Testing and selection of filter media for dedusting

Part 1: Standard laboratory tests in acc. with VDI/DIN 3926

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The VDI/DIN guideline 3926 „Testing of cleanable filter media" is an important step towards improving the characterisation and assessment of cleanable filter media. Since its introduction in December 1994 and the amendment in October 2004, both the testing method as well as the test equipment are widely used throughout Europe and meanwhile also applied in Japan, China and the USA. Especially in the USA, the guideline was largely integrated into the ASTM D6830-02.
The VDI/DIN guideline 3926 offers the possibility of comparative testing of cleanable filter media under exactly defined and controlled laboratory conditions. However, the results cannot be applied directly to asses a medium's suitability for a specific task or to obtain data for the design and optimisation of a filter system. The guideline does not expressively cover this either.
Therefore, in a further step, a mobile filter probe for the performance of „field tests" was developed as a derivation of the technology applied in the laboratory. With this technology, which will be introduced further down in this essay (see part 2), it is possible to obtain data required to assess the suitability of a medium for a specific application and improve the design of a filter system or optimise plant operation.

1. Introduction

Due to its outstanding separation properties – also in the fine particulate matter range – cleanable filters are very common in almost all exhaust gas dedusting applications and for the separation of dust-like valuable materials and products obtained from gasses. Due to extensive experience in this field, it is today possible to realise economic operation of the filter systems – also in difficult cases – and sufficient filter media service lives in practice. However, extensive pilot tests or a „development on the project" are often required.

The long-term operating behaviour of cleanable filters depends on numerous plant, operating and substance parameters. The effects of the individual influencing factors are closely linked to each other, but often hard to distinguish. In this context, some of the relevant system parameters concern the constructive design of the filter system (e.g. number of filter chambers, design of the dirty gas flow control, geometry of the filter elements), others the layout and operating mode of the cleaning system (e.g. on or offline cleaning, design of the venturi insert, high or low-pressure system). Operating conditions, e.g. filter face velocity, average temperature and temperature peaks as well as dew point shortfalls, have a decisive influence on the filtration and cleaning behaviour. Important substance parameters in this respect are the composition of the gas to be cleaned (e.g. steam content or acidy gas component concentrations), the agglomeration properties and reactivity of the dusts to be separated and especially their particle size and particle size distribution.

The selection of the filter medium, however, takes up a special position in system planning, and is often still based on empirical criteria these days. Although the characterisation of cleanable filter media and possibility of their evaluation were improved in the meantime, this is still not sufficient. The material-specific or textile data as well as data concerning particle separation („BIA test" resp. DIN EN 60335-2-69) usually communicated by the manufacturers and data on the pressure drop of the new filter media does not provide enough information about their long-term filtration behaviour.

The present situation is that cleanable filters have achieved a high stage of development with respect to filter technology, and can be applied for sophisticated separation tasks. However, filter media selection methods and system design have hardly evolved beyond the 'trial and error' stage, which is unsatisfactory. At present, a model-assisted design of the filters and above all of the cleaning properties, which considers the substance-specific data of the dusts (e.g. their cohesive and adhesive properties) is not yet possible. Therefore, it is still necessary to improve both the characterisation and evaluation of cleanable filter media with respect to their long-term operating behaviour as well as the collection of data for the design of filter systems.

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2. Testing of filter media in acc. with VDI/DIN 3926

2.1 Development of the test method and objective

Already at the start of the 1980s, filter media manufacturers, plant operators and constructors started demanding improved methods for the characterisation and evaluation of cleanable filter media. This demand concerns data allowing statements about the filtration properties of a medium in long-term operation, which exceeds the data supplied by filter media manufacturers about the non-dusted material. The underlying question concerns the correlation of the „textile" and the filtration properties of a filter medium, to which there are no standard answers yet.

The VDI/DIN guideline 3926 „Testing of cleanable filter media" in the original version /1,2/ is an important step towards improving the characterisation and rating of cleanable filter media. This is achieved by a comparative evaluation in a standard test based on the results of long-term tests including the periodical filtration and cleaning process. With this test, it is supposed to be possible to test almost all filter media qualities.

Examinations concerning the suitability of a medium for a specific task or obtaining data for the design or optimisation of a filter system are expressively not part of the guideline. This concerns e.g. measurements at changed filter surface loads and tank pressures, high temperatures (with heatable systems) and/or with special dusts (originating from

a certain system, for example). Such measurements have been performed in laboratories for a long time, whereby it needs to be considered that the value of the data thus obtained for a system layout or optimisation essentially depends on the skill and experience of the tester. It must be pointed out that although it is possible to gain important insights in a laboratory, it is usually only possible to approximate the dirty gas conditions of a 'real' system here. This concerns both the gas composition (e.g. the share of acidy gases, condensing gas components, steam content) as well as the dust properties of the redispersed dusts (e.g. particle size distribution, particle matter content, agglomeration behaviour, surface properties). Still, testing in the laboratory can significantly reduce the efforts of extensive pilot tests.

However, in case of precise system-specific questions, it is advisable to perform the measurements with a mobile system on-site. To perform such „field tests", a mobile filter probe was derived from the measuring equipment in VDI/DIN 3926 and developed to market maturity. The plant engineering, measuring methods and the resulting possibilities will be discussed in part 2, which will be published later on.

2.2 Current amendments and further developments of the guideline

Since 1998, a work group chaired by the VDI/KRdL has revised the VDI/DIN guideline 3926, Page 1 „Testing of cleanable filter media". Initially, the work group asserted that after several years of experience with the guideline and the test method as well as with the test apparatus type 1, both the measuring method as well as the test apparatus had generally proven its value. However, subsequent to an operator congress in June 1999 /3/, the guideline was nevertheless revised and adapted to the current requirements. Essential modifications concerned the selection of one single test dust (Pural NF), the reduction of the filter face velocity from 3 to 2 m/min as well as the introduction of a permanent load phase („ageing") consisting of 10,000 time-controlled cleaning operations. The whitepaper was approved in December 2002 after inclusion of the objections to the outline and has been subjected for approval in October 2004 /4/.

In this context it is interesting that the plant engineering (test stand type 1) and largely also the measuring methodology of VDI/DIN 3926 were adopted in the USA in the scope of an EPA ETV project. The long-standing experiences resulted in the ASTM standard D6830-02 /5/ (published in 2002), in which the test apparatus was adopted without any changes and supplemented with an impactor. The measuring methodology was only slightly modified.

At present, an ISO standard is being developed, which largely orients itself on VDI/DIN 3926. The test stand in acc. with VDI/DIN 3926 type 1 was defined as reference system. A project proposal was included to this respect in July 2007 (New Work Item Proposal) in ISO TC146/SC1. After a positive vote, the project was approved in 2008 for registration as a committee draft (CD) for a new standard ISO 11057.

3. Standard test for cleanable filter media

The laboratory filter test apparatus in acc. with VDI/DIN guideline 3926 allows permanent long-time measurements on round, even filter samples under exactly defined and controllable test conditions with respect to filter face velocity, concentration and particle size distribution in the dirty gas dust as well as cleaning conditions. It allows the periodical cleaning of the filter

samples during automated operation and with fast sample change. The filtration and cleaning conditions can be programmed in such a way that they are comparable with the 'real' conditions in filter systems. The experiences gained with this test apparatus over several years show that the results and measured trends match the experiences gained in practical application /3, 6, 7/.

Illustration 1 shows the proven construction design of the apparatus. To create the dust-charged gas flow (dirty gas flow), test dust is added evenly in exactly defined quantities to the ambient air sucked in at the top end of the dirty gas channel with the help of a dust feeder. This dirty gas flow is guided downwards and mixed, whereby a defined partial flow is sucked into the filter sample aligned flush in the channel wall. This results in the build-up of a filter cake on the filter, which is cast off with a defined pulse of compressed air from the clean gas side once a defined pressure drop is reached on the filter sample, without having to interrupt the suction.

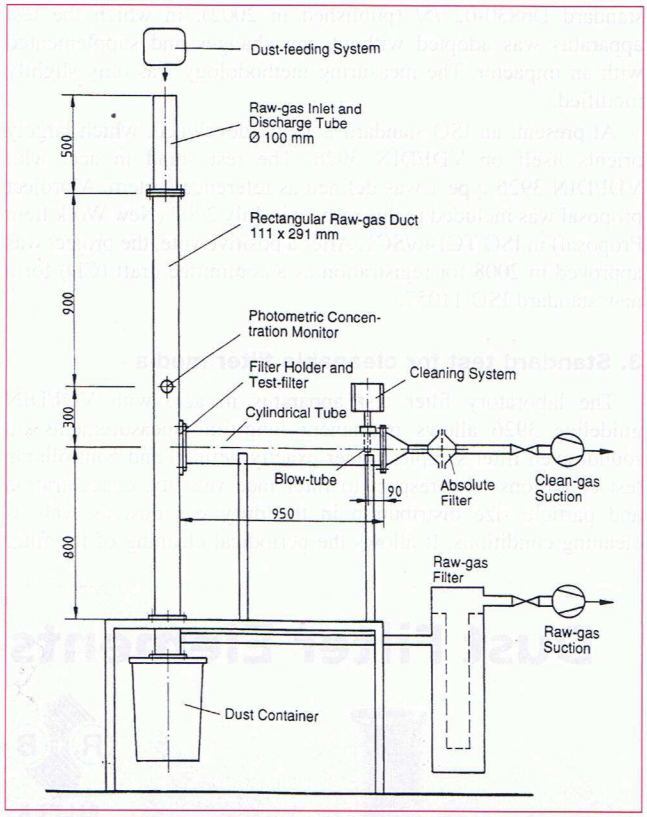

Fig. 1: Laboratory test apparatus (type 1) acc. to VDI/DIN guideline 3926

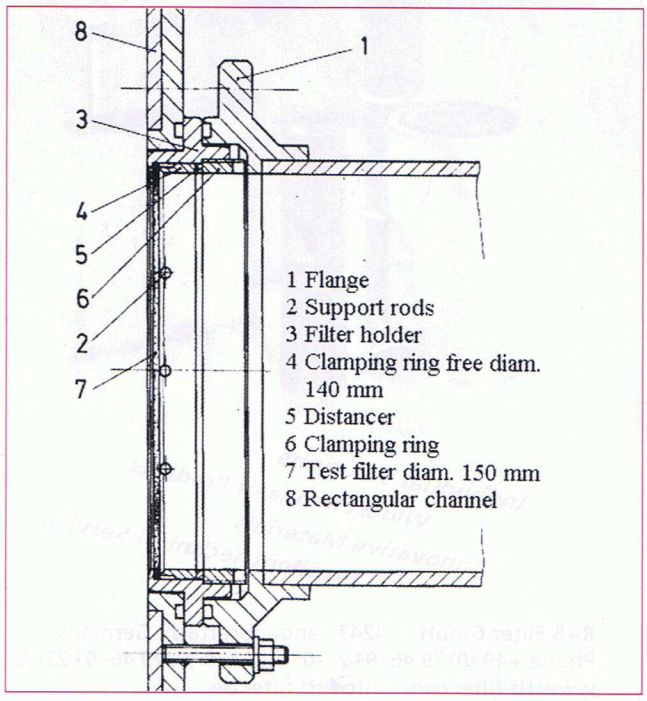

Fig. 2: Filter holder with clamping for the test filter sample

The essential components of the test apparatus are:

- The continually operating dust dosing and dispersion system (dust feeder) /8/, which allows long-time tests with only minor maintenance and operating efforts,
- A cylindrical dirty gas feed pipe connected to the dirty gas channel with its rectangular profile. This pipe can optionally be fitted with a Kr85-β-radiation source for discharge of the dusts electrostatically charged due to the dispersion,
- The vertical dirty gas channel with a rectangular profile of 300 x 120 mm,
- Photometric concentration measuring directly above the filter sample for monitoring the concentration and dispersion of the test dusts in the dirty gas,
- A cylindrical, horizontally aligned suction pipe with the filter retainer (free diam. 140 mm), which ensures the flush installation of the filter sample in the wall of the dirty gas channel,
- The cleaning system consisting of a pressure tank with integrated solenoid valve and a blow pipe with an axial blow hole (with reference to the suction pipe) and controlled by a measuring computer,
- An absolute filter aligned in the clean gas extraction for gravimetric determination of the clean gas concentration and
- The dirty gas extraction with inertial separation, dust store and final filter.

The illustrated layout with vertical dirty gas flow and partial horizontal flow through the filter sample was deliberately chosen because it has decisive advantages compared to other systems. These are:

- The cross-flow alignment of the test filter resembles the situation in technical filters as tests by Sievert /9/ have shown, and allow the build-up of realistic filter cakes (see chapter 4),
- The vertical dirty gas channel with horizontal extraction offers a sufficiently long mixing path for generating a homogeneous dust load in the dirty gas and thus exactly defined and reproducible dirty gas conditions,
- Setting of the gas conditions is independent of the gas volume flow through the filter sample, so that the dust feeding system can always be operated under optimum conditions,
- During cleaning of the filter, both the detached filter cake as well as the redispersed particles are removed from the flow in the filter area and do not impair the measurement of the progression of the pressure drop and the remaining (residual) pressure drop,
- The cleaned off filter cakes and dusts redispersed during cleaning are separated in clearly defined sections, which allows error-free long-time operation. Exhaustive and extensive measurement interruptions to remove dust deposits are not required.
- Cleaning of the system in case of a dust change is pretty simple and merely requires knocking off and vacuuming the dirty gas channel.

Exactly defined dirty gas conditions are important, especially when measuring the residual pressure drop, meaning the pressure drop of the cleaned filter sample directly after cleaning. In the end, these can only be realised by sucking off the dirty gas on the bottom end of the system. Redispersed dusts that are not directly removed around the filter sample are otherwise collected again in an uncontrollable fashion and result in systematic excess measurement of the residual pressure drop values.

Fig. 2 shows the filter holder that must be accurately weighed together with the filter sample to determine the dust quantity

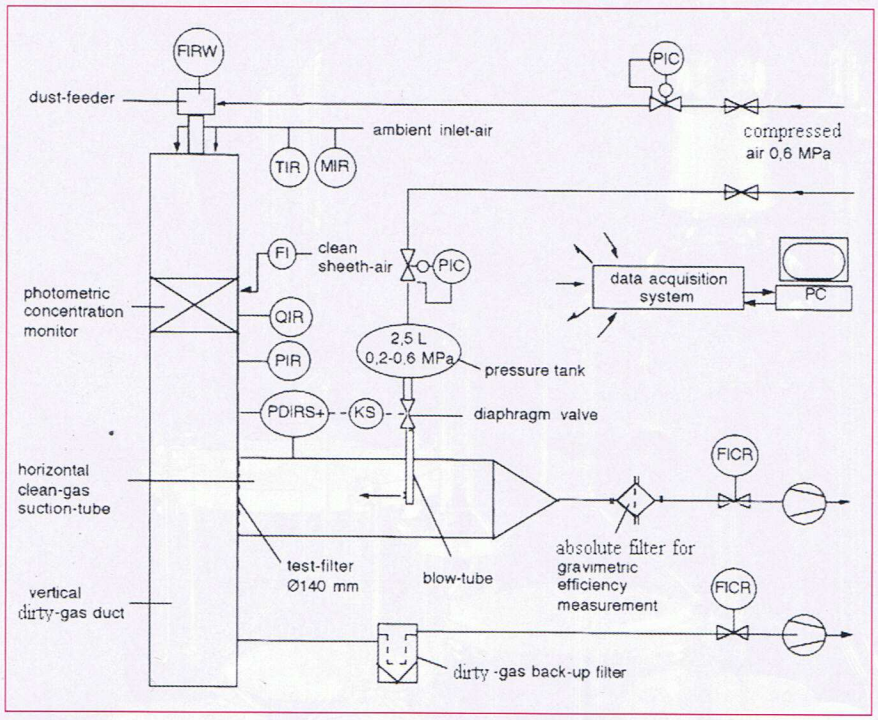

Fig. 3: Diagram of the test apparatus' measuring and control technology
Icons and code letters in acc. with DIN 19227

FI	=	*Flow indicator*
FICR	=	*Self-acting flow indicator and control with registration*
FIRW	=	*Measurement, indication and registration of the dust quantity flow*
KS	=	*Timer with non-continuous control*
MIR	=	*Humidity sensor, indication and registration*
PDIR	=	*Differential pressure indication and registration*
PDIRS+	=	*Differential pressure switch and indication*
PIC	=	*Self-acting pressure control and indication*
PIR	=	*Pressure indication and registration*
QIR	=	*Concentration measurement, indication and registration*
TIR	=	*Temperature indication and registration*

Table 1: Settings for a standard test in acc. with VDI/DIN 3926 amended in 2004

Primary test parameters and tolerances

Parameter	Unit	Target value	Tolerance
Filter face velocity	m/min	2	± 3 %
Dust concentration near the filter	g/m³	5	± 10 % *)
Test dust		Pural NF	mps approx. 4,5 µm
Pressure drop prior to pulse-jet cleaning	Pa	1 000	± 1 %
Excess tank pressure	MPa	0,5	± 3 %
Valve opening time (electric)	ms	60	

*) in ISO 11057 – changed to 7 %

Table 2: Progress of a standard test in four phases

Sequence of the standard test phases

Measuring phases	Conditions	Determination of clean-gas concentration
Phase 1: conditioning	30 loading cycles with differential pressure controlled pulse-jet cleaning and a cleaning set-point of 1.000 Pa	yes
Phase 2: ageing *)	10.000 pulse-jet cleaning cycles at an interval of 5 s each	no
Phase 3: stabilizing	10 loading cycles with differential pressure controlled pulse-jet cleaning	no
Phase 4: measuring	2 hour loading cycle with differential pressure controlled pulse-jet cleaning and a cleaning set-point of 1.000 Pa	yes
Phase 5: optional measuring **)	2 hour loading cycle with raised cleaning set-point of 1.800 Pa	yes

*) in new ISO 11057 – 2.500 cleaning cycles at an interval of 20 s each
**) only in new ISO 11057, not in VDI/DIN 3926

without having to remove the filter sample. The exposed filter surface has a diameter of 140 mm, the filter sample a diameter of 150 mm.

The two extracted volume flows (vertical and horizontal) are selected in such a way that their sum is larger than the sum of the air quantities supplied via the dust feeder and the photometer purge air. The dust feeding is set in such a way that a dust concentration of 5 g/m³ results in the dirty gas with respect to the volume flow sucked in through the test filter. The setting of the feeder, meaning the dust mass flow rate to be dosed and dispersed, is defined by weighing the separated dust cake load on a filter sample after cleaning a specific gas volume. The filter face velocity is kept constant and amounts to 2 m/min in standard cases, which corresponds to an air-to-cloth ratio of 120 m³/(m²/h) calculated with actual values.

The differential pressure on the filter is measured and recorded continuously. Cleaning by means of a pressure pulse in case of exceeding a pre-selected pressure drop value is triggered by the measuring computer. The pressure pulse for cleaning is set up in such a way (specification of the tank pressure, the valve opening time and the blow hole diameter) that realistic cleaning conditions result. A blow hole diameter of 3 mm was determined to be suitable in pre-tests for the design of the system.

Illustration 3 shows a diagram of the entire layout including the required measuring and control technology. The two gas flows (vertical and horizontal) are controlled by two mass flow controllers whose actually measured values are transmitted to the measuring unit for registration. The compressed air for the dust feeder and the cleaning system is taken from the compressed air net supply via self-acting pressure controllers. The dust volume flow is determined by continuous weighing of the feeder and the dust concentration and dispersing consistency permanently controlled with a photometer. The temperature and pressure in the dirty gas channel and the differential pressure of the filter are also continuously measured and registered. All analog signals of the measuring instruments are digitised and processed in the measuring computer. Measuring operations are largely automated. In newer versions of the system, monitoring and operation via modem or internet connection is also possible.

The following important specifications were derived for the performance of a standard test after amendment of the original guideline:

- Equal conditions for all filter qualities
- Pural NF is used as uniform test dust

- The filter face velocity is reduced from 3 to 2 m/min (from 180 to 120 m/h),
- After a conditioning phase of 30 differential pressure-controlled cycles, a permanent load (ageing) phase with 10,000 time-controlled cleaning operations is introduced every 5 s. These values are changed in the new ISO 11057 to 2,500 cleaning every 20 s.
- This ageing is followed by 10 differential pressure-controlled settling cycles and an additional 30 measuring cycles. This second measuring phase with determination of the clean gas concentration shall last at least 2 hours, even if this increases the number of cleaning operations to more than 30!

Tables 1 and 2 summarise the most important test settings and the test sequence valid since the new version of the guideline (October 2004).

4. Scientific basis of the development of the laboratory test apparatus type 1

The introduced cross-flow layout was selected to realise filtration conditions that are comparable with those for filter bags. Extensive tests on flat filter samples under exactly defined conditions had shown that this layout allows the formation of dust layers whose structure and properties are comparable with filter cakes forming on bags /9, 10/. This concerns the specific cake resistance as well as the cleaning behaviour. When measuring on filter bags, the local cleaning conditions and cleaning results must be considered, as these change with the bag length. The single-bag filter apparatus by Klingel /11/ used in these tests was equipped with several fast reacting pressure transducers, which allowed measuring the pressure build-up during cleaning on the inside of the bag as well as the acceleration and deceleration of the filter medium on several spots on the bag locally and simultaneously (Fig. 4). In addition, an X-ray fluorescence radiator positioned across the length on the inside of the bag and three detectors positioned on the outside of the bag allowed the contactless determination of the local dust areal weight before and after cleaning. A local cleaning efficiency R was determined from the locally measured dust areal weight, which states the relation of the cleaned off dust quantity to the dust quantity deposited during a filtration cycle.

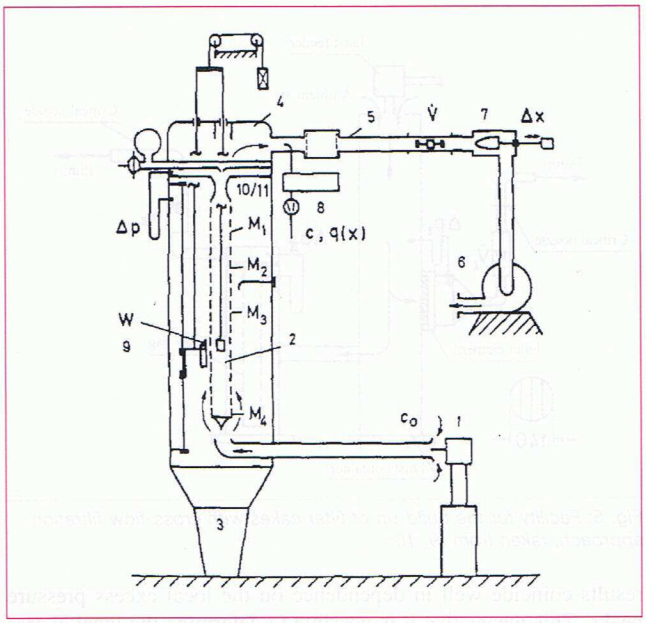

Fig. 4: Single-bag facility for testing the local processes when cleaning filter bags, taken from /9, 10/

With the cross-flow apparatus in Fig. 5, filter cakes were build up in parallel tests under the same conditions and cleaned off outside of the apparatus using two different methods. With the first method, the filter was accelerated and the filter cake merely removed by inertia forces at sudden delay. In the second case, the filter was backflushed and the filter cake detached by the resulting pressure force (reverse flow cleaning).

The results show that a critical local excess pressure must be achieved on the clean gas side in order to detach the filter cake completely and with sufficient efficiency. Cleaning results are compared in Fig. 6 that were measured locally on the filter bag and with filter circles on the cross-flow laboratory apparatus. In both cases, the filtered dust areal weight was 340 g/m². The cleaning

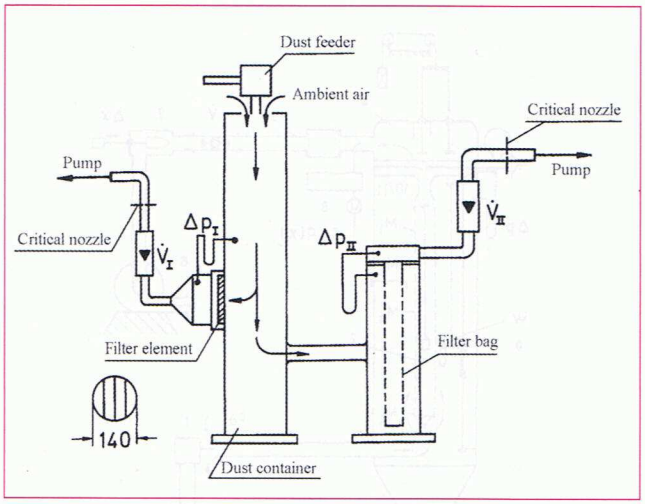

Fig. 5: Facility for the build-up of filter cakes with cross-flow filtration approach, taken from /9, 10/

results coincide well in dependence on the local excess pressure peaks. This means that it is possible to determine the local excess pressure required for the detachment of the filter cake and the necessary local separation forces for overcoming the adhesive forces in laboratory tests. The results indicate that it is possible to adequately simulate the filtration in bag filters with the suggested cross-flow apparatus.

Besides the reasons stated in chapter 2, they therefore comprise the basis on which the VDI/DIN guideline 3926 was developed.

Based on the above facts, the basics of the cross-flow system shown in Fig. 5 were taken over for the development of the test facility (Fig. 1 to 3) for the VDI guideline 3926 (system type 1) and supplemented with a continuously working dust feeding and weighing system, a photometric concentration monitor and a cleaning system. The geometries of the cylindrical feed pipe, the transition to the vertical, rectangular dirty gas channel and the arrangement of the cylindrical cross extraction with round filter samples were especially retained. Some construction details, especially for the filter attachment, were changed. The cleaning system was adapted to the system geometry in such a way that cleaning conditions are created on the filter circles, which are idealised but comparable with the conditions observed in practice with reference to the extent of the generated separation forces. The adjustment parameters were: - the distance between the blow pipe and the filter sample, the blow hole diameter, the tank pressure and the valve opening time. Fig. 7 shows an example of two pressure signals measured with fast pressure sensors for different valve opening times and tank pressures with a blow hole diameter of 3 mm. The selected distance between the blow hole and the filter sample guarantees that the pressure signals above the pipe profile do not change over the pipe cross-section to prevent a 'blow-through' in the center of the filter sample.

An excess tank pressure of 0.5 MPa and a valve opening time of 60 ms was selected for the standard test whose basic data is compiled in table 1. Together with the relatively high filter surface load of 120 m/h, this results in the desired heavy strain on the filter, which is supposed to lead to short test times and clear measuring effects, especially due to the thus enforced accelerated particle deposit inside the filter medium and the related increased particle penetration.

The definition and development of the measuring methodology were based on the secured state of knowledge about the basic operating behaviour of cleanable filters as already described by Löffler /12/. Fig. 8 shows the chronological progression of the pressure drop Δp on a cleanable filter at a constant filter face velocity v and dust concentration c in the shape of a diagram. Due to dust deposited and the formation of a dust cake, the pressure drop increases with time and with the separated dust quantity. During the so-called clogging phase, it initially rises non-linear and changes to linear at a constantly maintained filtration speed. The filter cake is cleaned off once the specified pressure drop Δp_{max} is reached. The pressure drop falls back to the value Δp_R, but does not reach the initial value Δp_0, because dust particles remain inside and on the filter medium. The chronological progression of the residual pressure drop Δp_R after cleaning indicates whether stable operating conditions are achieved or whether the filter medium clogs more and more. Δp_R is the pressure drop of the cleaned filter medium and corresponds to Δp_1 in eq. 1. Δp_2 is the pressure drop of the dust layer that forms during filtration. This way, the total pressure drop at any time results to:

$$\Delta p = \Delta p_1 + \Delta p_2 \quad (1)$$

$$\Delta p = K_1 \cdot \eta_G \cdot v + K_2 \cdot \eta_G \cdot v \cdot W \quad (2)$$

In this,

K_1 means the residual resistance of the filter cloth after cleaning,

K_2 the specific resistance of the dust filter cake,

η_G the dynamic viscosity of the gas,

v the filtration velocity,

W the dust quantity collected per surface unit.

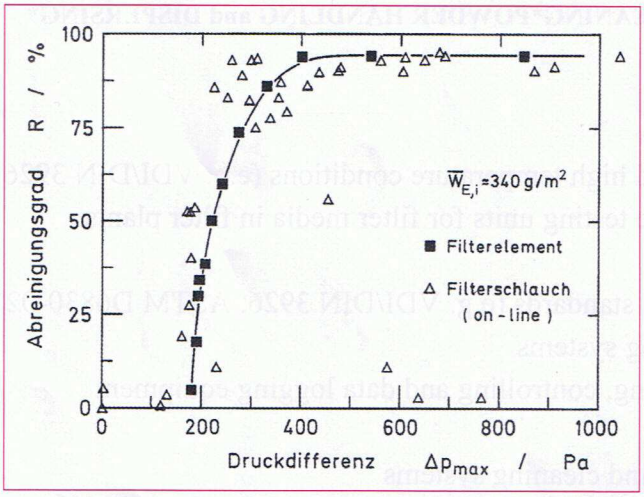

Fig. 6: Cleaning results measured on filter disks and locally on filter bags, taken from /9, 10/

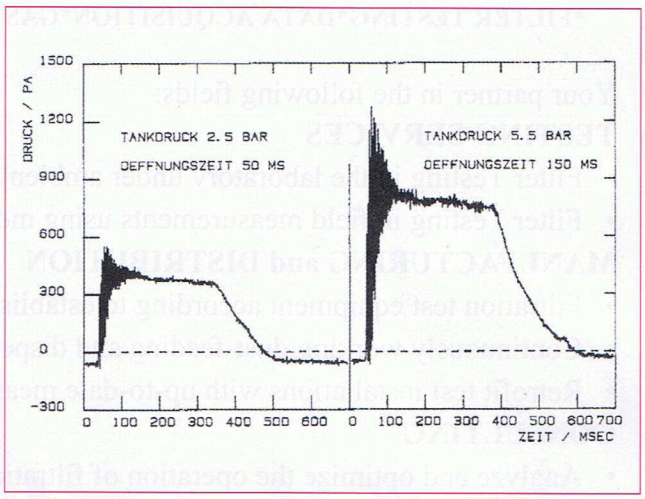

Fig. 7: Pressure signals during cleaning measured on the clean gas side of the test filter for different tank pressures and valve opening times

For the dust quantity collected per surface unit, one can write the following equation with a constant dirty gas dust content c, the filtration time after cleaning t and an almost complete dust separation:

$$W = c \cdot v \cdot t \quad (3)$$

This way, we can write for eq. 2:

$$\Delta p = K_1 \cdot \eta_G \cdot v + K_2 \cdot \eta_G \cdot c \cdot t \cdot v^2 \quad (4)$$

In practice, the linear pressure increase with the time t or the separated dust quantity w is observed in equations 1 to 3 only in the phase of undisturbed filter cake formation. A partially concave shape of the pressure drop curve results during the first conditioning phase, which indicates particle separation on the inside of the filter (depth filtration) or, in case of larger dust surface weights, a compression of the dust cake. However, a convex curve progression shows after just a few cleaning processes (cleaning cycles), which is determined by the structure of the cleaned off filter surface. With only partial removal of the filter cake (patchy cleaning) or the formation of fissures, this effect may be very prominent and lead to a significant reduction of the filtration cycles. With the definition of the maximum pressure drop prior to cleaning of 1000 Pa, it was assumed that a phase of linear curve rise, meaning undisturbed cake formation, is achieved prior to cleaning. The dynamic viscosity of the gas and above all the specific resistances of the cleaned filter K_1 and the filter cake K_2 also have an essential influence on the pressure drop. Both mainly depend on the operating conditions and the substance properties. Equation 4 also shows that an increase of the filter face velocity influences the pressure drop disproportionally – theoretically with the squared speed, in practice with compressing filter cakes or other „real influences", surely even stronger. Excess speeds are frequently caused by production expansions, which result in larger gas volume flows, or inadequately dimensioned filter surfaces. A change of the filter face velocity by 5 % can already be decisive for stable or unstable filtration operation.

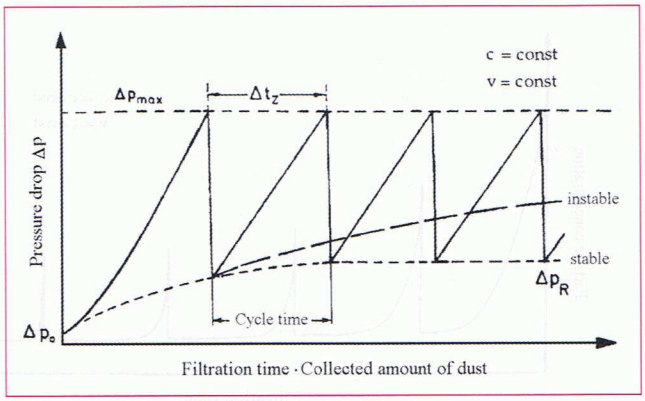

Fig. 8: Schematic pressure drop progression of a cleanable filter at stable and instable operating behaviour, taken from /12/

Typical for the online cleaning of cleanable filters is the increase of the particle concentration in the clean gas during the cleaning process as shown in the diagram in Fig. 9. The sketched behaviour is especially distinctive in bag filters with pulse cleaning. The particle penetration to the clean gas and the time span in which the concentration subsides after the cleaning process as well as the cleaning frequency decisively influence the average dust content in the clean gas and thus the degree of separation of a filter system.

It becomes evident that the characterisation of a cleanable filter medium using the degree of separation measured on the new material (e.g. with DIN EN 60335-2-69) does not take the special operating behaviour of such filters into account. When defining the

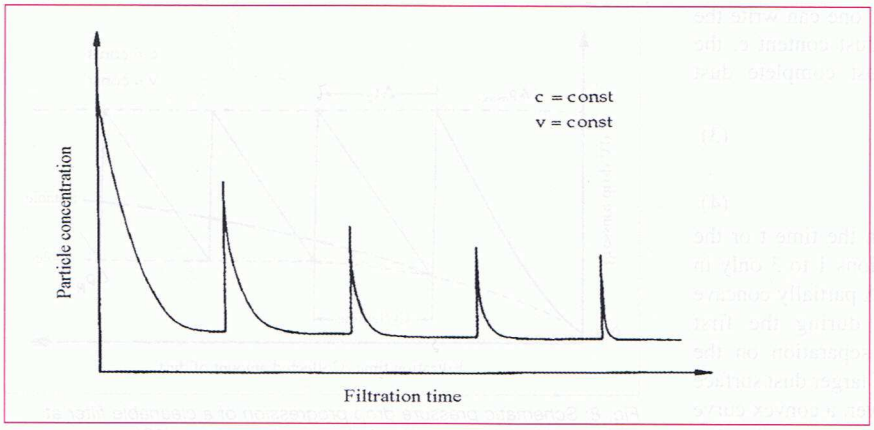

Fig. 9: Characteristic particle penetration to the clean gas when cleaning off a filter, taken from /12/

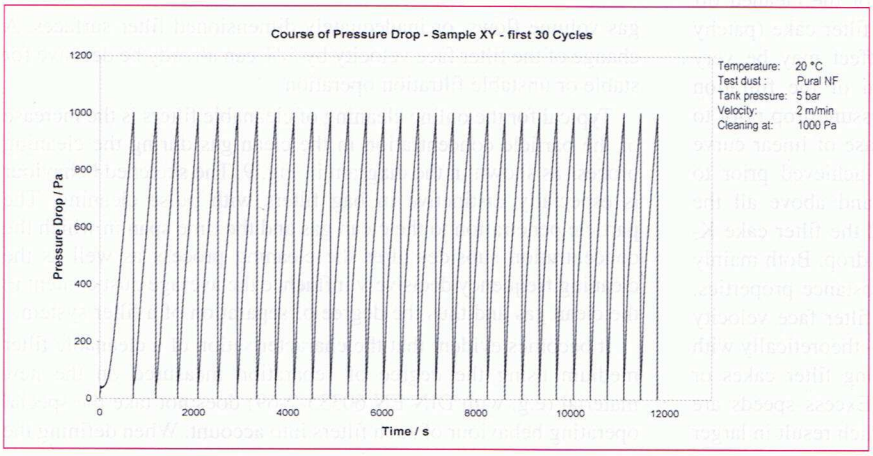

Fig. 10: Exemplary progress of the pressure drop curve during the first phase of a standard test over 30 filtration and cleaning cycles

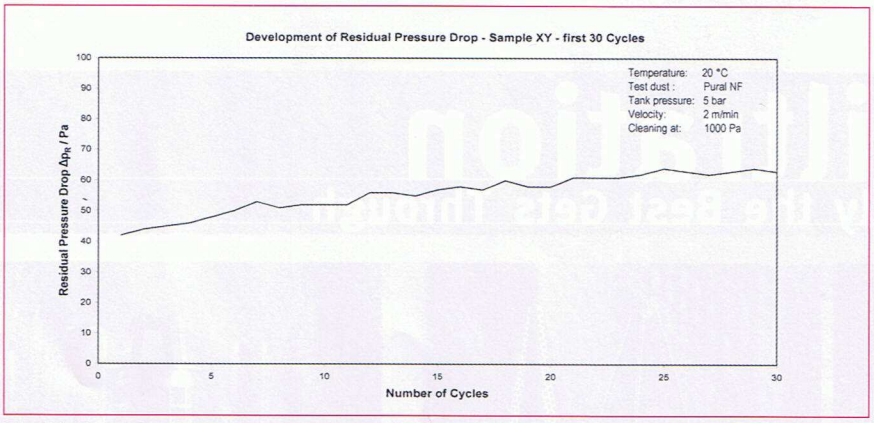

Fig. 11: Progress of the residual pressure drop in a standard test across the number of cycles

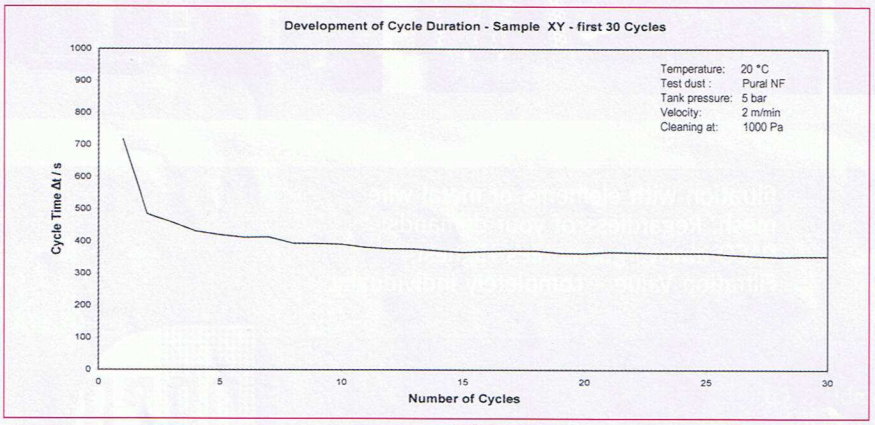

Fig. 12: Progress of the cycle duration in a standard test across the number of cycles

number of filtration and cleaning cycles to be performed in a standard test, it was assumed that filter conditioning is very rapid during the first cycles, which slows down during the further progression but is still distinctive. For this reason, the guideline dating back to 1994 suggested to measure the clean gas particle concentration during the first 20 and the last 80 cycles of a standard test. In the second phase of the tests, the measured concentrations are generally much lower than during the first 20 cycles. With highly efficient filter media, however, it may be necessary to extend the measuring times, otherwise the measuring accuracy is inadequate due to the insufficient dust quantities collected on the absolute filter. In the revised version passed in October 2004, the particle concentration in the clean gas is determined during a conditioning phase of 30 cycles and after ageing of the sample (see chapter 3).

5. Results of standard tests

The following characteristic data is determined for the comparative evaluation of filter media in a standard test acc. to VDI/DIN 3926:

A: Besides the pressure drop of the undusted filter medium, the development of the pressure drop and the residual pressure drop with time and/or cycle number

B: The development of the duration of filtration cycles, meaning the time between the differential pressure-controlled cleaning operations

C: The weigh increase of the filter sample due to dust penetration and deposits after the individual test phases

D: The dust concentration in the clean gas during the first 30 cycles and after ageing of the sample during another 30 cycles or during a test time of at least 2 hours.

Further, rather qualitative evaluations concern the characteristic of the pressure drop curve and the structure of the dust layer that remains on the filter surface after cleaning. Microscopic images of the cut cross section of the samples are also often used for further evaluation. Further measuring, e.g. of the fractional efficiency of a filter sample, or the number of particles passing through the filter during the cleaning process, require the application of a special particle measuring technology (e.g. using a scattered light particle counter). Fast pressure and acceleration sensors also provide information about the separation forces required for detachment of the filter cake and thus the adhesive forces to be

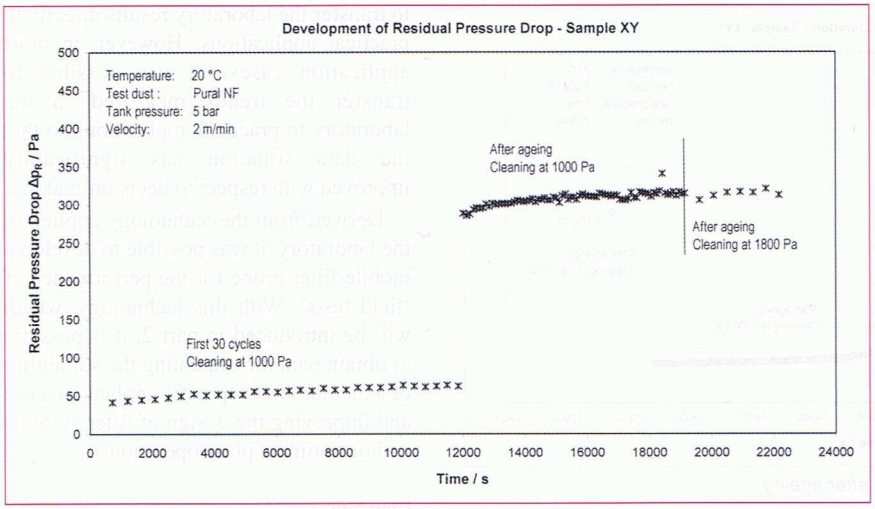

Fig. 13: Development of the residual pressure drop before and after ageing

overcome. However, such tests are not part of the comparative standard filter test.

Basis for the later test evaluation is the progress of the pressure drop curve as shown in Fig. 10 for the first test phase. It shows the complete test progress of all 30 filtration and cleaning cycles over approx. 11,800 s, whereby cleaning took place each time a pressure drop of 1,000 Pa was reached.

Recording and evaluation of the test data was largely automated and takes place using a PC. All measuring data is digitised and saved on the hard disk so that the entire test progress can be tracked continuously. The following test data is generally recorded: Both volume flows, the course of differential pressure drop of the filter, the pressure and temperature in the dirty gas channel, the photometer signal and the weight of the dust quantity in the dust feeder. As shown in Fig. 11 and 12, the progress of the residual pressure drop and the cycle time can be determined and displayed in a diagram using the recorded data sets.

The development of the so-called 'characteristic data', meaning the residual pressure drop, cycle time, dust content in the clean gas and the weigh increase of the filter sample, serve as basis for the characterisation and comparison of different filter media. The residual pressure drop can be measured in two ways:

- „manually" by shutting off the cross-flow and the dust feeding when triggering the cleaning operation and subsequent dust-free measurement of the pressure drop. Here, suction still takes place in the main channel until the main flow is dust-free. Then the cross-flow is activated again, one cleaning-pulse is triggered manually and the residual pressure drop read off. This way it is possible to measure several points of a residual pressure drop curve.
- „automatically" by means of measuring value recording without interrupting the measuring operation, if the waiting time between the cleaning impulse and the measuring operation was selected correctly. The waiting time must be determined in experiments, because the pressure drop curve „back-swings" with varying intensity depending on the permeability of the filter. The back swinging and thus the measuring error become larger the more the filter is clogged or the more convex the pressure drop curve rises.

When measuring with Pural NF test dust, good concordances between the 'automatic' and 'manual' determination of the residual pressure drop are generally achieved for needle felts with a waiting time of 4 s.

The first 30 loading cycles are followed by an ageing phase (see table 2) with 10,000 cleaning operations and dust addition and a stabilisation phase with 10 differential pressure-controlled cleaning operations. Although all test data is registered during this test phase, and the particle penetration is measured as well, this merely serves to control and document the test progress.

The fourth and last test phase consists of another 30 filtration and cleaning cycles with determination of the clean gas concentration. The test should, however, be performed for at least two hours, whereby more than 30 cycles may possibly have to be performed to ensure sufficient accuracy of the concentration measurement. Compared to the first 30 cycles, the residual pressure drop is much higher in this last test phase and the cycle times reduced. This becomes evident in the display format in Fig. 13 and 14, which is suggested in the guideline.

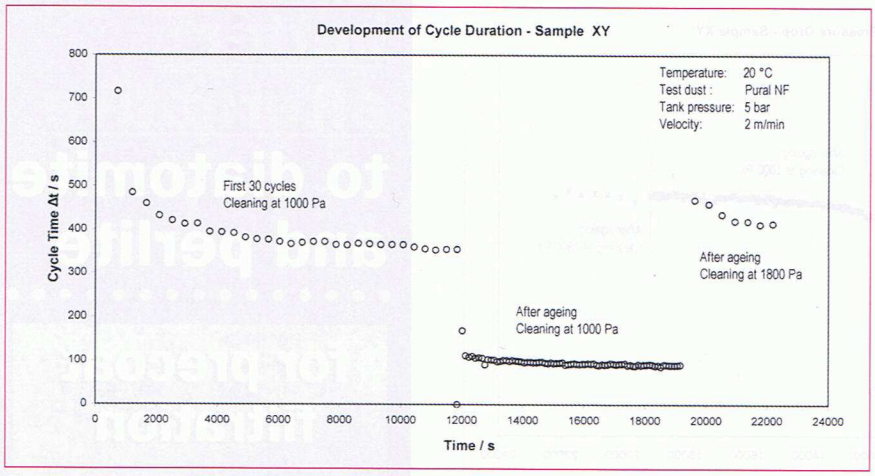

Fig. 14: Development of the cycle times before and after ageing

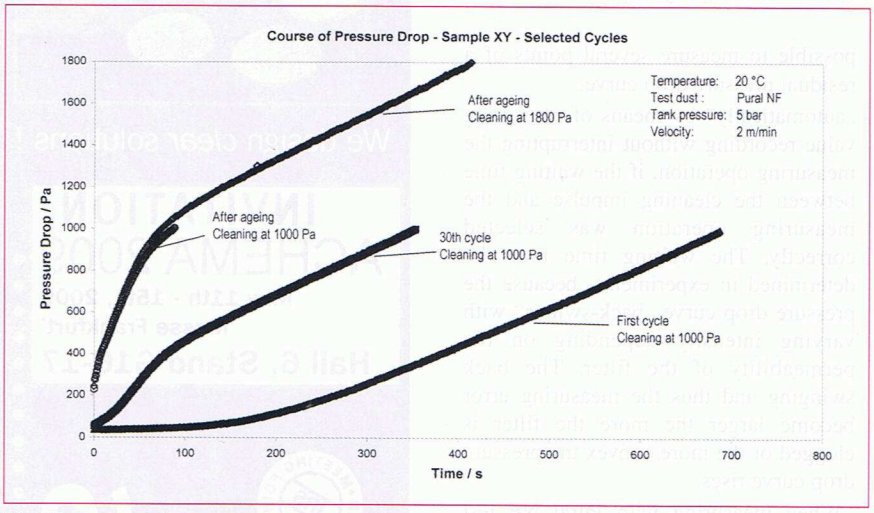

Fig. 15: Pressure drop progression of selected cycles before and after ageing

In addition, a test series with cleaning at 1,800 Pa was performed in the tests discussed here.

This modification resp. amendment of the test performance makes sense when the filtration cycles become so short after triggering the cleaning blast at 1,000 Pa that the filter cake formation phase is no longer achieved. This effect is impressively illustrated in Fig. 15. The shape of the pressure drop curve („after ageing, cleaning at 1,800 Pa") shows that the filter cake build-up phase (meaning a linear curve progression) is first achieved above 1,000 Pa, contrary to the curve after 30 cycles prior to ageing. This analysis of the shape of the pressure drop curve provides further information about the type of dust deposit on the surface and the dust deposit on the inside of the filter medium.

The guideline also suggests listing data for the identification of the filter sample, as well as the values for the dust contents in the clean gas, weight increase of the sample and some characteristic operating parameters, e.g. start and final pressure drop, in tables in addition to the graphic display of the measuring results.

When using the final results, one should always be aware that although they allow a comparative characterization and evaluation of cleanable filter media, it is not possible to transfer the laboratory results directly to practical applications. However, in most application cases, it was possible to transfer the trends measured in the laboratory to practical applications so that the data situation has significantly improved with respect to decision-making.

Derived from the technology applied in the laboratory, it was possible to develop a mobile filter probe for the performance of 'field tests'. With this technology, which will be introduced in part 2, it is possible to obtain data for evaluating the suitability of a medium for a specific application case and improving the design of filter systems and/or optimize plant operation.

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