New Procedure and Test-rig for the Characterization of Cleanable Filter Media [+]

Peter Gäng and Friedrich Löffler

Institut für Mechanische Verfahrenstechnik und Mechanik,
Universität Karlsruhe (TH), Kaiserstr. 12, D-7500 Karlsruhe

ABSTRACT

A new experimental set-up and test-procedure, based on earlier investigations by Sievert and Löffler /1,2,3/, has been proposed as VDI standard 3926 /4/ for the charakterization and evaluation of cleanable filter media. The experiments are carried out on a bench-scale basis with round, flat filter samples arranged in a cross-flow system in order to obtain similar conditions to those existing around bags in filter plants. In order to achieve a sufficient quantity of filtration cycles in non-stop tests, the filter elements are cleaned automatically by pressure pulses comparable with those measured inside filter bags. In order to extend the limited possibilities offered by the basic set-up, additional more sophisticated measuring equipment (e. g. fast pressure tranducers, scattered light particle size analyser) or specially developed apparatus versions (e. g. heated system, in conjunction with isocinetic extraction of raw-gas, doseing facillity for reactiv gases) give access to additional data concerning the filter performance and design, the filter-cake adhesion and the furthermore, the design of cleaning-systems.

INTRODUCTION

Fabric filters are usually employed for the separation of particles from gases containing dust quantities in the range of some g/m^3 to some hundreds of g/m^3. Depending on the inlet dust concentrations concerned, a dust cake is more or less rapidly formed upon the surface of the filter medium, which must be periodically removed in order to maintain the filtration process. With bag-filters this is usualy accomplished by injecting a pulse of compressed air from the clean-gas side, i. e. inside the filter. The required service-life of the filter bags is usually two to four years. They provide clean-gas concentrations of some mg/m^3 without an excessive rise in residual pressure drop for the cleaned filter. The number of cleaning-cycles is very often extends within the range of some tenthousand to hundredthousand.

Although extensive investigations have been carried out concerning the operating conditions and design of the filter and the cleaning system as well as the design and selection of the filter-media, the layout and operation of bag-filters are still extensively based on data which has been empirically obtained in industrial-size installations or pilot plants.

The characterization and evaluation of filter media with respect to their relevant longtime operational properties (filtration- and cleaning-behaviour) in addition to their well defined textile properties is not only a major problem for the manufacturers of filter-media, but also for the producers and users of filter installations.

[+] Vortrag bei "Clean Air World Congress" Montreal, Canada, 30.8.- 4.9.1992

The chief operational properties, which do not only have to be determined for the unused filter, but also following a definite number of filtration-cycles are:

(i) pressure loss during filtration and after cleaning
(ii) residual dust mass after cleaning and the cleaning efficiency
(iii) total collection efficiency
(iv) fractional collection efficiency
(v) cleaning pulse-induced particle penetration

These properties can be measured using the new laboratory filtration test-rig with plane, round filter samples. The basic procedure and experimental set-up for the measurement of (i), (ii) and (iii) have been proposed for a VDI standard 3926 for the "Testing of Cleanable, Textile Filter Media". which has proceeded to the "green-print" state.

The presented apparatus offers the opportunity of realizing filter operation incorporating both filtration and pressure-pulse cleaning cycles and is designed to automatically execute any number of cleaning cycles in non-stop tests.

In order to duplicate the conditions encountered around bags in industrial filter plants, the cross-flow arrangement, as described by Sievert and Löffler was chosen /1,2,3/, which was used to measure the properties of dust-cakes formed on a filter bag in a pilot scale single-bag apparatus and by cross-flow filtration.

The presented system, however, has been additionally equiped with a pulse-jet cleaning facility which delivers pressure pulses comparable with those measured inside filter bags.

Due to the apparatus design various test-parameters such as filter-face velocity, raw-gas concentration, test-dust properties and cleaning conditions are both explicite and easy to change. This allows different filter media to be compared and assessed under definite conditions very similar to those encountered in a pulse-jet filter.

The measurement of the fractional collection efficiency (iv) and the particle penetration during the cleaning pulse (v) requires sophisticated and fast measuring techniques (e. g. a scattered light particle size analyser).

In addition to the measurement of the filter media properties, the application of rapid pressure tranducers gives access to the determination of the separating forces reqired for filter-cake detachment and hence, the cake adhesion. Such data is vital for an efficient cleaning system design and operation.

In further developments it is intended to use the proposed cross-flow geometry and cleaning-system in a heated version of the apparatus as a "filter-tester" outside the laboratory in connection with a isokinetic probe which draws a slip-stream from an industrial raw-gas duct. Hence, different filter-media could be compared under "realistic" conditions and data could be collected for the design of a bag-filter and the cleaning system.

The presented results reveal the quality of the measurements and highlight the possibilities of reducing pilot filter test costs.

EXPERIMENTAL SET-UP

A scale drawing of the laboratory apparatus proposed for the VDI standard 3926 can be seen in **Fig.** 1. This basically consists of a rectangular, vertical raw-gas duct, a cylindrical, horizontal suction unit incorporating the sample of the fabric to be tested (filter area = 0.015 m^2) and the cleaning-system consisting of a 2 liter pressure tank, a quick acting diaphragm valve and a blow-tube.

At the top of the raw-gas inlet a continuously working dust feeder provides a particle laden gas-stream (approx. 4 m^3/h) which is mixed in the cylindrical inlet-tube with additional atmospheric air, drawn into the apparatus. Inside the inlet-tube the raw-gas (5.5 m^3/h, dust concentration 5 g/m^3) passes a 10 mC β-source, in order to discharge the particles, and is subsequently sucked through the rectangular duct, whereby a certain proportion is drawn through the test filter in a cross-flow filtration manner. The gas in the horizontal duct is additionally fed through a total filter in order to gravimetrically measure the particle concentration in the clean-gas. The rest of the uncleaned raw-gas leaves the apparatus at the bottom, whereby it is partially cleaned by the raw-gas exit, working as a inertial separator, to be finally cleaning by a 2.5 m long, Ø 140 mm single-bag back-up filter (not shown). Directly above the test filter the raw-gas dust concentration is continuously monitored by a photometric device which measures the extinction of white light. The scattered light particle size analyser which incorporates two isocinetic probes to allow the filter´s fractional efficiencies and the particle penetration during the cleaning pulses to be measured is schematically included.

Fig. 2 shows the aluminium filter holder which can be weighed together with the filter sample, without having to remove the filter from the clamp. The free filter area has a diameter of 140 mm and is supported by three rods which are mounted verticaly during filtration. All dimensions are shown according to scale.

A schematic survey of the complete experimental set-up including the measuring and controll equipment may be seen in **Fig.** 3. The two main vertical and horizontal gas streams, are measured and controlled by mass-flow-controllers, situated upstream of a pump and additionally protected by high efficiency filters. The remaining raw-gas is precleaned by a back-up filter. The dust feeder and the cleaning system reservoir are supplied with pressurized air of 6 bar from the laboratory network. During the filtration, the pressure drop Δp across the test filter is continually monitored with the aid of a pressure transducer. All analog measuring signals are digitalized by a data aquisition system and sent to a personal computer to be stored and analyzed. The cleaning of the filter is triggered by the computer, which continually compares the pressure drop with a predetermined upper limit.

OPERATIONAL CONDITIONS AND TEST-DUSTS

Depending on the controlling and measuring equipment used, the described apparatus offers a extremely flexible operation. Nevertheless the proposed VDI standard is primarily aimed at providing guide-lines in order to be able to compare measurements obtained by different test-laboratories. For purposes of standardization, operation

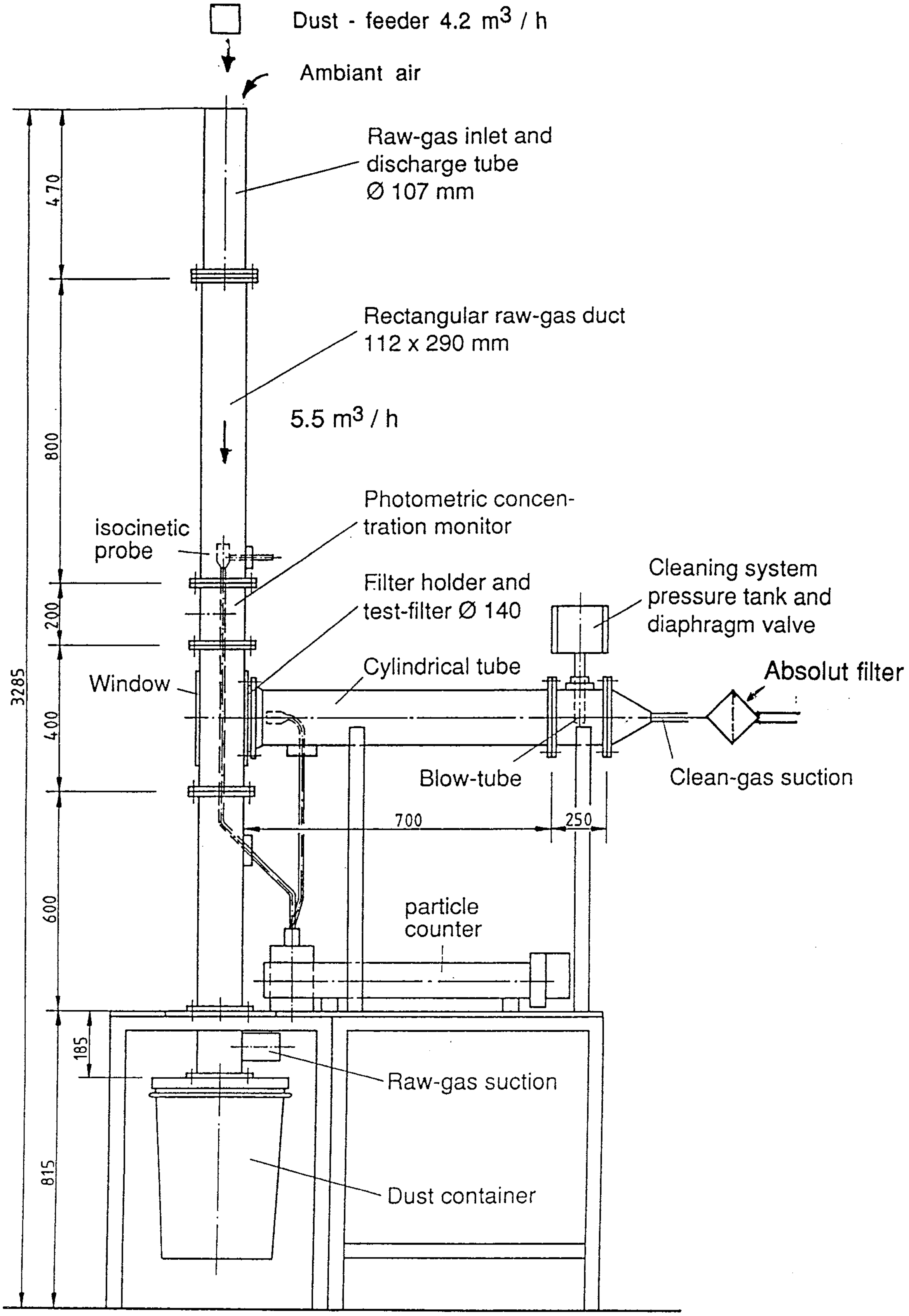

FIGURE 1. Dimensions and geometry of the filtration apparatus proposed as VDI standard 3926 (according to scale)

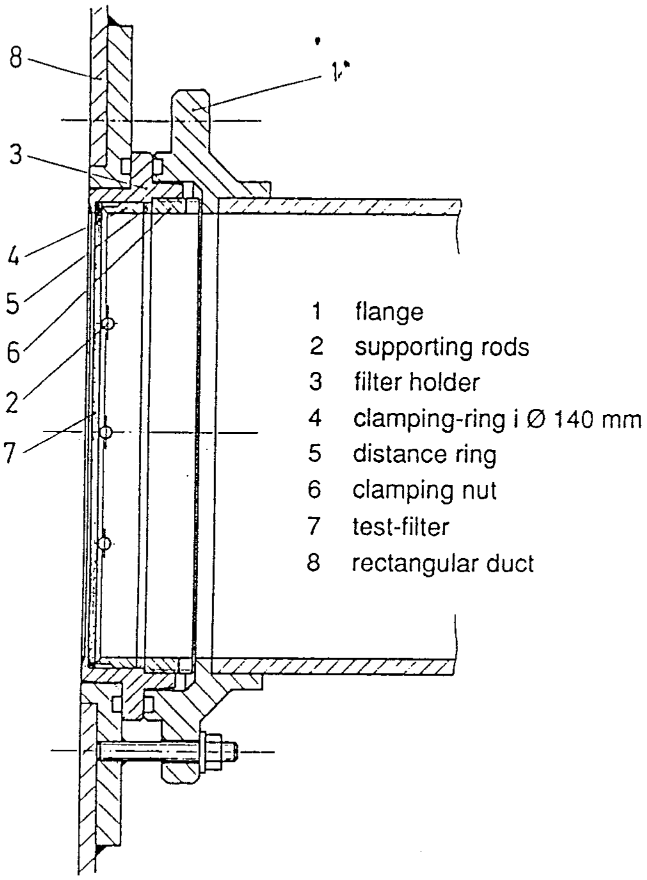

FIGURE 2.
Dimensions and construction of the filter holder

with the settings listed in **Table 1** and the four test-dusts shown in **Table 2**, are recommended. The test-dusts differ mainly with respect to their chemical composition, particle-size distribution and their tendency towards agglomeration.

EXPERIMENTAL PROCEDURE

The proposed standard test procedure is as follows:

- weighing and mounting of the test-filter holder and the total filter for the gravimetrical measurement of the total efficiency,
- establishment of one of the proposed test conditions and the execution of, as a rule, 100 filtration-cycles, continuously recording the pressure-drop, and cleaning the filter at one of the two proposed upper pressure-drop limits,
- extraction and weighing of the test and total filters.

In more sophisticated tests, the following data can additionally be measured:

- fractional efficiencies of at least three different unused samples taken from the same material, in order to judge the filter homogenity,
- fractional efficiency change with respect to the filter loading at low particle concentrations (approx. 100 mg/m^3), in order to classify the filter´s behaviour with respect to it´s deep-bed or surface filtrational behaviour and judge the homogenity of it´s structure,

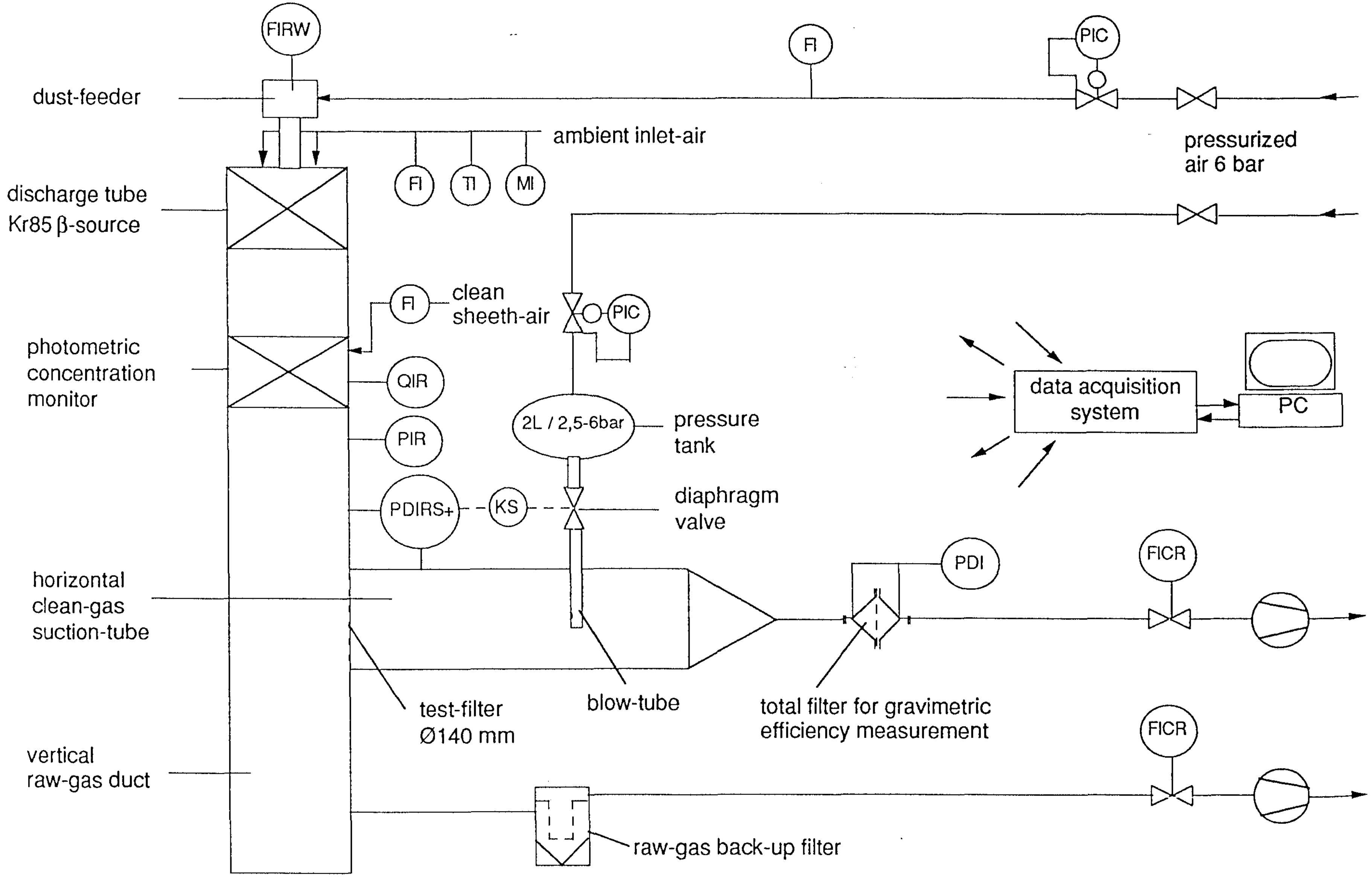

FIGURE 3.
Schematic of the test-assembly as well as the measuring and controll equipment

TABLE 1.
Operational conditions proposed in the VDI standard 3926

Total raw-gas flow-rate			5.5 m^3/h
Filter face velocity	60	and	180 m/h
Particle concentration at filter			5 g/m^3
Pressure drop limit before cleaning	1000	and	2500 Pa

TABLE 2.
Test-dusts proposed in VDI standard 3926

Test-dust	Alumina-oxide	Limestone	Limestone	Titanium-oxide
Distributor	Condea Chemie GmbH	KSL Staubtechnik GmbH	Ulmer Füllstoff Vertrieb	Kronos Titan GmbH Sachtleben Chemie GmbH
Trade-name	PURAL® SB	Eskal 100	Mikro-Calcilin	Kronos RNC
				Hombitan®
Adhesion	free flowing	agglomerating	agglomerating	strongly agglomerating
Chemical composition	Al_2O_3	$CaCO_3$	$CaCO_3$	TiO_2
Particle-size distribution $Q_3(x)$	90 % < 90 µm 50 % < 45 µm 25 % < 25 µm	98 % < 15 µm 83 % < 10 µm 44 % < 5 µm	99 % < 12 µm 50 % < 3,2 µm 30 % < 2 µm	100 % < 1,2 µm 50 % < 0,9 µm

- fractional efficiency and weighing of the sample after the 1th, 20th and 100th pulse-cleaning,
- particle penetration during and shortly after the cleaning-pulse, taking the peak-values as a quality attribute.

After extracting the filter it is usually prepared for scanning electron micrographs of the cross section, in order to assess the tendency of a permanent particle retainment within the filter structure. The preparation includes the fixing of the particles on and inside the filter according to the technique put forward by Schmidt and Löffler /5/, using the vapour of a single-component instant adhesive (super-glue) based on cyano-acrylic acid.

RESULTS AND DISCUSSION

As previously mentioned, the cross-flow arrangement was selected to obtain similar conditions to those encountered around bags in filter plants. Measurements of the specific cake resistance have shown, that in the case of the test conditions used for the investigations, values for the specific filter-cake resistance were determined similar to those of a dust cake on a filter bag in a pilot scale apparatus. It may therefore be assumed, that dust cakes of similar structure and properties were formed in both cases. This could be verified from a comparison of the cleaning efficiencies measured in a single-bag apparatus and from filter cakes formed in a cross-flow system.

The single-bag apparatus was equiped with fast-reacting pressure transducers and miniature accelerometers of just 0.5 g weight, in order to measure the acceleration of the filter cloth and the pressure signal at each point of the 2.5 m filter bag, i. e. the cleaning conditions whithin the bag. Furthermore a radioactive X-ray source, which could be positioned inside the bag and three scintillation counters outside the bag, were used to measure the dust loading, i. e. the areal dust mass before and after the cleaning pulse. From both results the local cleaning efficiency was determined. The cross-flow method was used to form filter cakes under the same filtrational conditions as in the bag. The filters were subsequently cleaned outside the apparatus by means of two different methods. The first involved the use of a reverse-flow only, the other the acceleration and deceleration of the test-filter.

The results reveal, that a certain critical overpressure is necessary inside the bag, in order to obtain an efficient dust-cake discharge. **Fig.** 5 compares the data obtained from laboratory-scale experiments with plane filters (full line) and data derived from the

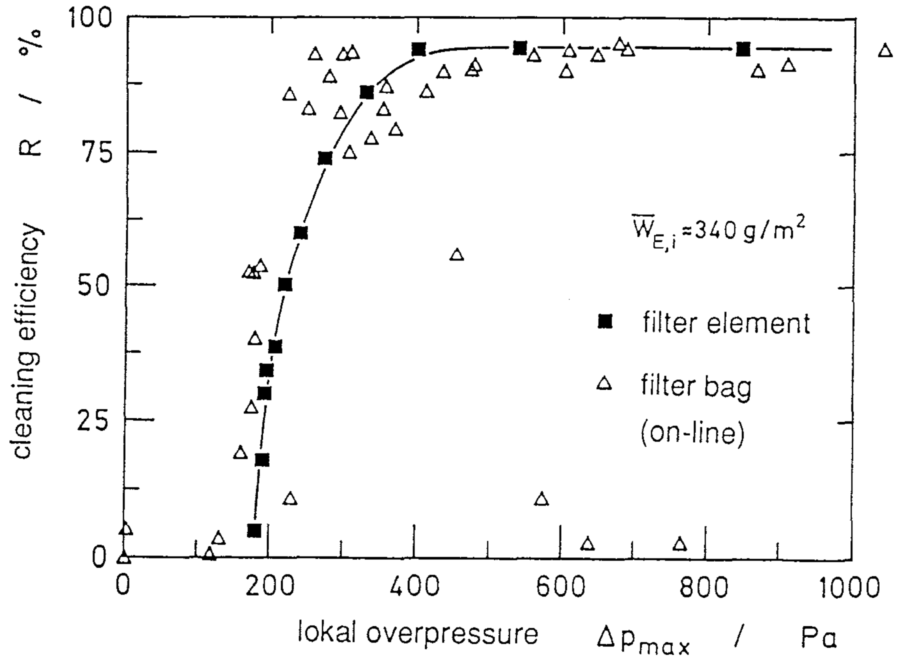

FIGURE 5. Comparison between data gained from laboratory-scale experiments with flat geometry (full line) and data gained from pilot-scale single-bag filter

2.5 m bag. In both examples the areal dust mass before cleaning ($W_{E,i}$) was 340 g/m^2. In both examples the data comply quite well, which means that the overpressure which is necessary inside a bag for an efficient dust-cake discharge at any location, can be derived from tests using laboratory equipment.

Typical pressure pulse traces for a 2.5 m filter bag are shown in **Fig. 6** as a function of time for a reservoir pressure of 6 bar. When the compressed air pulse is injected, the pressure difference Δp across the fabric increases rapidly, leading to a positive pressure inside the bag. Following this, pressure oscillations can be observed, being highest in the upper bag region. This incites a high accelerations and decelerations of the filter cloth, hence stressing the filter medium. These oscillations of the filter material varies considerably along the bag´s length, decreasing progressively until, finally, at the bottom of the bag hardly any dynamic movement occurs. An analysis of the data shows, that peak pressures are highest in the top and bottom bag regions with a minimum in the middle. This coincides with measurements which have revealed that the cleaning efficiency in this region will be minimal, if the reservoir pressure is too low.

In order to simulate the fabric cleaning in the bag, the pressure pulses produced in the cross-flow apparatus illustrated in Fig. 1 must be comparable to the signals shown in

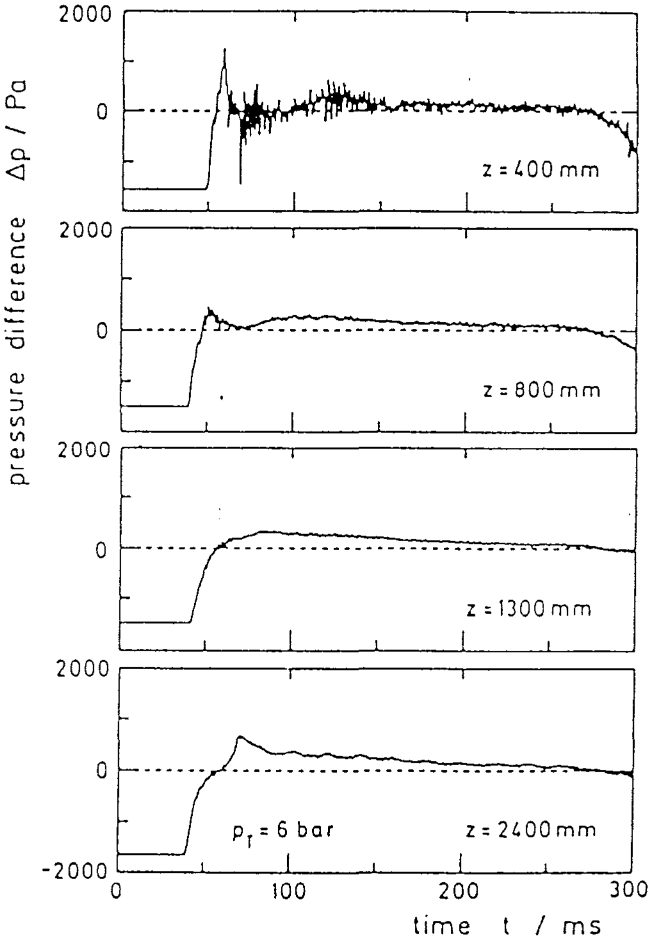

FIGURE 6.
Local pulse pressure inside a 2.5 m bag during cleaning

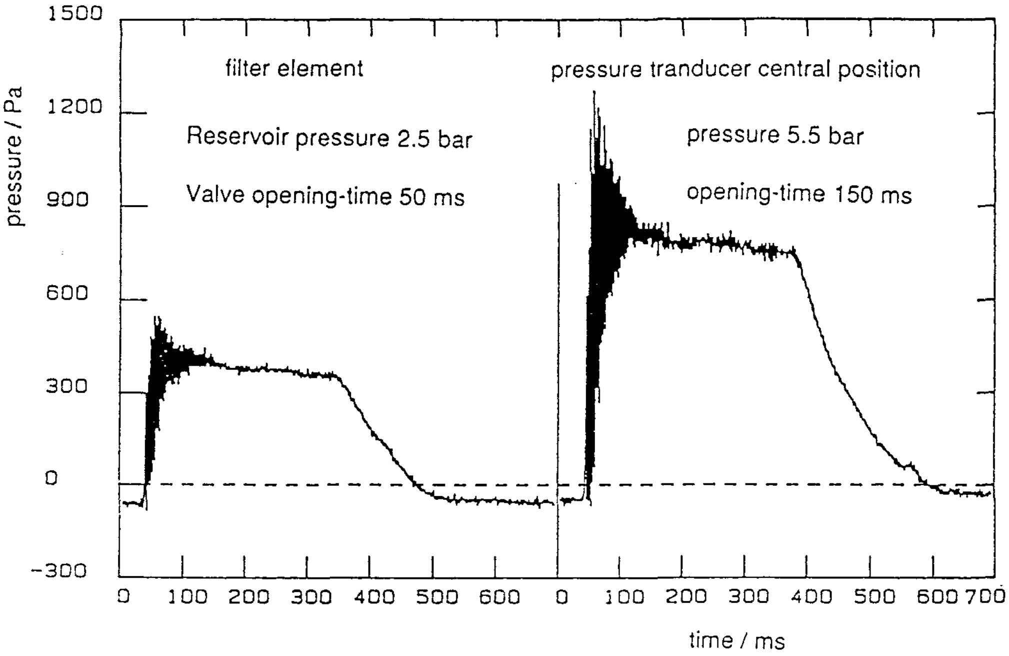

FIGURE 7. Pressure pulses measured directly at the filter sample at a central duct position in the cross-flow apparatus as proposed for the VDI standard 3926

Fig. 6. Typical examples of pressure pulses, measured directly at the filter sample at a central position of the duct, upon changing the reservoir pressure from 2.5 to 5.5 bar and the valve opening-time (electric) from 50 to 150 ms, have been plotted in **Fig. 7** . Measurements at different radial locations within the duct yielded constant values. As such, the pulse is uniform and well developed over the entire cross-section. The pressure peaks can be adjusted to comply with those encountered in the bag. Higher filter sample permeabilities result in weaker pressure peaks. Although the blow-hole diameter was kept constant at 3 mm, this can be changed, in order to influence the slope of the pressure rise. From the derived calibration data, different operational conditions, extreamly similar to those encountered in filter-bags with respect to the dust-collection, the formation of the filter-cake and the pulse-cleaning procedure, can be realized.

In the following, some experimental results are demonstrated to show the capability of the apparatus. The filtration and cleaning conditions were kept constant, the filter-face velocity was chosen as high as 5 cm/s, in order to set rather difficult conditions for the filter and also reduce the test duration. The differential pressure curves as functions of the cleaning cycle-number and the operating time for two different polyester needle-felts may be seen in Fig. 8, which includes the trends for the cycles 0 to 50, 50 to 60 and 90 to 100. The upper plot displays, what one would call a regular behaviour for a cleanable filter. Starting from a basic differential pressure for the clean filter, the residual pressure drop after cleaning rises slowly and should remain constant for an extensive period. Following a slight change during the first 10 to 20 cycles, the cycle duration remains constant with an almost linear pressure rise with each cycle, i. e. with the increase in the areal dust mass on the filter. This means, that after the filter cake is detached, the filter surface is rapidly coated and a new filter cake is built. Hardly any deep-bed filtration exists

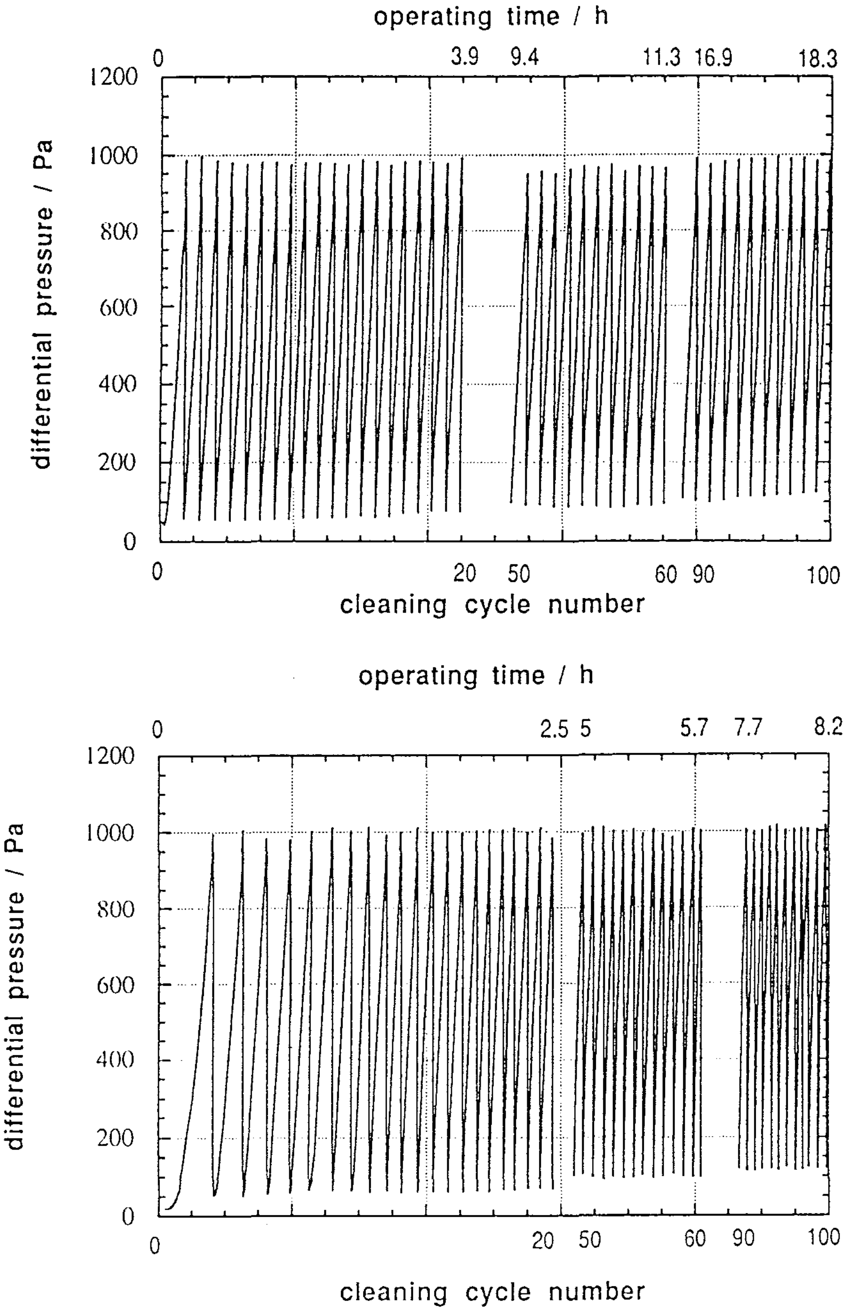

FIGURE 8. Filtration cycles measured with two polyester needle-felts,
upper: calandered, lower: untreated

Filter face velocity 5 cm/s, dust concentration $5 g/m^3$, reservoir pressure 5 bar, limestone $x_{50,3} = 3{,}2\ \mu m$

after cleaning. The lower plot reveals completely different filter properties. Although the pressure drop after 100 filtration cycles is almost the same as in the upper case, this was initially lower, due to the higher fiber structure porosity. Especially during the first 10 to 20 cycles, the sample reveals distinct deep-bed filter characteristics with the differential pressure rising progressively with a concave curve shape. The filter surface was not thoroughly cleaned and retained a crust of dust which could not be removed,

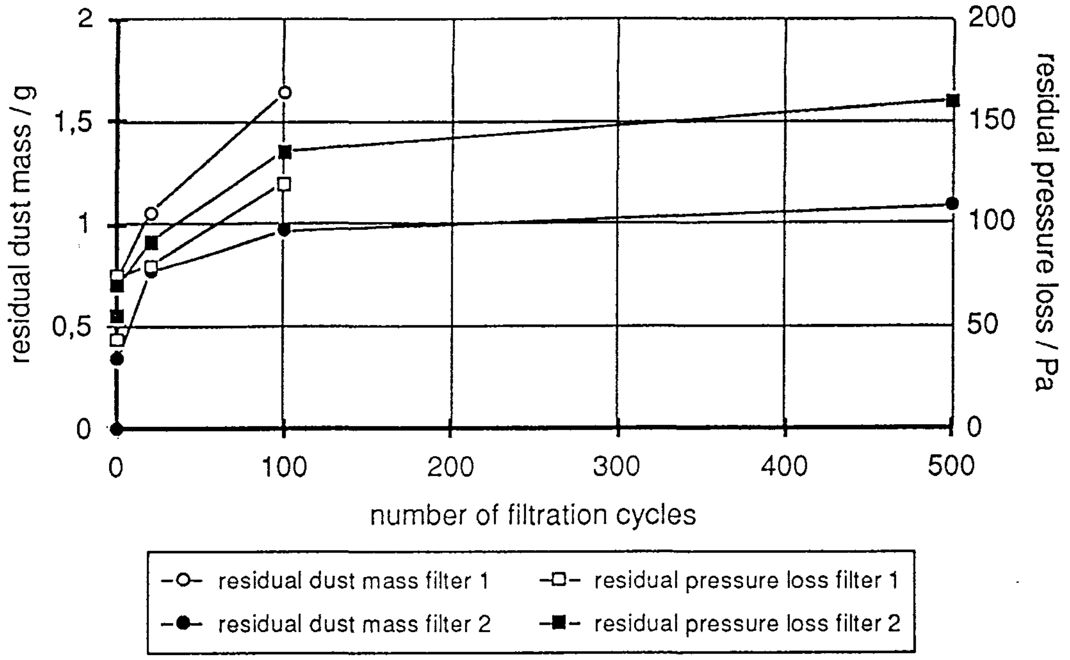

FIGURE 9. Residual pressure loss and weight gain of two filter samples after cleaning

leading to a significant decrease in the filtration cycle-time from approx. 20 minutes in the beginning, to less than 3 minutes for the 100th cycle. As a result, the overall time for the experiment for the lower graph was less than half of that for the calendered medium. A close analysis reveales that the characteristics of the curve change during the course of the experiment, showing a linear differential pressure rise after the first 20 to 30 cycles and even developing a convex trend for higher cycle numbers. This can probably be explained by the formation of cracks in the undetached filter cake which would indeed cause a low initial residual pressure drop, to be closed immediately by fresh collected dust, leading to a sharp initial differential pressure rise which becomes linear during progressive filter cake formation. The residual dust mass after 100 filtration cycles was 1,4 g for the first filter and 8.9 g for the second one.

In **Fig.** 9 two other samples (polyester needle-felts) with almost identical textile properties are compared. Nevertheless they can be distinguished rather well with respect to their residual pressure loss and residual dust mass gained during a long-term test.

A further quality measure for a filter medium is the total efficiency (E_3) and the fractional efficiency (T(x)), not only for the new cloth but also during the service life of a bag, revealing the influence of the structural stability and the quality of the seams. With a new filter sample, T(x) after cleaning usually continuously improves with the number of filtration cycles (i. e. with increasing residual dust mass collected inside and on the surface of the filter medium). This is shown in **Fig.** 10 for a polyester needle-felt. Already during the first 20 cycles T(x) can be seen to ris considerably, together with the total efficiency which begins at a moderate 95,8 % and attains more than 99,9 % after 20 filtration and cleaning cycles. From the upper three curves in Fig. 10, one may conclude that practically no particles larger than 0.5 μm should be expected in the clean gas after

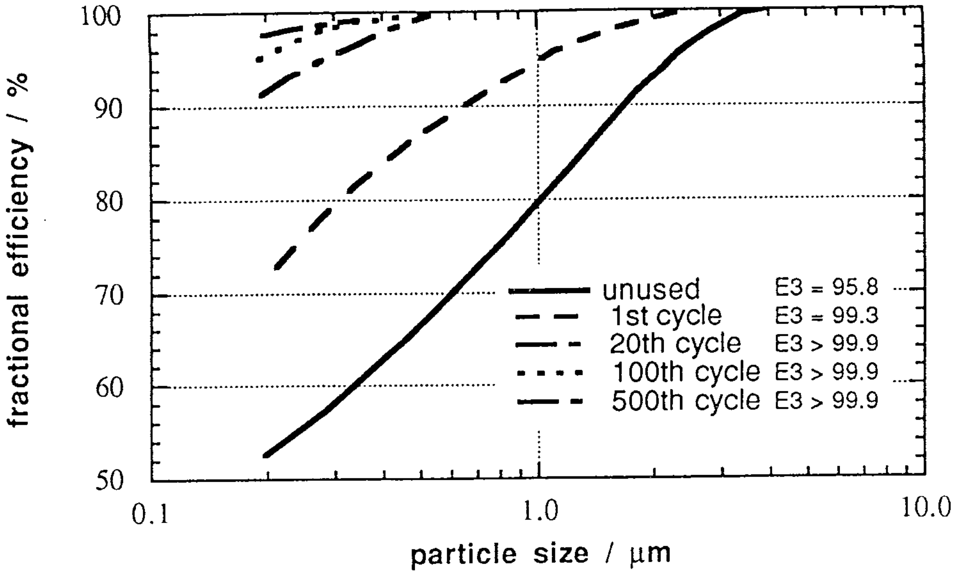

FIGURE 10. Fractional (T(x)) and total efficiencies measured from a polyester needle-felt after different numbers of filtration cycles (measured directly after cleaning)

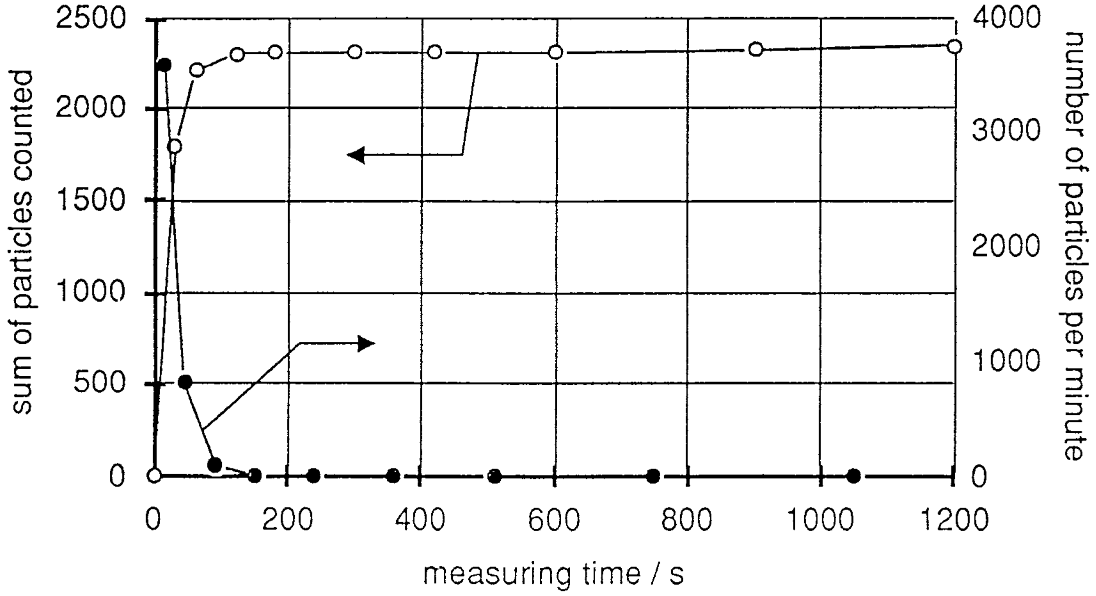

FIGURE 11. Cleaning pulse-induced particle penetration measured between the 80th and 90th filtration cycle downstream of a polyester needle-felt

the filter has gained enough dust during the first 20 cycles. That this is not the case in practice can partially be explained by **Fig. 11**, which shows the number of particles penetrating the filter during and shortly after the cleaning pulse. For the example in Fig. 11 approx. 2.400 particles were counted (empty symbols) in a clean gas sample drawn during a period of 20 minutes, the measurements being started a few seconds before the filter element was pulse-cleaned. From the data demonstrated by the full symbols, one can derive that more than 90 % of the particles can be counted during the first minute following the cleaning action. This has already been reported by Klingel and Löffler /6/ from measurements on a single-bag filter and can be confirmed with the test-rig introduced here. It is assumed that the particle penetration induced by the cleaning pulse might also be a means of judging filter media in terms of the deep-bed or surface filter properties (i. e. the collection of more or less dust inside it´s structure) and hence assess it´s long time behaviour.

CONCLUSIONS

A new experimental set-up and test procedure has been developed which offers the oportunity of collecting data in order to characterize and evaluate cleanable filter media with respect to their long-term filtration behaviour. Furthermore the introduced cross-flow filter system is intended to yield data necessary for the design and operation of filter plants and cleaning systems, as a filter-tester under laboratory and field conditions.

ACKNOWLEDGEMENT

The introduced apparatus was constructed and put into service in the course of a project concerning the "Quality Controll of Cleanable Filter Media" which was financed by the Arbeitsgemeinschaft Industrielle Forschungsvereinigung e. V. (AIF). The authors wish to thank this organisation for it´s support.

NOMENCLATURE

Key of abbreviations in Fig. 1 according to DIN 19 227, Blatt 1
FI = Flow-rate measurement andindication
FICR = Flow-rate measurement, indication, controll and registration
FIRW = dust flow-rate measurement, indication and registration
KS = Signal generator and timer
MI = Moisture measurement and indication
PDI = Differential pressure measurement and indication
PDIRS+ = Differential pressure measurement, indication, registration and switch gear
PIC = Pressure indication and controll
PIR = Pressure indication and registration
QIR = Concentration measurement, indication and registration
TI = Temperature measurement and indication

REFERENCES

/1/ J. Sievert
Physikalische Vorgänge bei der Regenerierung des Filtermediums in Schlauchfiltern mit Druckstoßabreinigung, Dissertation Universität Karlsruhe (TH) 1988, VDI-Fortschritts-Berichte Reihe 3, Nr. 161
/2/ J. Sievert, F. Löffler
Dust-cake release from non-woven fabrics, Proc. World Filtration Congress IV, Ostende 1986, Royal Flemish Society of Engineers, Antwerp and Filtration Sodciety, London, Part I, pp.2.35-2.42
/3/ J. Sievert, F. Löffler
Fabric Cleaning in Pulse-Jet Filters, Chem. Eng. Process., 26(1989) 179-183
/4/ VDI Richtlinie 3926, Teil 2: "Prüfung von Filtermedien unter anwendungstechnischen Bedingungen, Kommission Reinhaltung der Luft im VDI und DIN, Postfach 1139, D-4000 Düsseldorf
/5/ E. Schmidt, F. Löffler
Preparation of Dust Cakes for Mikroscopic Examination, Powder Technology, 60(1990) 173-177
/6/ R. Klingel
Untersuchung der Partikelabscheidung an einem Schlauchfilter mit Druckstoßabreinigung, Dissertation Universität Karlsruhe (TH) 1983, VDI-Fortschritts-Berichte Reihe 3, Nr. 76