

Operation Parameters of Vacuum Cleaned Filters

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Abstract—For vacuum cleaned dust filters there exist no calculation methods to determine design parameters (e.g. traverse velocity of the nozzle, filter area...). In this work a method to calculate the optimum traverse velocity of the nozzle of an industrial-size flat dust filter at a given mean pressure drop and filter face velocity was elaborated. Well-known equations for the design of a cleanable multi-chamber bag-house-filter were modified in order to take into account a continuously regeneration of a dust filter by a nozzle. Thereby, the specific filter medium resistance and the specific cake resistance values are needed which can be derived from filter tests under constant operation conditions.

A lab-scale filter test rig was used to derive the specific filter media resistance value and the specific cake resistance value for vacuum cleaned filter operation. Three different filter media were tested and the determined parameters were compared to each other.

Keywords—Design of dust filter, Dust removing, Filter regeneration, Operation parameters.

I. INTRODUCTION AND AIM OF THE WORK

THE separation of fibrous dusts using filter apparatus with jet-pulse cleaning system creates problems because fibres can still remain on the filter media after regeneration. For the separation of such fibrous dusts therefore commonly filter systems with vacuum cleaning (or reverse air flow cleaning) are used [1]-[3]. These apparatus operates at a high filter face velocity and low pressure drop across the filter and with a low concentration of dust in the raw gas. These filter systems find application e.g. suitable for use in areas of fibre dust, such as found in paper/tissue converting mills, textile applications and nonwoven production units in the cigarette industry [4]-[6].

Vacuum cleaned filter can be distinguished into two groups: filter systems with stationary filter medium with moving nozzle or filter systems with moving filter medium with stationary nozzle. Thereby, the design of the filter system can be flat (panel filter, disk shaped filter) or cylindrical (drum filter).

The simplest design of a vacuum cleaned filter system is a rectangular stationary filter with a carriage mounted on the upstream/raw gas side for a horizontal and vertical traverse movement of the suck-off nozzle (Fig. 1). Thereby, the aspirated dust loaded air (=main air flow, with low dust concentration and high air flow volume) is sucked through the

filter. The build-up fibre/dust layer will be removed by a traversed suck-off nozzle (vertical nozzle traverse velocity v_{nv} and horizontal nozzle traverse v_{nh}) which is attached on the raw gas side of the filter medium. Within the sucked-off air flow (high dust concentration, low air flow volume) the particles are mostly composed of large agglomerates, so that the secondary separation system for this dust is much easier to realize.

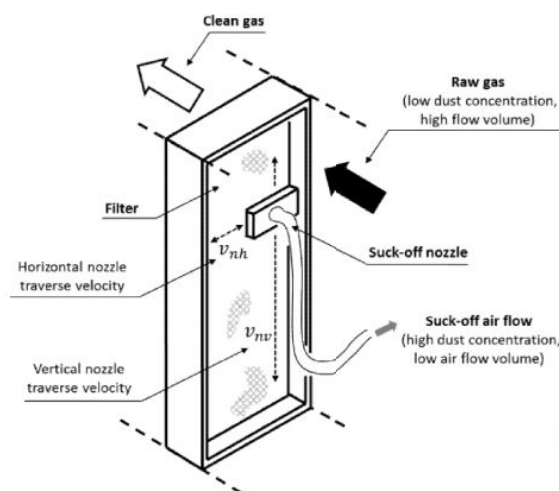


Fig. 1 Schema of a rectangular dust panel filter which becomes cleaned by vertically traversed suck-off nozzle

At constant dust concentration and constant main air flow for a certain setting of nozzle traverse velocities (v_{nv} and v_{nh}) the vacuum cleaned dust filter operates at a constant pressure drop level. The time to clean the whole filter area, respectively the mass of dust cake at the filter surface, depends on the nozzle traverse velocity. At higher traverse velocities the pressure drop becomes lower for a constant gas flow throughput. Otherwise, at a constant pressure drop level the traverse velocity limits the main gas air flow throughput. For an efficient design of such filters, model relations between gas throughput, traverse velocity and pressure drop will be necessary.

An additional advantage of filter systems with a suck-off-regeneration is that the dust concentration in the raw gas space stays low even during the regeneration. The risk of a dust explosion (especially for fibre-particles) is therefore minimized as the lower dust explosion limit will not be exceeded [7]. In contrast, at jet-pulse cleaning systems, the removed dust becomes whirled again in the raw gas and the dust concentration can locally reach the explosion limits [8].

The aim of this work is therefore to develop a model, as mentioned above, which relates pressure drop and traverse

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velocity of the suck-off nozzle to the gas volume flow (or gas velocity) to be cleaned. Therein the influence of the kind of the filter medium and the dust material should be included by a specific filter cake resistance and a filter medium resistance parameter. Following the layout equations of a cleanable multi-chamber bag-house-filter system [9], which relate the pressure drop and the cycle time of a filter bag to the average filtration pressure drop, a model for the traverse velocity at given constant pressure drop and air filtration velocity should be derived in a similar way. Further exemplary measurement results to derive the filtration specific resistance parameters of three different filter media samples will be presented.

II. MODEL DEVELOPMENT

One important point for the operation of a vacuum cleaned filter is the setting of the traverse velocity of the suck-off nozzle during a continuous operation. An efficient operation of such filter system at a constant pressure drop can be achieved by a continuous regeneration of the filter surface at a certain (minimum) traverse velocity. This (minimum) traverse velocity of the suck-off nozzle is necessary to remove the mass of separated dust which becomes accumulated at the filter depth and/or filter surface within a regeneration interval time (=time to regenerate the total filter surface by a relative small suck-off-nozzle).

Therefore, for a proper adjustment of the traverse velocity the relations of the resulted pressure drop, due to the mass of separated dust, and regeneration cycle time for a given gas volume flow have to be considered.

A. Analogy to the Equations for Multi-Chamber Cleanable Dust Filters

Considering the traverse velocity of a vacuum cleaned filter system, respectively the filtration period for a complete regeneration of the whole filter surface area, some basic equations can be derived from well-known equations and knowledge of the design and operation of multi-chamber cleanable bag-house-filter systems. For the basic layout of such filter systems the pressure drop is the main point of interest. [9], [10].

The overall pressure drop (Δp) is the sum of pressure drop across the filter media (Δp_{medium}) and pressure drop across the dust cake (Δp_{cake}):

$$\Delta p = \Delta p_{medium} + \Delta p_{cake} \quad (1)$$

Using an approach by Darcy the pressure drop can be formulated by using a constant specific filter medium resistance (k_m) and a constant specific cake resistance (k_c) [9]:

$$\Delta p = k_m \cdot \mu \cdot v + k_c \cdot \mu \cdot v \cdot w \quad (2)$$

where μ is the gas viscosity, v the filter face velocity and w the cake area load.

The cake area load (the cake mass per filter unit area) (w) after a certain operation time (t) can easily be calculated at constant conditions of the dust concentration of the raw gas (c)

and an estimated dust separation efficiency of the filter medium of 100%:

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

Equation (2) now appears as follows:

$$\Delta p = k_m \cdot \mu \cdot v + k_c \cdot \mu \cdot v^2 \cdot c \cdot t \quad (4)$$

Equation (4) is commonly used for describing the filter pressure drop of a dust loaded filter medium with time. It is obvious that Δp will rise with time, respectively with increase of filter cake thickness or cake area load, at all other conditions being fixed.

For a multi-chamber bag-house-filter, the large numbers of chambers are sequentially regenerated one after another (see Fig. 2), the filtration velocity in each single chamber decreases until the next regeneration occurs, so that for a certain given regeneration time (T) the multi-chamber bag-house-filter works at constant mean pressure drop (Δp_m) and constant mean velocity v_m (ratio of the air flow (dV/dt) to the filter area (A)). Re-arranging (4) under this circumstances lead to (5) [9]:

$$\Delta p_m = k_m \cdot \mu \cdot v_m + \frac{1}{2} \cdot k_c \cdot \mu \cdot v_m^2 \cdot c \cdot T \quad (5)$$

In (5) T is the time period until all chambers have been sequentially cleaned one after the one. A correlation of the mean pressure drop and the regeneration time interval of a vacuum cleaned filter with a suck-off-nozzle can be derived from a multi-chamber bag-house filter.

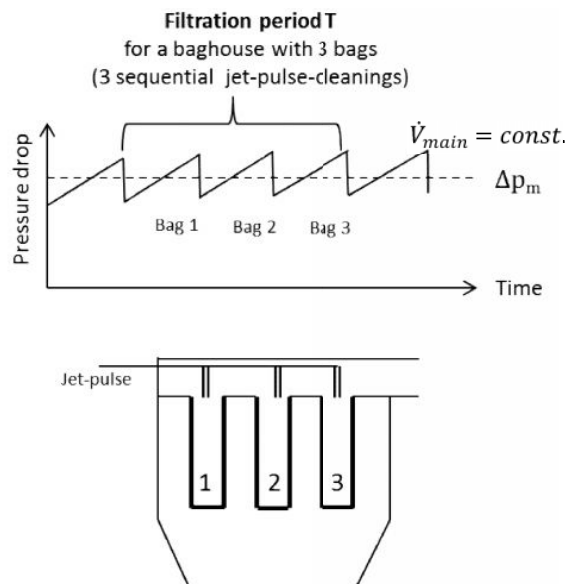


Fig. 2 Development of the pressure drop over time of a multi-chamber bag-house-filter

The situation at a vacuum cleaned dust filter is similar to a multi-chamber bag-house-filter. At a vacuum cleaned dust filter system the stationary filter area becomes cleaned

gradually by a suck-off-nozzle. The suck-off-nozzle covers a small rectangular patch (patch area = nozzle height h_n x nozzle width w_n) compared to the filter area (A_f). At a rectangular filter (with filter area A_f = filter height h_f times filter width w_f) the suck-off nozzle is moving traversal in a circle shaped pattern (1, 2, 3...n) across the filter area, so that within a filtration period T the whole filter area becomes regenerated once (see Fig. 3). In this work, the horizontal shift of the suck-off nozzle after reaching the top or the bottom of the filter is neglected. Therefore, in the following work only one mean nozzle traverse velocity \bar{v}_n is considered.

Following this kind of sequential regeneration, for each sucked-off patch (1, 2, 3...n) the mass of deposited dust differ from each other, respectively the local filter face velocity of the patches. But at an overall view the mean filter face velocity of the whole filter stays constant, respectively also the pressure drop over the whole filter stays constant. As in sum the situation at a vacuum cleaned filter is the same as at a sequential regenerated multi-chamber bag-house filter, the principle (5) can be adapted to relate the mean pressure drop of a vacuum cleaned dust filter to the traverse velocity of the suck-off nozzle (\bar{v}_n).

filter area (A_f), respectively the filter height (h_f) and filter width (w_f):

$$v_m = \frac{\dot{V}_{main}}{A_f} = \frac{\dot{V}_{main}}{h_f \cdot w_f} \quad (6)$$

If the vacuum cleaned dust filter is equipped with only one traversal moving nozzle, which has as small nozzle height h_n (compared to the height of the filter h_f) and a nozzle width w_n (Fig. 3), just a small patch of the filter area (A_n) becomes regenerated within a certain moving interval h_n :

$$A_n = h_n \cdot w_n \quad (7)$$

The number of needed steps of the nozzle (n) to go once across the whole filter area (A_f) (with no overlaps) is therefore

$$n = \frac{A_f}{A_n} = \frac{h_f \cdot w_f}{h_n \cdot w_n} \quad (8)$$

Furthermore, the complete traverse length (l) of the nozzle to go once across the whole filter area is

$$l = (n - 2) \cdot h_n + 2 \cdot w_n \quad (9)$$

With a defined mean nozzle traverse velocity (\bar{v}_n) the filtration period (T) to clean the whole filter area appears as follows:

$$T = \frac{\text{nozzle traverse length}}{\text{mean nozzle traverse velocity}} = \frac{l}{\bar{v}_n} \quad (10)$$

With this definition, the mean nozzle traverse velocity (\bar{v}_n) as a function of the specific filter medium resistance (k_m) and a specific cake resistance (k_c) at a constant mean pressure drop of a filter (Δp_m) and constant mean filter face velocity (v_m) and nozzle traverse length (l), using (5) and (10), can now be formulated as follows:

$$\bar{v}_n = \frac{k_c \cdot \mu \cdot v_m^2 \cdot c \cdot l}{2 \cdot (\Delta p_m - k_m \cdot \mu \cdot v_m)} \quad (11)$$

Equation (11) can now be used for the estimation of the setting of the mean nozzle traverse velocity to achieve a certain constant mean pressure drop at a mean filtration velocity with given suck-off-nozzle height, drum height, dust concentration, specific filter medium resistance (k_m) and a specific cake resistance (k_c). These resistances values can either directly be determined on the filter apparatus or also from a special small lab- test apparatus.

It has to be mentioned, that in this presented case (Fig. 3) a complete filter regeneration cycle (to clean the whole filter area) is defined by moving the operating suck-off nozzle one time across the whole filter with a mean traverse velocity (\bar{v}_n) which is a result of the horizontal nozzle traverse velocity (v_{nh}) and of the vertical nozzle traverse velocity (v_{nv}) of the suck-off nozzle:

$$\bar{v}_n = \frac{v_{nv} \cdot (n-2) + v_{nh} \cdot 2}{n} \quad (12)$$

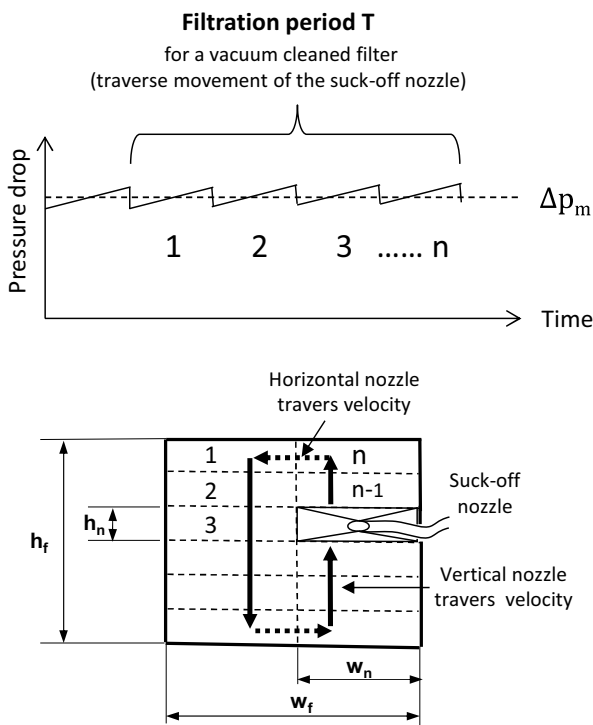


Fig. 3 Development of the pressure drop over the time of a flat rectangular dust filter which is regenerated by a traversal moving suck-off-nozzle

B. Correlation of the Filtration Period and the Traverse Velocity of a Moving Suck-off-Nozzle

For a vacuum cleaned rectangular flat dust filter the mean filter face velocity (the mean air velocity) (v_m) can be easily calculated by the ratio of the main air flow (\dot{V}_{main}) and the

The vertical nozzle traverse velocity and the horizontal nozzle traverse velocity should relate to the proportion of the nozzle width (w_n) and nozzle height (h_n):

$$\frac{v_{nh}}{v_{nv}} = \frac{w_n}{h_n} \quad (13)$$

$$v_{nv} = \bar{v}_n \frac{n}{(n-2)+2 \cdot \frac{w_n}{h_n}} \quad (14)$$

$$v_{nh} = \bar{v}_n \frac{n}{(n-2) \cdot \frac{h_n}{w_n} + 2} \quad (15)$$

In the presented case (Fig. 3), the suck-off nozzle is moving in a defined circular shaped traverse pattern (1, 2, 3...n) so that each patch is cleaned once in a filtration period T . Other constructive designs of the filter system (e.g. drum filters, moving panel filter...) use other defined traverse pattern (saw tooth, spiral, circular...) across the filter area where the starting point and end point of the traverse length are not always equal. Thereby, the suck-off nozzle is stopped after reaching the end position of the traverse length and is shifted back to the start point. But this kind of operation interruption of the suck-off nozzle should be only a few seconds, whereas a filtration period T lasts a few minutes. Therefore (10) can also be used in these cases –neglecting the short interruption time.

III. DETERMINATION OF SPECIFIC FILTER MEDIUM RESISTANCE AND SPECIFIC CAKE RESISTANCE USING A FILTER APPARATUS

At constant mean air velocity (v_m) and dust concentration (c), following from (5) to (11), the mean pressure drop (Δp_m) of a vacuum cleaned dust filter can be written as a function of the mean nozzle traverse velocity (\bar{v}_n):

$$\Delta p_m(\bar{v}_n) = k_m \cdot \mu \cdot v_m + \frac{1}{2} \cdot k_c \cdot \mu \cdot v_m^2 \cdot c \cdot \frac{l}{\bar{v}_n} \quad (16)$$

With a linear approach of the mean pressure drop a function of the nozzle traverse velocity (16) appears as follows:

$$y = k \cdot x + d. \quad (17)$$

For a linear regression of the mean pressure drop (Δp_m) as a function of the inverse nozzle traverse velocity ($1/\bar{v}_n$) each factor of (17) appears as:

$$y = \Delta p_m(\bar{v}_n) \quad (18)$$

$$k = \frac{1}{2} \cdot k_c \cdot \mu \cdot v_m^2 \cdot c \cdot l \quad (19)$$

$$x = \frac{1}{\bar{v}_n} \quad (20)$$

$$d = k_m \cdot \mu \cdot v_m \quad (21)$$

For an experimental determination of k_m and k_c therefore tests should be executed for different nozzle traverse velocities

and the measured mean pressure drops at a different constant inverse nozzle traverse velocities should be plotted (see Fig. 4). By linear regression of the ordinate intercept (21) and gradient (20) the specific filter medium resistance k_m and specific cake resistance k_c result.

Fig. 5 shows schematically how the pressure measurement for different nozzle traverse velocities exhibits over the time. Thereby, at a given nozzle traverse velocity at least a constant mean pressure drop level has to be awaited before switching to another nozzle traverse velocity. This awaiting time should be at least the time to clean the whole filter area once (T).

In Fig. 5 it can be seen, by lowering the nozzle traverse velocity (\bar{v}_n) the mean pressure drop (Δp_m) becomes higher. This is due to the longer time period to clean the whole filter area (T) with lower mean nozzle traverse velocity (\bar{v}_n), respectively the higher mass of dust at the filter surface.

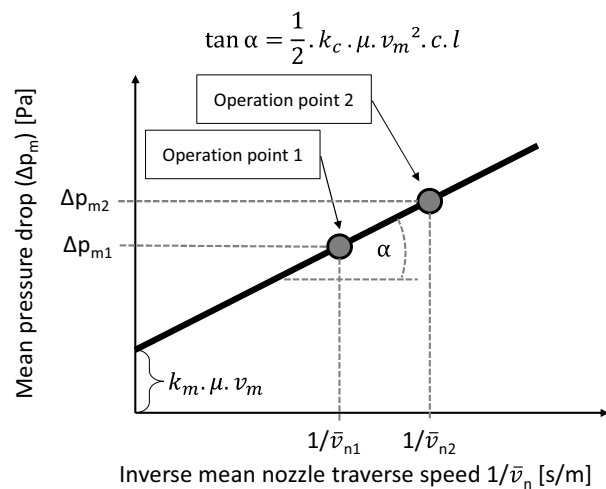


Fig. 4 Linear regression of k_m and k_c by plotting the mean pressure drop of a vacuum cleaned filter versus the inverse mean nozzle traverse velocity

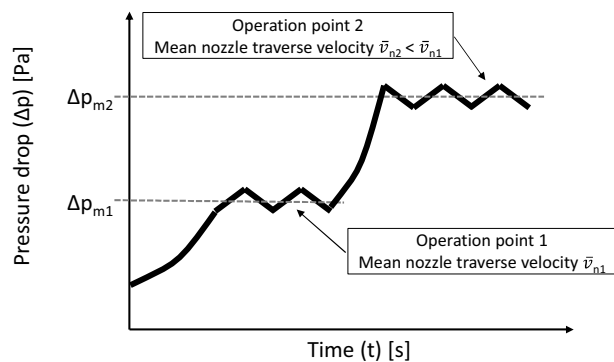


Fig. 5 Pressure drop over time at different operation points (mean nozzle traverse velocities) of a vacuum cleaned filter – demonstrative curve at two operation points (two nozzle traverse velocities)

IV. MEASUREMENT EXAMPLES FOR THE DETERMINATION OF SPECIFIC FILTER MEDIUM RESISTANCE AND SPECIFIC CAKE RESISTANCE USING A LAB-SCALE FILTER TEST RIG

To demonstrate the method to derive the specific filter medium resistance and specific cake resistance values a special developed lab-scale filter test rig was used [11], [12].

A. Lab-Scale Filter Test Rig for Flat Vacuum Cleaned Filter Media

In analogy to existing standards for testing filter media (e.g. DIN ISO 11057:2012-05 for cleanable dust filter media [13]) the layout and its main components were identified: a dust feeder, an air flow channel with a filter holder, a cleaning device and measurement devices for pressure drop and particle size distribution.

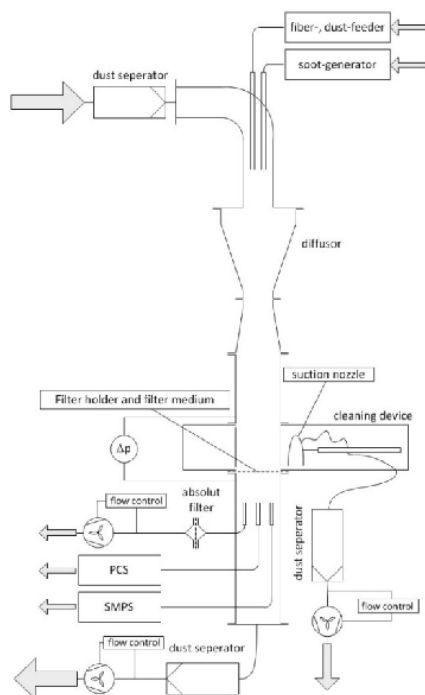


Fig. 6 Schema of the lab-scale filter test rig for testing flat vacuum cleaned filter media

Fig. 6 shows the schema of the designed test rig. Ambient air, which is first cleaned by a HEPA-filter, is sucked through the vertical air flow channel (=main air flow) and is mixed in the raw gas channel with the test dust generated by a band feeder (TOPAS, SAG 440) or by a soot generator (JING, MiniCast 5201C). Various test dusts e.g. ASHREA No.1, Pural SB...) can be dispersed. This test aerosol is homogenized in the diffuser and is filtered at the test filter. Downstream the clean gas channel a dust separator protects the main blower from the residual particles. A differential measuring gauge determines the difference of the pressure across the horizontal mounted flat filter medium (rectangular filter area ($h_f=300\text{mm}$ and $w_f=100\text{mm}$)). In the clean gas channel samples of the particle penetrating the filter medium can be analyzed by a particle counter sizer PCS (0.3-30 μm),

by a scanning mobility particle sizer SMPS (20-800 nm) and by an absolute filter.

The flat filter sample becomes regenerated by the cleaning device (suck-off-nozzle with nozzle area 50mm x 10mm, linear actuator, suck-off air-blower and a secondary dust separator). The dust cake on the filter medium is removed by the suck-off air flow and is separated in the secondary dust separator. At the lab-scale filter test rig the suck-off nozzle moves over the fixed filter medium at a certain fixed nozzle traverse velocity, where the suck-off-nozzle moves across the filter sample (forward and backward – see Fig. 7) continuously all the time. At a constant filter face velocity a constant pressure drop across the filter medium will develop.

B. Definition of the Nozzle Traverse Length of the Lab-Scale Filter Test Rig for the Regeneration of a Flat Filter Sample

The suck-off nozzle and the filter sample of the lab-scale filter test have a rectangular shape. The nozzle is thereby shifted at both end positions perpendicular to the primary moving direction, which is going along the height of the filter sample (see Fig. 7). The total filter sample area (filter width w_f is 100mm and filter height h_f is 300mm) becomes cleaned by moving the nozzle across the filter sample to clean the whole filter area. Nozzle width w_n is 50mm and nozzle height h_n is 5mm. Following (8), for the lab-scale filter test rig $n=A_f/A_n=(300\times 100/50\times 5)=120$ and according to (9) the nozzle traverse length $l=2\times 300=600\text{mm}$ (the vertical shift of the nozzle at the left and right end position is done within a few seconds and is in this work negligible short).

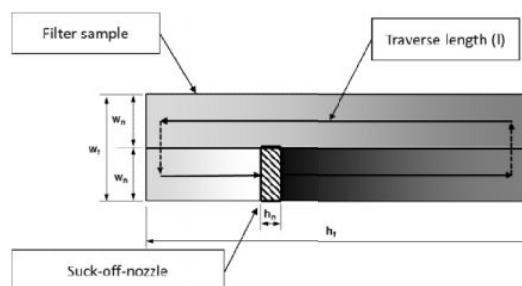


Fig. 7 Schema of continuous filter regeneration of a flat filter medium sample using the suck-off-nozzle at the filter test rig (the intensity of grey indicates the mass of dust cake)

C. Measurement Examples for the Determination of the Specific Filter Medium Resistance and Specific Cake Resistance Using the Lab-Scale Filter Test Rig

Using the lab-scale filter test rig, a filter test series with three different flat filter media was done. The tested flat filter media have comparative high air permeability (Table I) which allows a relative high filter face velocity at a low pressure drop level. The separation efficiency of micro-scale particles of these filter media at very high filter face velocities (0.2-0.4m/s) are higher than 90% for micro-sized particles but for nano-sized particles only about 10-30% [11].

In these test series filter tests were done with Pural SB dust at constant dust concentration ($c=200\text{mg/m}^3$) with three new, undusted filter medium samples (Table I). Thereby, the

suck-off nozzle was moved continuously across the filter at a constant nozzle traverse velocity. In this case the suck-off-nozzle had to move twice across the filter sample to clean the whole filter surface. In the forward-movement of the suck-off-nozzle half of the filter area (a stripe of 50mm x 300mm) was cleaned and in the backward-movement the other half of the filter area (again a stripe of 50mm x 300mm) (Fig. 7).

It has to be noted, that the regeneration parameter values of suck-off air velocity at nozzle (12m/s) and nozzle distance to the filter medium (0.25mm) had been chosen to guarantee a nearly total regeneration of the filter medium after a complete regeneration cycle. Further details concerning the regeneration parameters can be found in [11]-[12].

As exemplary, for the filter medium A, in Fig. 8 the measured pressure drop over time at different mean nozzle traverse velocities (\bar{v}_n) is plotted. A relative constant pressure drop after a short run-in time period has been developed for each nozzle traverse velocity. After approximately 20 minutes the mean nozzle traverse velocity (\bar{v}_n) was varied and another constant pressure drop was awaited. At least five different nozzle traverse velocities were operated.

In Fig. 9 the determined mean pressure drop (Δp_m) as a function of inverse mean nozzle traverse velocity ($1/\bar{v}_n$) is plotted.

Using (18)-(21) a linear trend curve was used to calculate the specific filter medium resistance value and the specific cake resistance value for the filter medium. In Fig. 9 the determined results of k_c and k_m for Filter medium A also are given.

At least for all three different filter media the filter test were done and the specific filter medium resistance values and the specific cake resistance values were determined (see Figs. 10 and 11) within approximately three to four hours of filter testing.

TABLE I
FILTER MEDIA PROPERTIES

	Material	Air permeability @ 200Pa [l/(m ² s)]	Mass per unit area [g/m ²]
Filter medium A	PPS/PTFE	740	480
Filter medium B	PPS/PTFE	560	660
Filter medium C	PPS	1500	320

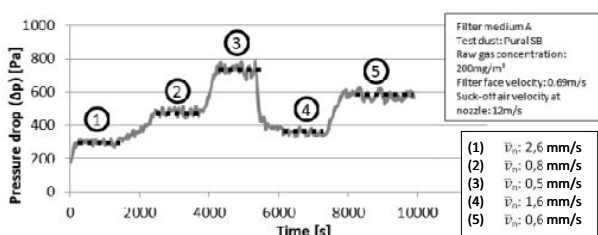


Fig. 8 Pressure drop over time for filter medium A at various mean nozzle traverse velocities

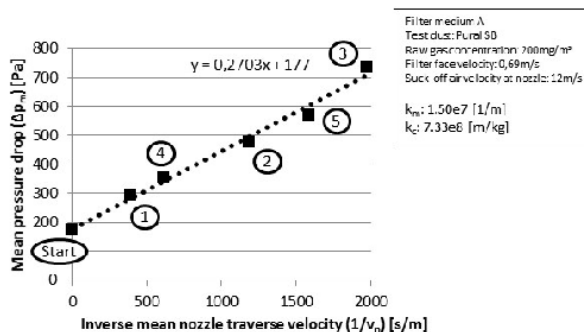


Fig. 9 Mean pressure drop as a function of the inverse mean nozzle traverse velocity, for filter medium A

D. Comparison of the Determined Specific Filter Medium Resistance and Specific Cake Resistance of the Three filter Media

In Figs. 10 and 11, a comparison of the determined specific filter medium resistance and specific cake resistance of three filter media with continuous filter regeneration is presented.

Comparing the three tested filter media, the specific filter medium resistance values (Fig. 10) follow the trend of their air permeability values (Table I). The determined specific cake resistance values (Fig. 11) resulted in the same magnitude, which indicates that the cake formation of the used test dust does not dependent on the filter medium material (e.g. PPS or PPS/PTFE) or on the air permeability of the filter medium.

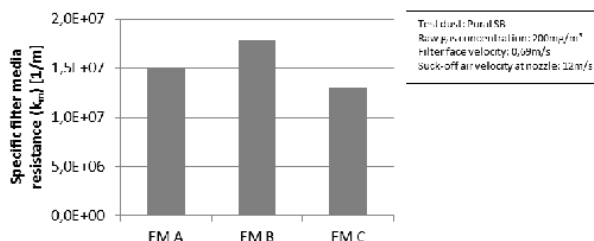


Fig. 10 Specific filter media resistance value of three different filter media

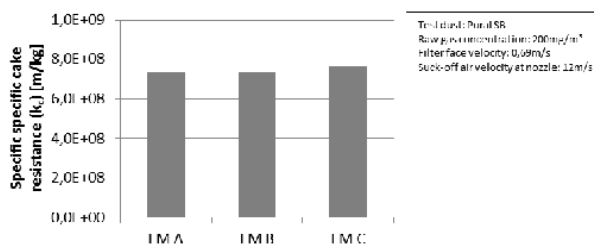


Fig. 11 Specific cake resistance value of three different filter media

Based on these findings, it was shown that the presented calculation model and experimental method to derive the specific filter medium resistance value and the specific cake resistance value are possible and can easily applied on a test rig for testing vacuum cleaned filter media. It is supposed this can also be done using an industrial-sized dust filter system at any given geometry and design (e. g. disk shaped filter, panel

filter, drum filter...). The presented calculation method for the nozzle traverse velocity further allows a fast and simple way to estimate an efficient nozzle traverse velocity of a vacuum cleaned filter system.

V. CONCLUSION

In this work a method to calculate an efficient nozzle traverse velocity of a vacuum cleaned filter system at a given mean pressure drop and filter face velocity was elaborated. Well-known equations for the design of a cleanable multi-chamber bag-house filter were modified in order to take into account a continuously regeneration of a flat vacuum cleaned dust filter by a suck-off-nozzle. Thereby, the specific filter medium resistance and the specific cake resistance values are needed.

A method to derive the specific filter medium resistance and the specific cake resistance values from filter tests were presented. In order to present the usability of the presented calculation model, only the evaluation from a lab-scale filter test rig was demonstrated. Thereby, operating with continuous regeneration of the filter medium, the specific filter media resistance value and the specific cake resistance value for three filter media were determined. For all three filter media samples it was possible to derive the specific filter medium resistance value and the specific cake resistance value in a very short time at the filter test rig. These values could have now be used for the estimation of an efficient nozzle traverse velocity of a vacuum cleaned filter system at any given geometry.

APPENDIX

In Table II the used formula symbols, physical units and descriptions are listed in alphabetical order.

TABLE II
FORMULA SYMBOLS, UNITS AND DESCRIPTIONS

Symbol	Unit	Description
A_f	m ²	filter area
A_n	m ²	Suck-off nozzle inlet area
c	kg/m ³	dust concentration of the raw gas
h_f	m	filter height
h_n	m	height of the nozzle
k_c	m/kg	specific cake resistance
k_m	l/m	specific filter medium resistance
l	m	nozzle traverse length to clean the whole filter area
n	1	number of needed steps of the suck-off nozzle to clean the whole filter area
T	s	filtration period
t	s	time
\dot{V}_{main}	m ³ /s	main air flow through a filter apparatus
v	m/s	filter face velocity
v_m	m/s	mean filter face velocity
\bar{v}_n	m/s	mean nozzle traverse velocity
\bar{v}_{nv}	m/s	vertical nozzle travers velocity
\bar{v}_{nh}	m/s	horizontal nozzle travers velocity
w	kg/m ²	cake area load
w_f	m	filter width
w_n	m	width of the nozzle
Δp	Pa	overall pressure drop of a dust loaded filter medium
Δp_{cake}	Pa	pressure drop across the dust cake
Δp_m	Pa	mean pressure drop
Δp_{medium}	Pa	pressure drop of a unloaded filter media
μ	kg/m·s	gas viscosity

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