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New Solutions for Improved Intake Air Filtration of Gas Turbines and Turbocompressors

Dipl.-Ing. Antje Klink
Dipl.-Ing. Thomas Schroth

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Introduction

Largely dust-free combustion air is essential for high availability and consistently high efficiency levels of gas turbines throughout a long operating life.

Two main types of filters are used for intake air filtration: depth-loading filters and cleanable filter inserts. Inertial separators available in different versions constitute a third variant, this however, is used only for coarse separation in prefiltration applications.

Viledon MaxiPleat filters, with their paper-like filter medium and depth-loading filter cartridges with a nonwoven filter medium made of synthetic-organic fibers, are presented as a new design variant for depth-loading filters. The salient features of these Viledon MaxiPleat filters achieving average dust spot efficiency levels of between 75% and 98% include extremely low pressure drops and a high dust holding capacity. The Viledon depth-loading filter cartridge provides an effective solution to the problems of excessively high pressure drop and an inadequate filter life encountered in unsatisfactorily working pulse-jet systems.

Depth-loading filters and cleanable surface-loading filters

To understand why a particular type of filter operates to the owner's complete satisfaction at location A, i.e. produces a high clean air quality coupled with a cost-efficient pressure drop increase and adequate useful life, whereas the same type of filter exhibits excessively fast pressure drop increase and a concomitantly short useful filter life at location B, it is necessary to examine in detail the filtration mechanisms involved in air filter design work.

The air filters used in gas turbines can be divided into the following categories: depth-loading filters and cleanable surface-loading filters. As can be seen from its name, the working method of a depth-loading filter is to arrest the dust and dirt particles in the inner depth of the filter medium. This is conditional on either a voluminous structure of the filter medium concerned - to make it easier for the dust to penetrate into the depth of the medium and to hold as much dust as possible - or on using a large effective filter area when relatively thin, paper-like filter media are used, thus also resulting in high dust holding capacity with uniform dust loading.
The advantage of the depth-loading filters is that they achieve high collection efficiencies coupled with relatively low pressure drops. This is attributable firstly to the dust being held in the medium's interior, thus preventing the formation of a continuous dust cake, and secondly to the fact that the depth-loading filter configuration offers optimized flow conditions in the air intake system, since elaborate cleaning and dust storage systems can be dispensed with.

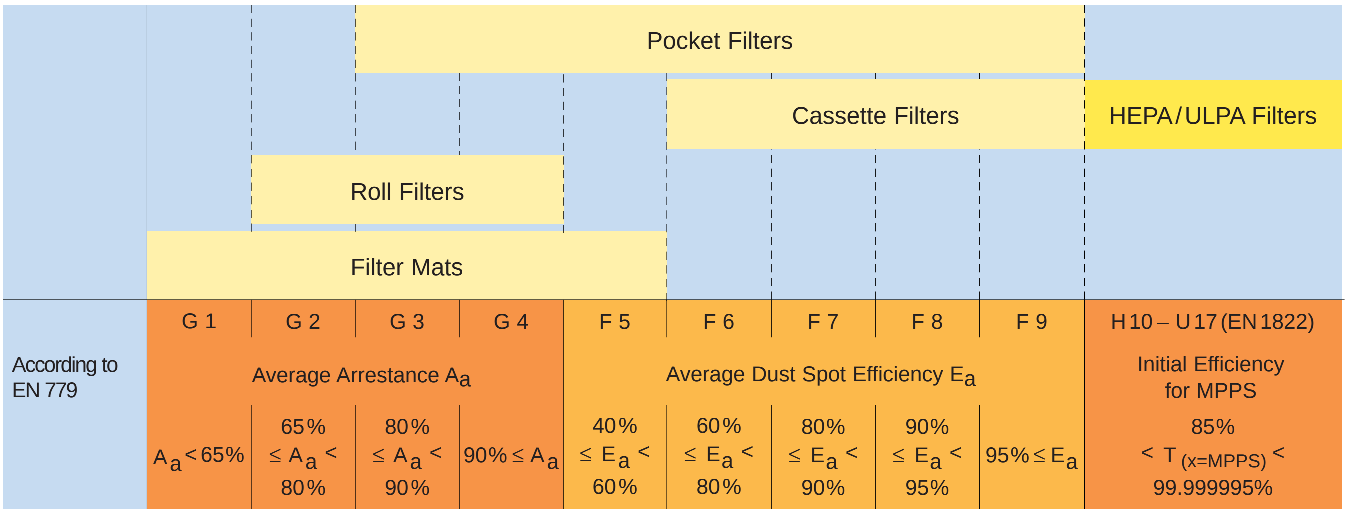
Based on their gravimetrically determined arrestance for synthetic dust (e.g. AC-Fine, ASHRAE dust), or on their photometrically determined average dust spot efficiency for atmospheric aerosols, the depth-loading filters are categorized in different filter classes according to EN 779 valid for Europe. The measuring principle of EN 779 corresponds to a large extent to the American ASHRAE standard 52.1-1992.

Table 1 provides an overview of the different design variants of depth-loading filters, and of the performance classes which each of them covers. As can be seen from Table 1, the higher filter classes or efficiency-level ranges can only be covered by pocket filters and cassette filters. These design variants are normally used in gas turbines for final filtration.

The filter media used for pocket filters are high-volume types (thickness > 4 mm) with a high dust holding capacity per unit area. Nonwovens made of synthetic-organic fibers have proved to be particularly suitable for this application, since they are extremely tough and moisture-resistant. However, the filter medium area which can be implemented in a pocket filter is limited, due to the voluminous media structure involved.

The filter media normally used for cassette filters are paper-like glassfiber media with a thickness of < 1 mm. The relatively low dust holding capacity of the cassette filters per unit area (as compared to the nonwoven version) is compensated for by a filtering area twice as large as that provided by pocket filters. The salient feature of most cassette filters is a shorter overall depth when compared to pocket filters, thus permitting air intake systems to be designed in conveniently compact dimensions.

The job of the filter media used in surface-loading filters is to prevent dust particles from penetrating into the medium. Like the glassfiber papers for cassette filters, a surface-loading filter medium is relatively thin, i.e. < 1 mm. The lower porosity of the filter medium faced to the raw gas side leads to a fast dust cake formation. Once a dust cake has been formed, the air filter separation performance rises significantly, since the dust cake itself acts as a filter and in most cases exhibits a higher collection performance than the actual filter medium behind it. The basic thinking behind the surface-loading filter design variant is to remove the dust cake collected from the surface of the medium periodically when a certain pres-



<table>
<tr><td></td><td></td><td></td><td colspan="7">Pocket Filters</td><td></td></tr>
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<tr><td rowspan="3">According to EN 779</td><td>G 1</td><td>G 2</td><td>G 3</td><td>G 4</td><td>F 5</td><td>F 6</td><td>F 7</td><td>F 8</td><td>F 9</td><td>H 10 – U 17 (EN 1822)</td></tr>
<tr><td colspan="4">Average Arrestance A_a</td><td colspan="5">Average Dust Spot Efficiency E_a</td><td>Initial Efficiency for MPPS</td></tr>
<tr><td>$A_a < 65\%$</td><td>$65\% \leq A_a < 80\%$</td><td>$80\% \leq A_a < 90\%$</td><td>$90\% \leq A_a$</td><td>$40\% \leq E_a < 60\%$</td><td>$60\% \leq E_a < 80\%$</td><td>$80\% \leq E_a < 90\%$</td><td>$90\% \leq E_a < 95\%$</td><td>$95\% \leq E_a$</td><td>$85\% < T_{(x=MPPS)} < 99.999995\%$</td></tr>
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Table 1 Depth-loading filters and corresponding filter classes

sure drop has been reached, thus reducing the filter resistance again, and freeing it for continued utilization.

It is on this method that the so-called pulse-jet filters work. A pulse-jet cleaning procedure separates the dust cake collected from the surface of the medium, so that it drops down into the dust hopper.

To ensure that the cleaning procedure is effective, two basic preconditions have to be met at the gas turbine's location:

a) The dust concentration must be high enough to ensure that a dust cake can build up within a relatively short period. As long as a dust cake has not yet formed, fine particles (of a size <1µm) can still penetrate into the filter medium and lead to an irreversible rise in pressure drop. It is practically impossible to get this fine dust out of the medium's interior. A dust cake will largely prevent penetration by fine dust.

b) The dust involved must not be sticky, since the adhesive forces between the dust particles and the filter medium would become too strong. So in most cases the pulse-jet cleaning would be unable to overcome them. Typical examples of sticky dust include: soot particles, unburnt hydrocarbons and highly hygroscopic salts. If periods of high humidity or fog are encountered at the location of the gas turbine even free-flowing dusts with little adhesion capability may cake onto the surface of the medium. In this case, too, cleanable filters will frequently give unsatisfactory results in terms of pressure drop charactristics. The pressure drop cannot be reduced sufficiently by the pulse-jet procedure. Furthermore, the influence of the van der Waals' forces which are the most important adhesive force between the dust particles and the filter fibers increase with decreasing particle diameter. So if the intake air of the turbine contains a high proportion of fine dust, this renders the cleaning of surface-loading filters significantly more difficult.

Table 1 provides a comparison of the specific characteristics exhibited by cleanable surface-loading filters and depth-loading filters.

Depth-loading filters	Surface-loading filters
• With synthetic nonwoven filter medium: low pressure drop of the filter element due to high porosity and thickness	• Relatively high pressure drop of the filter element due to low porosity and thickness of the filter medium
• With glass fiber paper as filter medium: low pressure drop of the filter element as a result of the large filter medium area used	• After the dust cake has been removed from the surface of the filter medium, the filtration can continue
• Must be replaced when the specified final pressure drop has been reached	• Can cope even with extreme dust situations in desert areas (sand storms)
• High dust holding capacity of progressively structured, voluminous depth-loading filter media required in order to achieve an adequate useful life for the filter	• High dust concentration required in order to achieve fast dust cake build-up
• Uniform dust deposition and full utilization of the filter area used are essential to achieve an adequate useful filter life with paper-like filter medium	• Dust holding capacity is of minor importance, since dust can be removed
• Reliable and maintenance-free operation with low-to-medium dust concentrations	• High humidity or fog may bind dust particles on the medium surface, pulse-jet cleaning becomes almost impossible

Table 2 Comparison of depth-loading and surface-loading filters

Innovative milestone for cassette filters: Viledon MaxiPleat filters

Cassette filters are normally used as final stage depth-loading filters for fine filtration (see table 1). This air filter design variant mostly utilizes glassfiber papers as filter medium.

As already mentioned, the specific characteristics of paper-like filter media entail large filter medium areas (e.g. a filter medium area of 18 m^2 on a face area of 0.36 m^2) at the filter element. In order to achieve a large ratio of active filter area to gross filter area, the medium must be spaced and fixed in place in a suitable way. This means that the manufacturing technique involved is of crucial importance. The spacer configuration significantly influences the performance achieved later in actual practice as well as the performance data of the filter, such as dust holding capacity, operating pressure drop, efficiency level.

The oldest cassette filter type is produced with so-called separator configuration (see Fig. 1). Corrugated aluminium separators serve as spacers in these filter types. The advantage here is that pleat depths of up to 280 mm can be achieved, thus providing relatively good utilization of the overall depth available for the filter element (usually 292 mm). However, the large number of points where aluminium separators and filter medium are actually in contact means that about 20% of the filter area is rendered inoperative. Furthermore, the reduction of the distance between the pleats is minimized by the manufacturing process.
In actual practice, the sharp-edge aluminum separators often damage the sensitive filter paper when the filters are being transported, handled or installed.

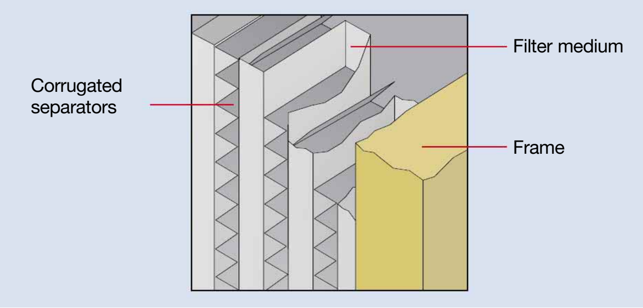


Fig. 1 Separator technique

The parallel pleat geometry caused by the separator configuration is of particular importance (see Fig. 2). The significantly reduced free air inlet aperture of the pleat means that the velocity at which the air is flowing into the pleat is substantially accelerated. Due to the air passing through the filter medium and due to the constant, free cross-sectional area within the pleat, the air velocity continuously decreases until the air reaches the bottom of the pleat. On the clean air side of the filter medium, this procedure is repeated but in the reverse sequence, resulting in a high outlet velocity from the pleat. The flow conditions described here, involving a double air acceleration, result in inner friction of the air molecules with a corresponding increase in pressure drop.

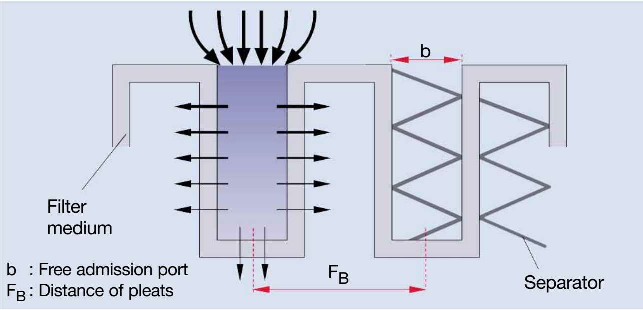


Fig. 2 Parallel pleat geometry (separator technique)

The production of cassette filters using the Minipleat technique constituted a new development in intake air filtration for gas turbines (see Fig. 3). The most important advantages offered by these filters are that sharp-edged separators are no longer necessary, and that smaller distances between pleats can be achieved, with a concomitant increase in filter medium area. The spacers used here are cotton or glass fibers coated with adhesive, or adhesive threads applied to the filtering paper before it is pleated. Once the pleats are in place, the threads touch, thus spacing the filter medium.

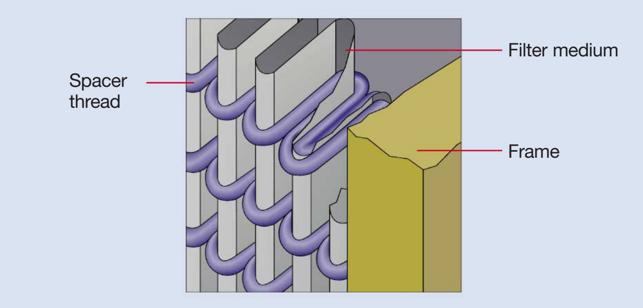


Fig. 3 Minipleat thread technique

However, the substantially more marked instability of the pleated medium package when compared to filters with separators limits the pleat depth achievable when using the Minipleat configuration. To compensate for this important disadvantage, and to implement a sufficiently large filter area in the filter element, individual pleat packages are arranged in a V-shaped configuration (see Fig. 4).

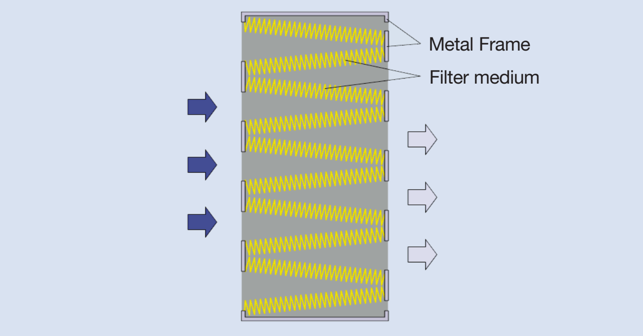


Fig. 4 Minipleat V-filter

As shown in Fig. 4, an important part of the Minipleat filters' face area is covered by mounting rails for the pleated medium packages. This, together with the double deflection of the air while it passes through the medium packages, entails relatively unfavorable flow conditions, which in turn has the effect of increasing the pressure drop of the filter element.

As with separator type filters, the manufacturing technique used for Minipleat filters entails a parallel pleat geometry since the distance between pleats corresponds to double the thread diameter (see Fig. 5). The double deflection and acceleration of the air as it passes through the filter medium combines with a relatively small distance between pleats and parallel pleat geometry to produce an adverse effect on the filter paper's dust loading during filtration. Dust deposits which are not uniform shorten the useful life of the filter.

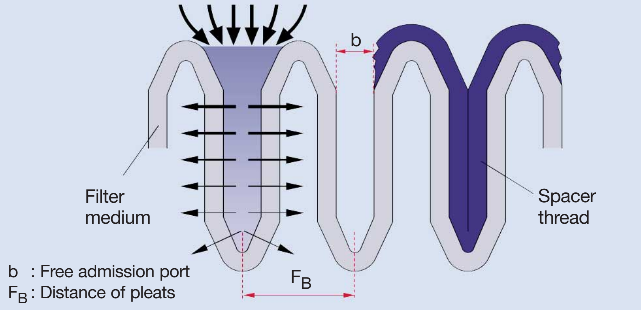


Fig. 5 Parallel pleat geometry (Minipleat thread technique)

The newly developed Viledon MaxiPleat filters (see Fig. 6) combine the favorable properties of both separator and Minipleat filters.

Fig. 6 Viledon MaxiPleat filter

Even without metal separators pleat depths of 250 mm are no problem at all. The patented process for manufacturing MaxiPleat filters is referred to as the „thermal embossing process" (see Fig. 7). A complementary pair of rolls simultaneously embosses conical dimples and the subsequent pleat tips into a heated glassfiber paper finished with a thermoplastic bonder. The shape of the dimples creates a V-shaped pleat geometry after pleating (see Fig. 8). Since the dimples are sprayed with adhesive prior to medium pleating, the medium package is fixed in its final shape. To conclude the process, stabilizing threads of polyurethane are applied at right angles to the pleat tips (see Fig. 9).

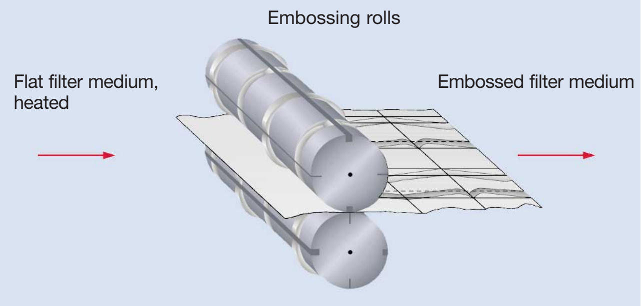


Fig. 7 Thermal embossing process

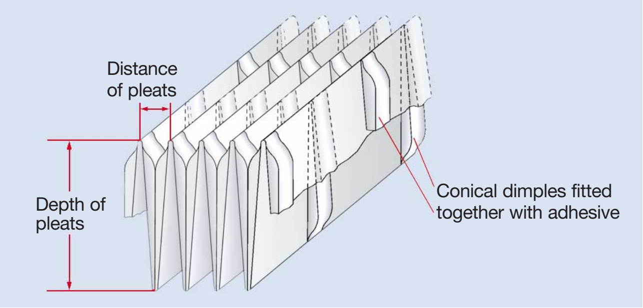


Fig. 8 Thermal embossing technique: no additional spacers

Due to this design, reductions of the filter face area caused by the installation of additional design elements are minimized, and the pleat geometry is precisely equidistant. This means that when the air flows through the medium package the entire filter medium area is utilized and there are no pressure fluctuations which would lead to an unwanted increase in flow resistance (see Fig. 10).

The extraordinarily high dust holding capacity of Viledon MaxiPleat filters is attributable to the very homogeneous flow conditions and the concomitantly homogeneous dust deposits and of course to full utilization of the filter medium area available.

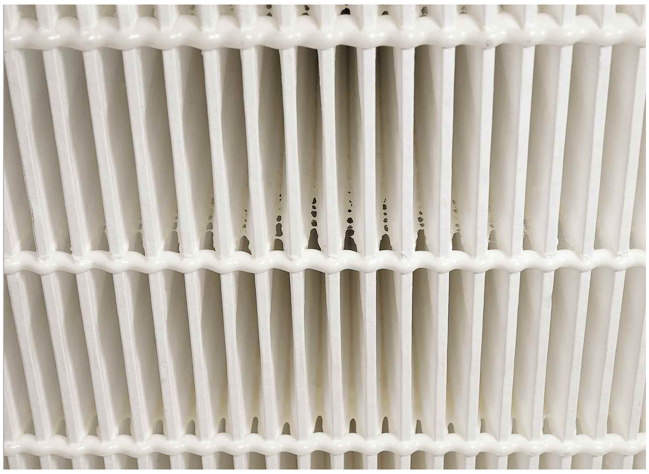


Fig. 9 Stabilizing threads on the pleat tips and glueing on dimples

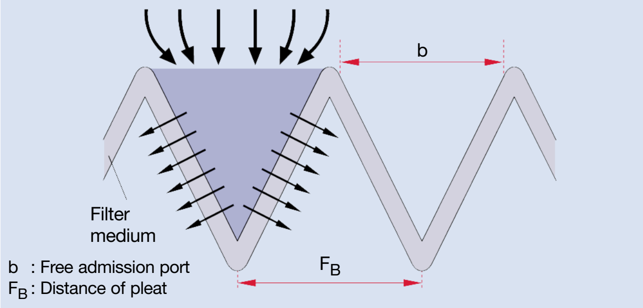


Fig. 10 V-shape pleat geometry (thermal embossing technique)

Table 3 shows the technical data of three cassette filters used in gas turbines as typical examples; the filters involved belong to Class F8 in accordance with EN 779, and have an average dust spot efficiency level of 90% to 95%. The table clearly shows the Viledon MaxiPleat filter's superiority.

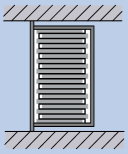
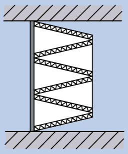
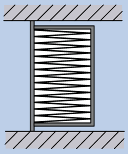
	 Separator filter	 Minipleat filter	 MaxiPleat MX 95
Filter class to EN 779	F8	F8	F8
Dimensions mm	592 x 592 x 292	592 x 592 x 292	592 x 592 x 292
Volume flow rate m^3/h	4,250	4,250	4,250
Initial pressure drop Pa	225	145	110
Average efficiency %	90	90	92
Dust holding capacity for AC-Fine at 635 Pa final pressure drop g	800	1,000	1,230

Table 3 Technical data of cassette filters

In addition to the technical filter properties achieved by the manufacturing technique for the medium package, the design of the filter frame also offers special advantages. The complete frame is made of corrosion-free plastic which is not susceptible to moisture. Since the filter element does not contain any metal components at all, it is lightweight, easy to dispose of and fully incinerable.

Viledon depth-loading filter cartridges as solution for unsatisfactorily working pulse-jet systems

Cleanable surface-loading filter cartridges are frequently used when intake air housings for turbomachines are planned. The argument that these filters can be cleaned has found a lot of supporters. But very often, the high proportion of soot particles floating in the surrounding air is not taken into account, and the dust concentration is lower than anticipated. Also, fundamental changes may occure in concentration and composition of the dust concerned, for instance if a soot source is added to the local environment of the turbine (e.g. a busy highway).

The difficulties mentioned in the paragraph “Depth-loading filters and cleanable surface-loading filters” above with regard to pressure drop and useful life characteristics as encountered with pulse-jet filters, caused by an erroneous choice of filters for use in the air intake system, encouraged the development of a cartridge with the same geometry as conventional cartridges (see Fig. 11). But instead of the cleanable filter medium it possesses a depth-loading filter medium. These cartridges will in the following text be referred to as “depth-loading filter cartridges”. This means that there is no longer any need for costly modification of the gas turbine intake air system to a version incorporating pocket filters or cassette filters, if the cleanable cartridge system does not work satisfactorily.

Fig. 11 Viledon depth-loading filter cartridge, metal-free version

Viledon depth-loading filter cartridges work successfully wherever the cleaning of surface-loading filter cartridges does not lead to an effective reduction in pressure drop, due to sticky dusts and/or low dust concentrations. These filter cartridges are not designed for pulse-jet cleaning.

The most important difference between the cleanable surface-loading filter cartridges and the depth-loading filter cartridge is the filter medium: a nonwoven entirely made of synthetic-organic fibers is used. The structure of the filter medium is progressive to achieve high arrestance and high dust holding capacity, coupled with a low average pressure drop.

The filter medium is very rigid to prevent the pleats from collapsing even at high pressure drops. The pleated medium and the plastic support cage are cast into the polyurethane cover and base for a leakproof configuration. Optimum sealing against the mounting plate is ensured by a foamed-on polyurethane seal. Table 4 contains significant technical data for the Viledon depth-loading filter cartridge TFP 60 P 66 P 2.

Technical data for type TFP 60 P 66 P 2	
Filter area	3 m^2
Thermal stability	70 °C
Temporary peaks	80 °C
Moisture resistance (rel. humidity)	100 %
Technical data in broad conformity with EN 779	
Nominal volume flow rate	1,000 m^3/h
Average arrestance	99 %
Average dust spot efficiency	65 %
Initial pressure drop	approx. 120 Pa
Recommended final pressure drop	800 Pa
Dust holding capacity (AC-Fine / 800 Pa)	1,200 g

Table 4 Technical data of the Viledon depth-loading filter cartridge

Initial experience with the Viledon depth-loading filter cartridge was acquired in a natural gas compressor station in the north of Germany, near the North Sea coast. Trials began in December 1994.

Equipment there includes two gas turbines of the Ruston Tornado type. One intake air filtration system is fitted with 80 conventional surface-loading cartridges. The second turbine features 80 Viledon depth-loading filter cartridges of the TFP 60 P 66 P 2 type. The volume flow rate per cartridge is 1,000 m^3/h.

The pressure drop of the cartridges, the ambient temperature and the humidity were all continuously measured and recorded during the first months of utilization to enable a clear statement to be made on the depth-loading filter cartridges' behavior during operation in high humidity and at critical temperatures (between +5 and -5°C there is a risk of icing up).
Fig. 12 shows the pressure drop behaviour of the depth-loading filter cartridges plotted against temperature and humidity.

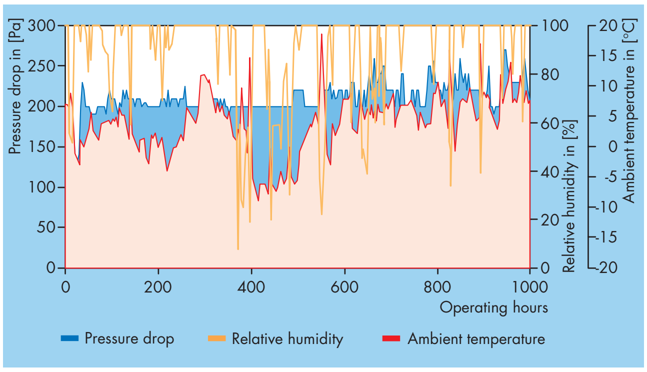


Fig. 12 Influence of the ambient temperature and the relative humidity on the pressure drop

The diagram clearly shows that neither the frequently very high humidity (the site is in the immediate vicinity of the coast) nor the critical temperatures have an adverse effect on the pressure drops of the cartridges.

Due to unfavorable flow conditions, e. g. caused by the Venturi nozzles, the pressure drop determined in the trials is higher than that determined in the test channel at Freudenberg in accordance with EN 779.

Fig. 13 shows the gradual rise of the pressure drop due to dust deposits.

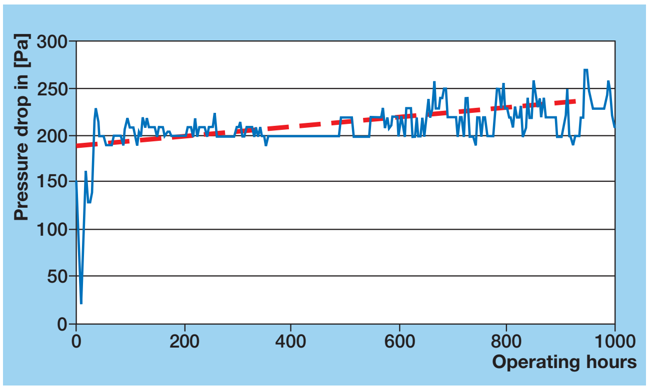


Fig. 13 Rise in pressure drop due to dust deposit

The behaviour of the cartridges when exposed to high humidities and simultaneous critical temperatures (risk of icing up) was of particular interest. Though a layer of ice was formed around the cartridge, it was still porous, very air permeable, and caused no significant increase in pressure drop (see Fig. 14). This means that pulse-jet cleaning was not necessary in these cases. Since the pulsing procedure is not envisaged for the cyclical cleaning process, either, the complete pulse-jet system can be switched off, thus eliminating any operating costs for the compressed air supply system.

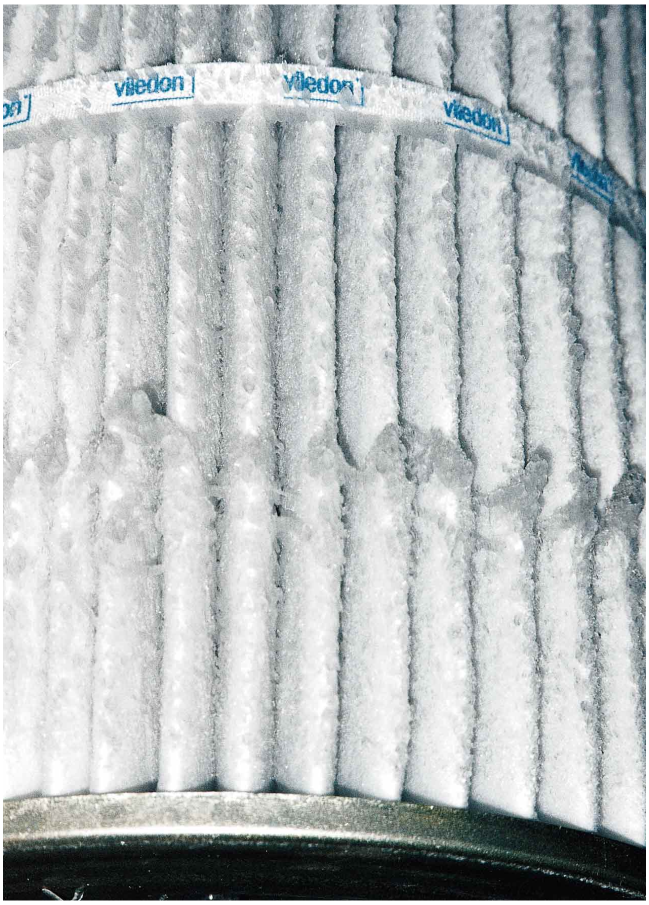


Fig. 14 Viledon depth-loading filter cartridge with porous ice layer

During the first three months operation of the Viledon depth-loading filter cartridges, the pressure drop (as measured in the Freudenberg test channel) rose from 118 Pa (new state) to 176 Pa. Dust deposit was measured at 100 g.

Table 5 shows a comparison between the surface-loading filter cartridge used in the compressor station and the Viledon depth-loading filter cartridge type TFP 60 P 66 P 2. Both cartridges were tested in the test channel in broad conformity with EN 779.

	Surface-loading filter cartridge	Depth-loading filter cartridge
Volume flow rate	1,000 m^3/h	1,000 m^3/h
Average arrestance	98.4 %	99 %
Initial pressure drop	147 Pa	118 Pa
Dust holding capacity (ASHRAE dust at 800 Pa)	522 g	610 g

Table 5 Comparison between surface-loading and depth-loading filter cartridges

This direct comparison clearly shows the higher initial pressure drop and the lower dust holding capacity of the surface-loading filter cartridge.

Further disadvantages are produced for the surface-loading filter cartridge by the use of an outer support cage increasing the weight of the cartridge. Thus the cartridges are heavier to handle and rendering disposal more difficult. This outer support cage is the main reason for icing up of these cartridges quite often.
Also, the filter paper in this kind of cartridge is extremely sensitive to moisture. Fig. 15 shows how the paper swells, and as a result the pleats are touching each other. In consequence operational reliability is reduced, especially when it is foggy.

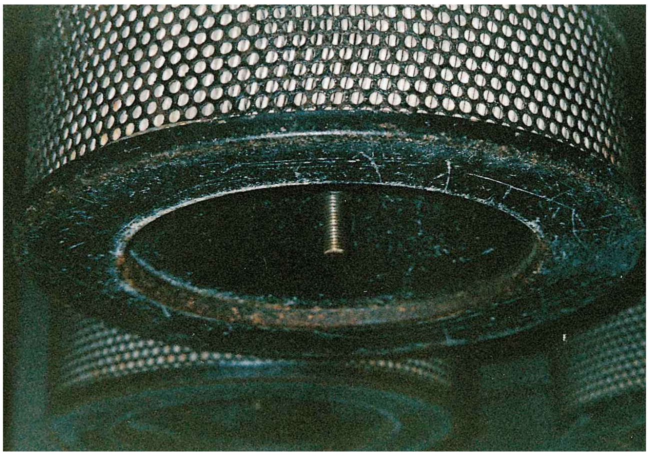


Fig. 15 Surface-loading filter cartridge with outer support cage

Viledon depth-loading filter cartridges, on the other hand, offer high operational reliability and a low damage risk during installation, due to the high mechanical strength of the filter medium.

Apart from the application described, further applications confirm the positive feedback from the field with regard to low operating pressure drop and the behaviour of the Viledon depth-loading filter cartridges when exposed to humidity and critical temperatures.

The behaviour of the cartridges at critical temperatures showed that pulse-jet cleaning is not necessary. There is no need for a compressed air supply either.

Since they do not have an outer support cage (compared to conventional cartridges), the Viledon depth-loading filter cartridges are easier to handle. Also disposal costs and the risk of icing up are reduced.

Conclusion

The newly developed depth-loading Viledon MaxiPleat filters and Viledon depth-loading filter cartridges offer the users of gas turbines and turbocompressors numerous advantages in terms of clean air quality in the combustion air, cost-efficiency due to favourable pressure drop, long life and high functional reliability over the entire operating period.

The Viledon MaxiPleat filters fitted with a paper-like filter medium are produced by using the patented thermal embossing process, distinctive for its solution to the spacing problem. Without using any additional materials as separators, depths of 250 mm can be achieved in pleating, with V-shaped, flow-optimized pleat geometries. This ensures low pressure drops and high dust holding capacities.

The Viledon depth-loading filter cartridge is intended as a replacement filter for surface-loading filter cartridges giving unsatisfactory results. A conventional pulse-jet system can be converted to a depth-loading filter without any expensive modification. The Viledon depth-loading filter cartridge substantially extends the useful life of the filters and significantly improves the pressure drop characteristics, especially when sticky dusts and high humidity locations are involved.

Freudenberg Filtration Technologies KG
69465 Weinheim / Germany
Tel. +49 (0) 6201/80-6264 | Fax +49 (0) 6201/88-6299
viledon@freudenberg-filter.com | www.viledon-filter.com