviour of different filter media

Therefore another idea is to use the time interval from the beginning of the test until this progressive pressure drop increase (named as characteristic aging parameter) occurs for a comparable characterisation of the long time clogging behaviour of different filter media (Figure 14) [10].

Characteristic aging parameter

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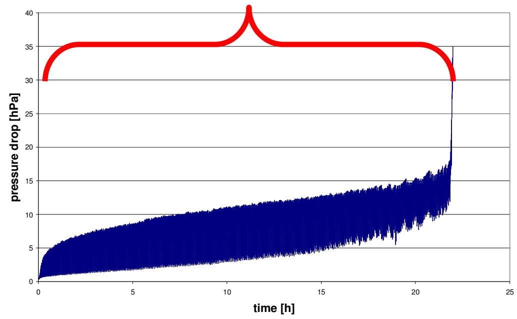

Figure 14. Characteristic aging parameter

When comparing different filter media all test parameters except the filtration velocity should be kept constant. As the filtration velocity is also a key parameter for designing the area of the filter media and the relative clogging behaviour could also change with the filtration velocity, the characteristic aging parameter should determined for different velocities (aging line), which is shown in the upper diagram of Figure 15. As can be seen in the diagram at low velocities usually the characteristic aging parameter is comparatively high and needs much test time. To save test time, the tests can be started with high velocities, going down to lower velocities and could be further extrapolated to small velocities, which must not be tested.

Further, as can be seen in Figure.6 between the filter sample and the vacuum pump an analytical filter is situated, by which all particles which pass the tested filter medium are collected.

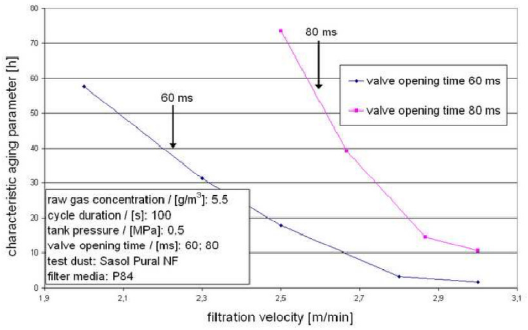

Figure 15. Characteristic aging line for different filter media

After the end of a test run, relating this collected particle mass to the total filtered gas volume a mean clean gas concentration can be calculated, which is then determined also for different filtration velocities (see Figure.16, middle diagram). In the same way the residual dust mass of the filter sample related to the total gas volume is shown in Figure 16 (lower diagram).

With these three diagrams the filtration performance of different filter media can be estimated.

Looking at the filter media in Figure 16 the filter medium FM2 shows the best performance, long filtration time until clogging occurs, which implies also low energy consumption, low clean gas concentrations and low residual dust mass in the filter sample.

6. Conclusion

To select a suitable filter medium standard test facilities are available. The test procedures includes a so called aging period, by which the filter medium is brought into a state, which is equivalant to one which was long in operation. The work in this paper could clear up the up to now unknown physical clogging mechanism during the aging period. The results can be further used for better planning and design of the aging procedure in standard filter testing.

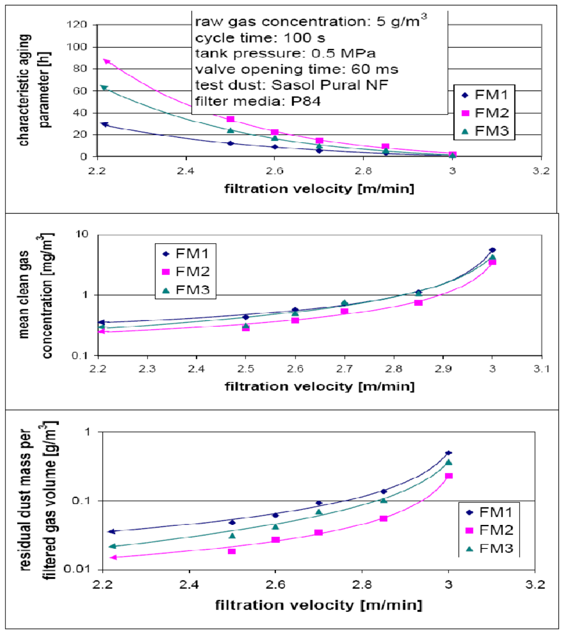

Figure 16. Characteristic aging parameter, mean clean gas concentration and residual dust mass per filtering gas volume for different filtration velocities

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