High Efficiency Oil Separator for Crankcase Ventilation in Passenger Car Applications

Leadership in Filtration

MANN+HUMMEL

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1. Introduction

Blowby is an aerosol which is produced in the crankcase of an internal combustion engine. The root cause is a gas leakage, which occurs at the piston rings of the combustion chamber, at the valve shafts and at the bearings of the turbo charger. At the same time different kinds of atomisation mechanisms and also condensation cause a significant loading of the blowby with small oil droplets. The amount of dispensed oil and also the particle size distribution of the droplets depend basically on the engine design and the operating conditions. In general the particle size ranges from a few microns down to nanometres. Additional components of the blowby are fuel, water, soot and other products of the complete and incomplete combustion.

The closed crankcase ventilation system protects the environment from the hazardous crankcase emissions. The blowby is passed into the intake system and thus finally is eliminated in the combustion process. The fundamental functions of the ventilation system are to recover the oil to the greatest possible extent and to control the crankcase pressure. A typical setup of a closed crankcase ventilation system of turbo charged gasoline engines is illustrated in figure 1. The crankcase ventilation system includes the components for oil separation and also additional components for crankcase pressure and flow control. The whole system is preferably integrated in the cylinder-head cover. Figure 2 gives a product example of a cylinder-head cover with an integrated ventilation system.

Of course an efficient oil separator is important for the minimisation of the oil consumption. But furthermore the oil separation in a closed crankcase ventilation system is fundamental for the compliance with the exhaust gas regulations of modern engines. For example the oil emission could cause critical deposits in the intake system, on surfaces of the turbo charger, the inlet valves or the intercooler. This would decrease lifetime and function of these components. In addition oil emissions from the crankcase could disturb the combustion process by preignition and could increase the soot particle content within the exhaust gas. Finally the residuals of combusted oil could affect the performance of the after-treatment of the exhaust gas.

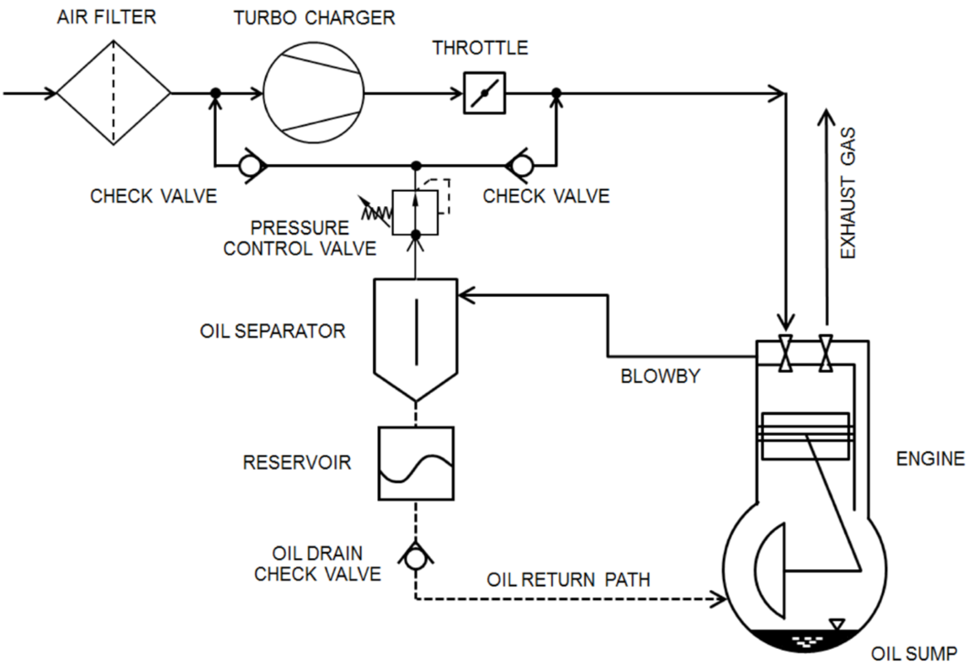


Figure 1: Typical setup of a closed crankcase ventilation system (turbo charged gasoline engine).

Figure 2: MANN+HUMMEL Cylinder-head cover with integrated crankcase ventilation system.

2. State of the art oil separation

The blowby volume flow, the size of the generated particles and the oil mass flow in the raw gas depend strongly on the engine design and the changing operation conditions. Thereupon the oil separator has to fulfil high demands on costs, minimum package and robustness. Especially for passenger car applications only lifetime parts have been accepted so far, which do not need any additional energy supply. As a consequence so called passive inertia separators are established worldwide for passenger car applications.

The separation principle of a passive inertia separator is based on acceleration and redirection of the flow, so that the oil droplets cannot follow the stream lines due to their inertia and are separated on a surface. The separation efficiency of smaller particles gets higher with increasing acceleration respectively redirection of the flow. An increasing pressure difference is needed for this purpose. As a consequence the separation efficiency depends on the pressure difference and the particles size distribution in the raw gas.

Figure 3 shows the MANN+HUMMEL inertia separator called SD-Separator (Structured Deflector Separator). The blowby is accelerated through small nozzles and redirected at a special structured deflector, where the oil droplets are separated. The surface structure of the deflector boosts the separation performance to the highest level of passive inertia separators (figure 8).

The maximum differential pressure of the oil separator is limited by the available vacuum in the intake system and the requirements on the crankcase pressure range, which in the end limits the achievable separation performance. The separation of large particles is usually a comparatively simple task, whereas separation gets more and more challenging the smaller the particles in the aerosol are. This is particularly true for the most commonly used separation concepts which are based on the inertia effect of the particles.

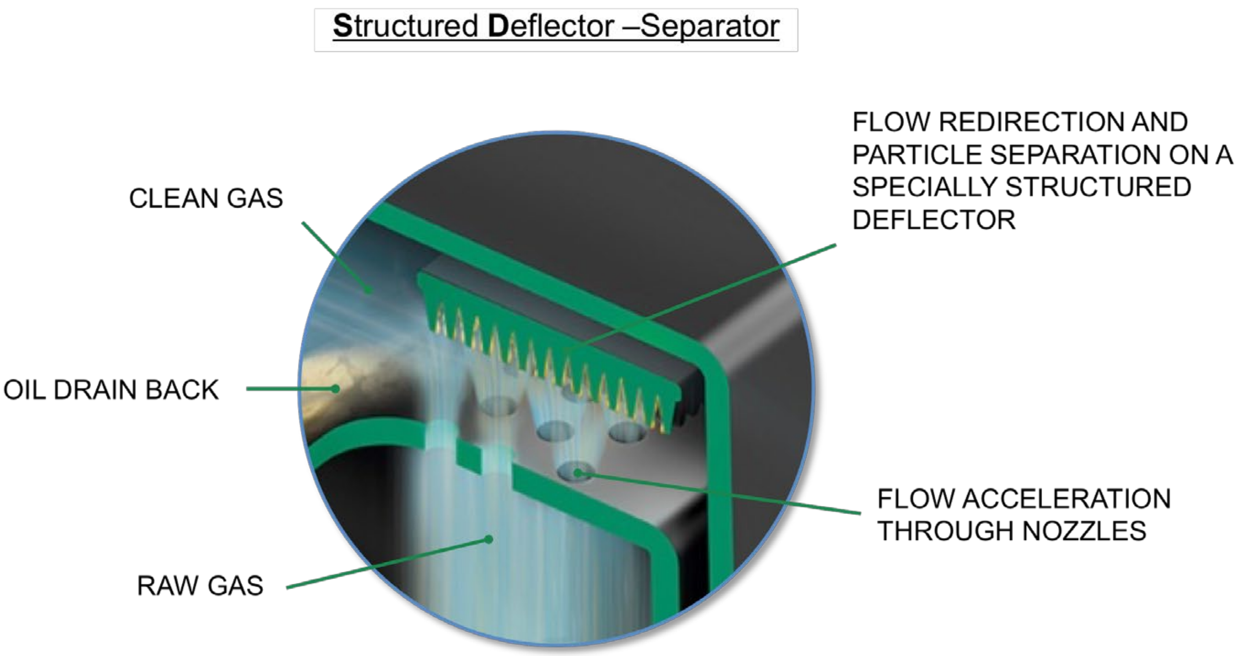


Figure 3: MANN+HUMMEL lifetime inertia separator.

3. Increasing requirements for oil separation

The steady increase of the combustion pressure as a consequence of downsizing as well as the use of low viscosity oils result in a significant decrease of the particle size. Accordingly the performance of the established passive inertia separators becomes more and more insufficient at the given limiting factors. New technologies are needed for passenger car applications in order to provide highly separation efficiency of particles much smaller than 1 µm (figure 4).

The separation efficiency of small droplets can be increased in principle by increasing the inertia force using additional energy. Centrifuges are well-known examples of this kind of separator technology. The energy is used to actuate some kind of rotor and particles are separated due to the resulting centrifugal force. Typically, such centrifuges need very high rotational speed in the range of 10.000 rpm or alternatively the package has to be very large especially for the separation of particles much smaller than 1 µm.

Another solution to increase the separation efficiency is the usage of additional separation mechanisms such as the diffusion separation. The so called fiber demister is a well-known example of this type of separator, combining the benefits of different additional separation mechanisms (see following paragraph).

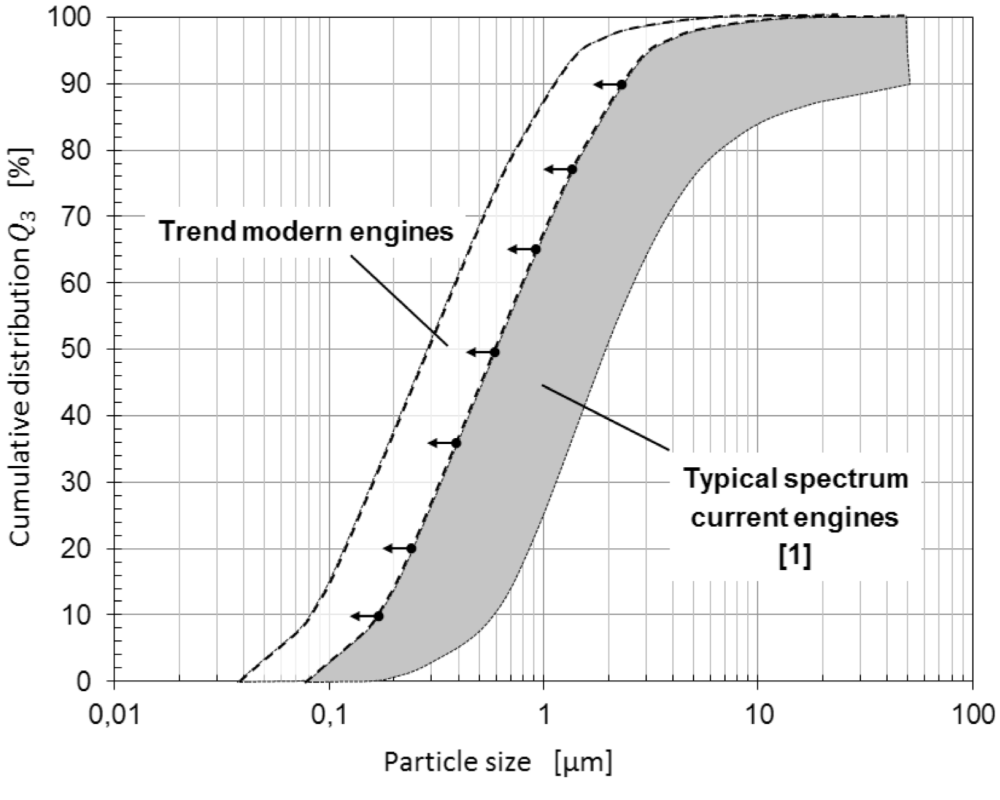


Figure 4: Blowby particle size distribution.

Both mentioned technologies are already well established in the area of truck and industrial applications, where similarly high requirements have existed for years. Especially fiber demisters could provide a very interesting solution for passenger car applications as well. The fiber demister could be individually designed in almost any round or flat geometry (figure 5). This enables the integration even in complicated packages without compromises in the performance, coincidently minimizing the integration complexity and the associated costs significantly. The fiber elements are usually exchanged within a service interval after a certain running time due to the deposit of soot on the fiber surface. The service interval depends strongly on the specific application.

The basic requirement for the suitability of a fiber demister for passenger car application is the development of new fiber demisters, which provide high performance and also an acceptable long service interval at the given operating conditions. At the same time the differential pressure and also the dimensions have to be compatible with common passenger car requirements. MANN+HUMMEL meets this challenge and is developing new fiber demisters for passenger car applications. After a short introduction into fiber demisters the latest results of ongoing development are presented to illustrate the potential of this technology for new passenger car applications.

Figure 5: Diversity of element design (examples).

4. Separation mechanism of fiber demisters

Filtering separators are a worldwide common method for highly efficient separation of superfine particles. The droplets coalesce in the liquid/gas separation process on the fiber surface forming a liquid film, which drains out of the filter media consecutively. Residual droplets on the clean gas side of the filter could either be non-separated droplets of the aerosol (so called penetration) or be generated by bubble formation and collapse from the separated liquid film (so called entrainment), see also figure 6.

The gravimetric separation efficiency η_g in the stationary condition is calculated according:

$$\eta_g = 1 - \frac{\dot{m}_{Penetration} + \dot{m}_{Entrainment}}{\dot{m}_{Drainage} + \dot{m}_{Penetration} + \dot{m}_{Entrainment}} \qquad (1)$$

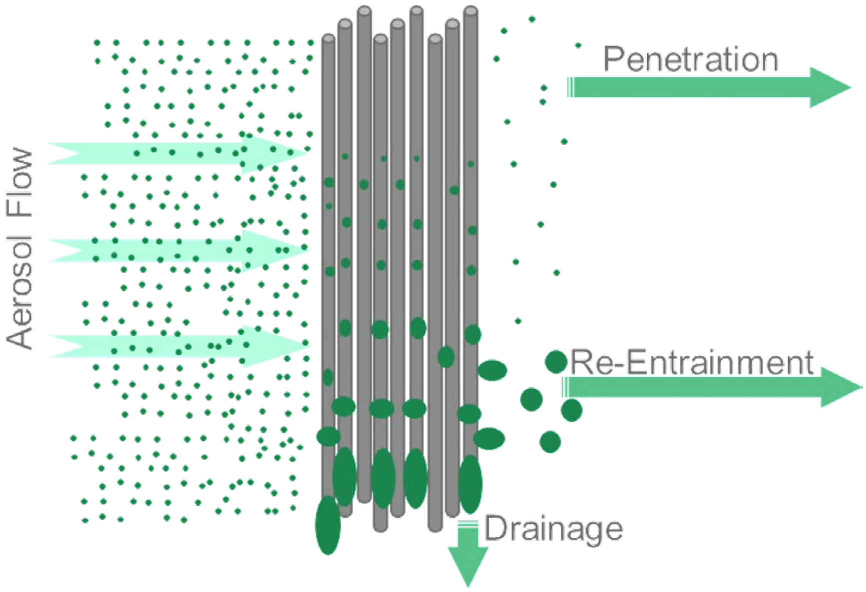


Figure 6: Separation principle of fiber demisters.

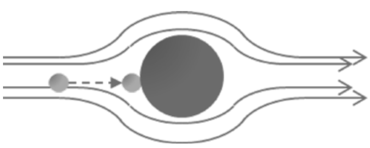
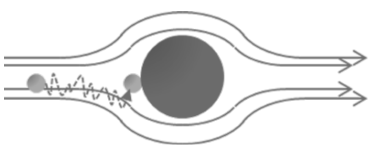
Impaction	Diffusion	Interception
		
Droplets cannot follow the gas flow lines around a fiber due to inertia and are separated.	Droplets can follow the flow line of the gas around the fiber, but collide accidentally with the fiber due to Brownian motion and are separated.	Droplets can follow the gas flow line around a fiber, but touch the surface and are separated.

Table 1: Relevant separation mechanism for fiber demisters in crankcase ventilation.

Different kinds of separation mechanisms can be distinguished in general according to the separation theory. For crankcase ventilation, relevant separation mechanisms are in particular impaction, diffusion and interception (see table 1).

The separation efficiency based on impaction and interception increases with increasing particle size, whereas the separation efficiency based on diffusion effects increases with decreasing particle size. Figure 7 illustrates the individual separation efficiencies as a function of the particle size, which is the so called fractional separation efficiency η_f. The resulting overall fractional separation efficiency is given by the cumulative curve accordingly. The theoretical approach shows clearly the significant impact of the diffusion mechanism in the relevant submicron size range.

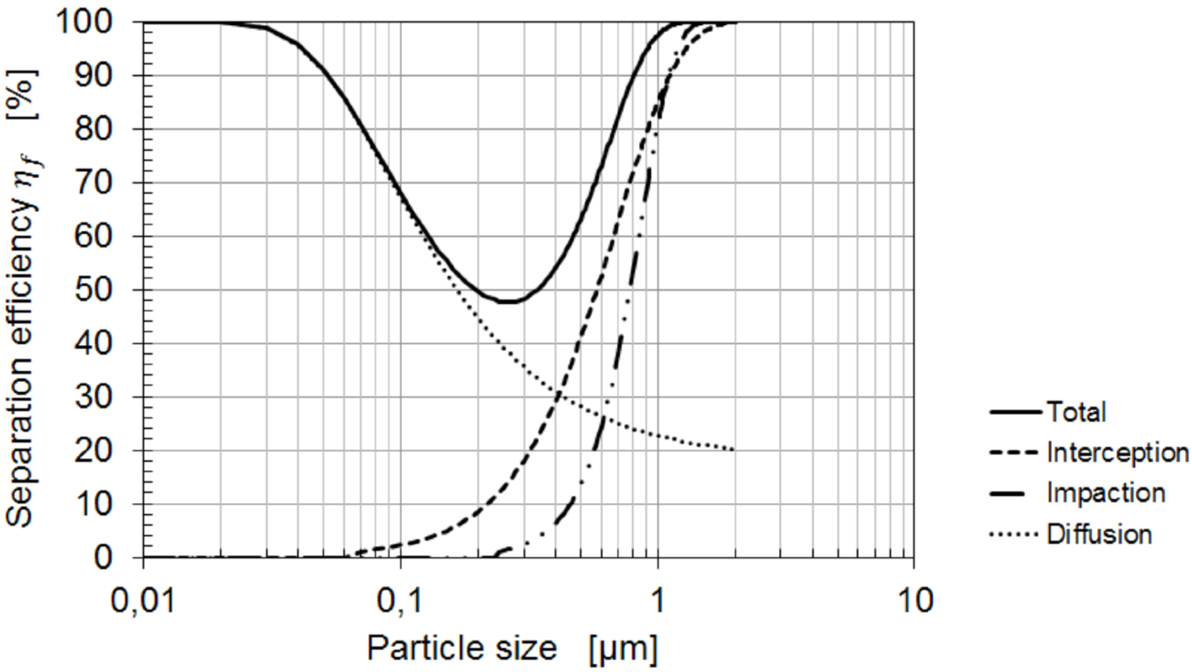


Figure 7: Fractional separation efficiency η_f of different mechanism on basis of a theoretical approach at typical operating condition of an oil separator [2].

5. Performance of the new fiber demister

The newly developed MANN+HUMMEL fiber demister for passenger car applications was tested on the test bench and compared to various state of the art inertia separators. The results are shown in the next section followed by parameter examinations providing the required basis for the design of customer specific solutions.

5.1 Test results

In figure 8 the gravimetric separation efficiency η_g as a function of the differential pressure Δp is shown. As already mentioned the separation efficiency of inertia separators will decline for low differential pressure due to the reduction of the resulting inertia force, which is the main separation effect for particles >1μm (see also figure 7). Due to additional interception and particularly diffusion effects, the separation efficiency of the fiber demister remains at a very high level >>90% for relevant operating conditions, depending in detail on the particle size distribution of the raw gas emissions.

The design parameter to achieve the required separation efficiency is the thickness of the filter media *H* and of course the media structure on the micro scale itself. The allocable surface of the fibrous filter media defines the pressure drop under the specific operating conditions.

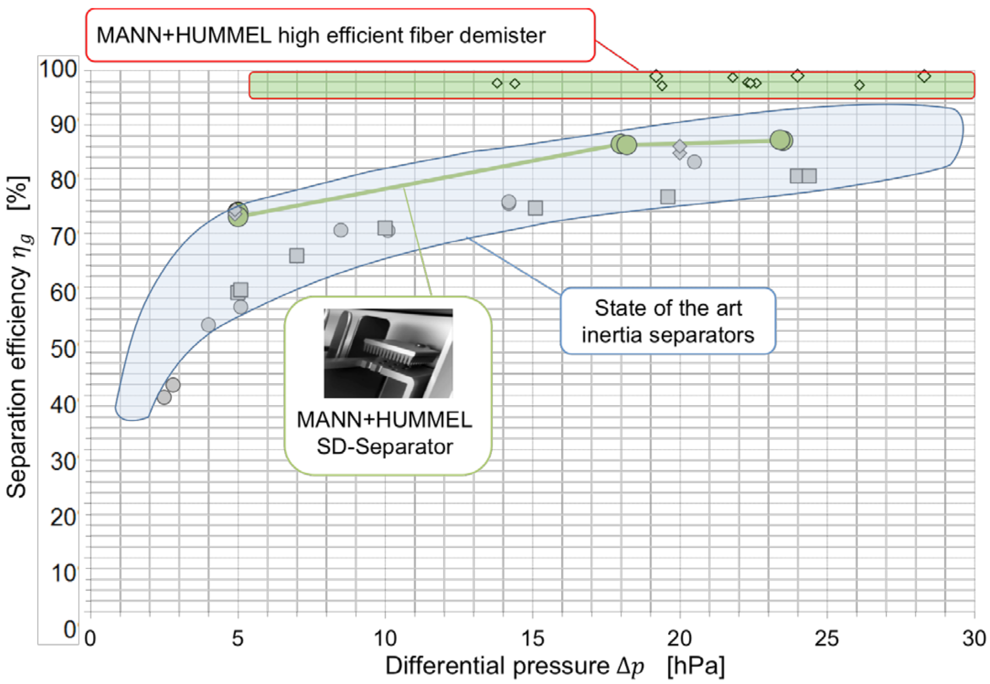


Figure 8: Fractional separation efficiency η_g of different mechanism on basis of a theoretical approach at typical operating condition of an oil separator [2].

The fractional separation efficiency η_f of a prototype of the MANN+HUMMEL fiber demister and a passive inertia separator at the same pressure loss is shown in figure 9. With the fiber demister droplets smaller than 0,3 μm can be separated additionally due to the diffusion mechanism compared to a passive inertia separator.

The prototype is designed within the available space of a real customer solution regarding media thickness and allocated filter surface. This illustrates the potential of the new MANN+HUMMEL high efficiency fiber demister meeting the needs of current and future customer demands regarding the separation of even the smallest particles. This advantage becomes even more important with future engine technologies, resulting in smaller droplet size distributions as illustrated in figure 4.

Figure 10 shows the increasing advantage of the fiber demister for decreasing d_{50} values of the raw gas particle size distribution with respect to the gravimetric separation efficiency η_g. Basis for this calculation is an assumed RRSB-distribution for the raw gas and the measured fractional separation efficiencies shown in figure 9.

Feasible automotive implementations of our new high efficiency fiber demister could be flexibly adjusted within the customer's engine compartment as a standalone part or also be integrated in the cylinder head cover. Such an example of an integrated concept is shown in figure 11.

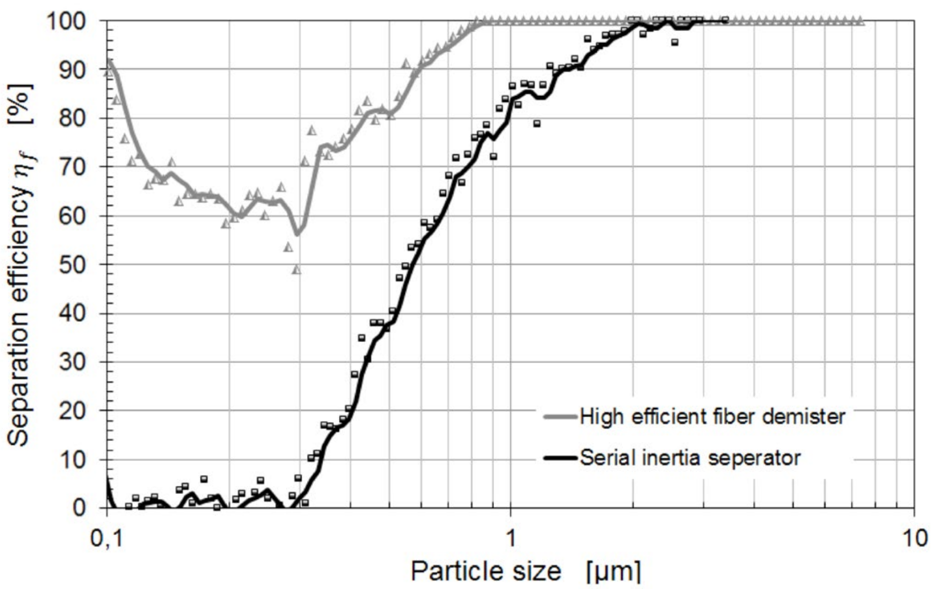


Figure 9: Fractional separation efficiency η_f of the high efficiency fiber demister (thickness: 2*H**, see also fig. 13) compared to a serial SD separator at the same pressure difference.

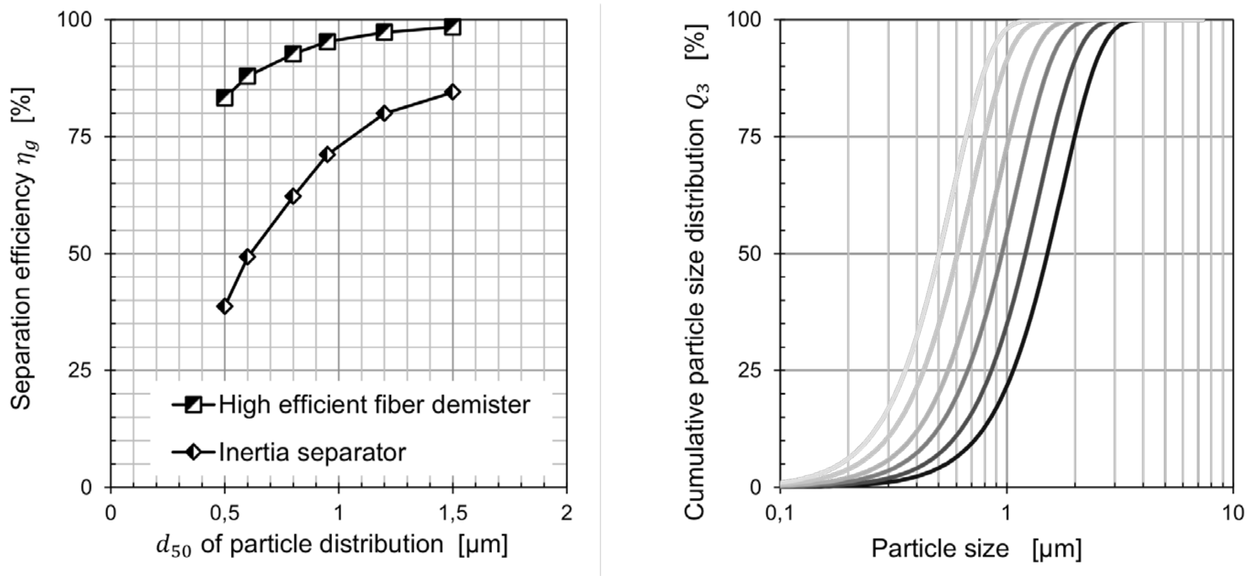


Figure 10: Comparison of the gravimetric separation efficiency η_g (left) calculated for different raw gas particle size distributions Q_3 (right). Variation of cumulative particle size distribution: d_{50} = 0,5 ... 1,5 μm; RRSB.

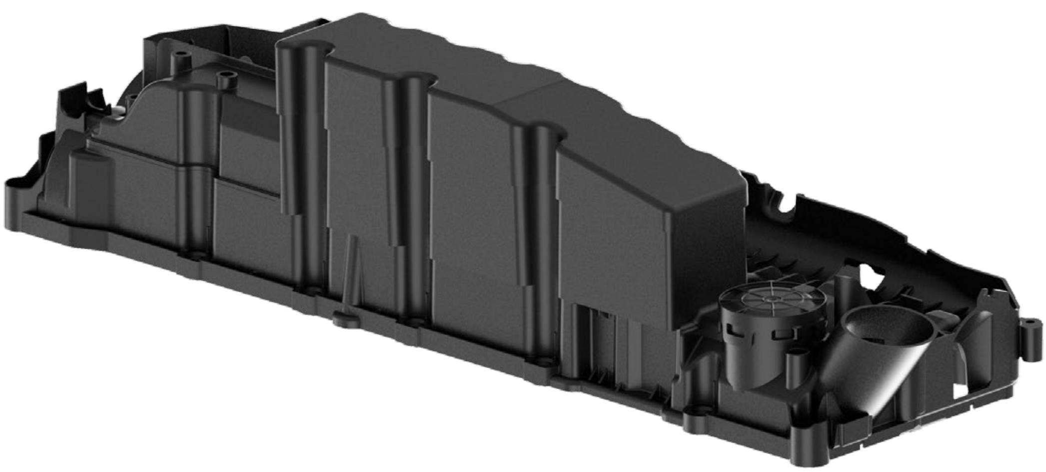


Figure 11: Integration of a high efficiency fiber demister in a cylinder head cover with a thickness of 3*H**
(definition of *H** see subsequent paragraph).

5.2 Design parameter and their influences on the characteristics of the fiber demister

In figure 12 the measurement of the differential pressure for different media thicknesses is shown. The starting point of the measurements was pre-saturated media. The velocity was successively increased without additionally charging the media with aerosol. There is a specific velocity *v** (independent of the media thickness) where reduced oil saturation in the layer results in a decrease of the slope of the curves progression. Looking back on figure 8 it is evident, that this increasing drainage does not lead to a reduction of the separation efficiency under the shown use-oriented operation conditions as the underlying filtration velocities in figure 8 are $\lessgtr v^*$. Figure 13 shows the effect of the design parameter media thickness *H* on the fractional separation efficiency η_f and normalized differential pressure *Δp/Δp** (figure 13, left). Testing conditions were a velocity of 1,7*v** and a raw gas oil concentration of 3,3 g/m³. The decreasing gradient of the pressure difference with increasing thickness H shows a more efficient separation for increasing media thickness (figure 13, right). The size of the separator (i.e. media thickness and filtration surface) is therefore the limiting design parameter for increasing the oil separation in real applications.

The oil raw emission of a passenger car engine is typically much higher than the emission of an industrial application. In addition the emission varies a lot among different engines and operating conditions. Therefore one scope of the investigation was the impact of high oil loads on the separation performance. The influence of the raw gas oil concentration was tested in the test bench. The filtration velocity was varied from 0,4*v** to 1,7*v** and the results are shown in figure 14. The separation efficiency of the MANN+HUMMEL fiber demister is independent of the raw gas oil mass in the considered range of 0,8 - 4,0 g/m³ and keeps a constantly high level.

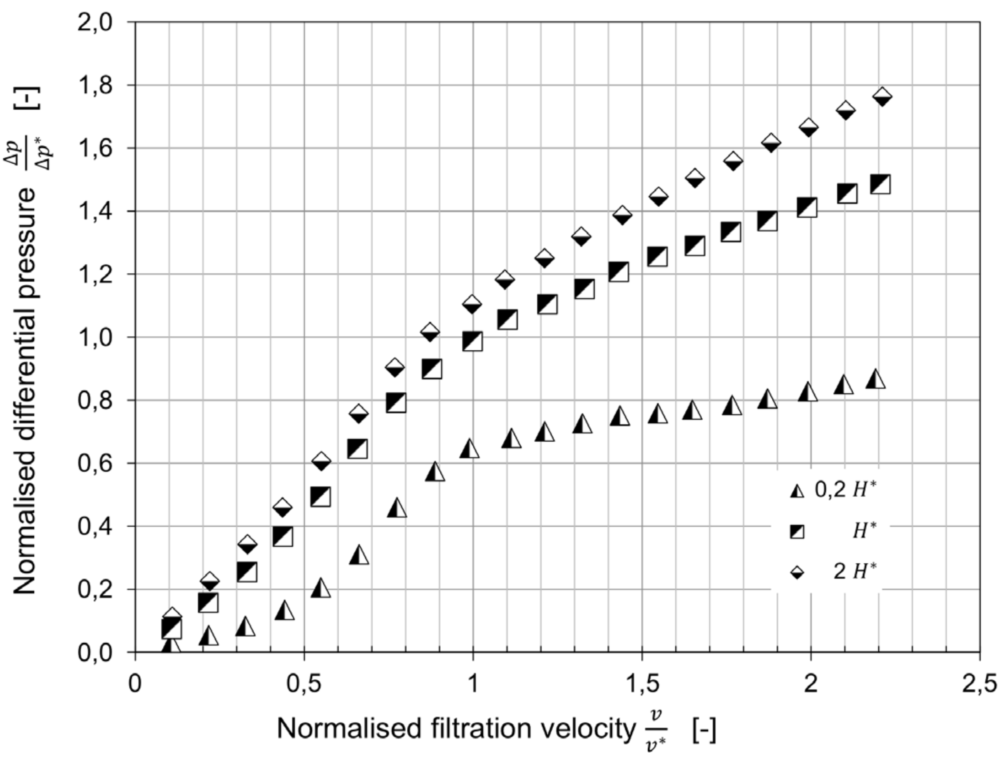


Figure 12: Normalized pressure drop as function of normalized filtration velocity and different media thickness.

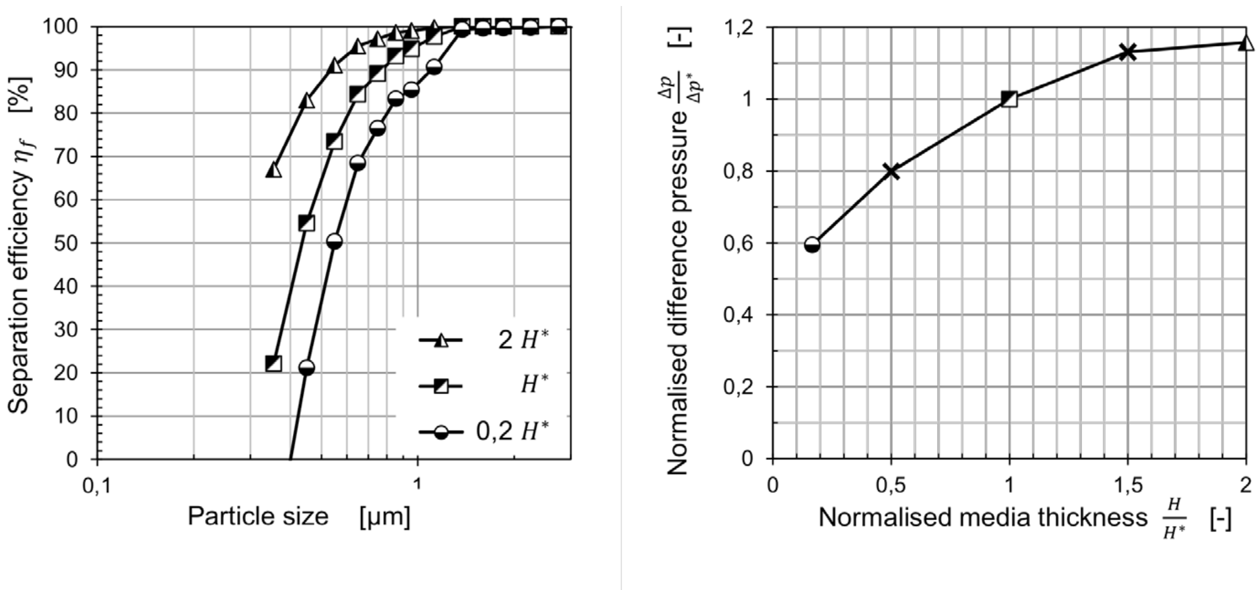


Figure 13: Fractional separation efficiency η_f at 1,7 v^* and 3,3 g/m³

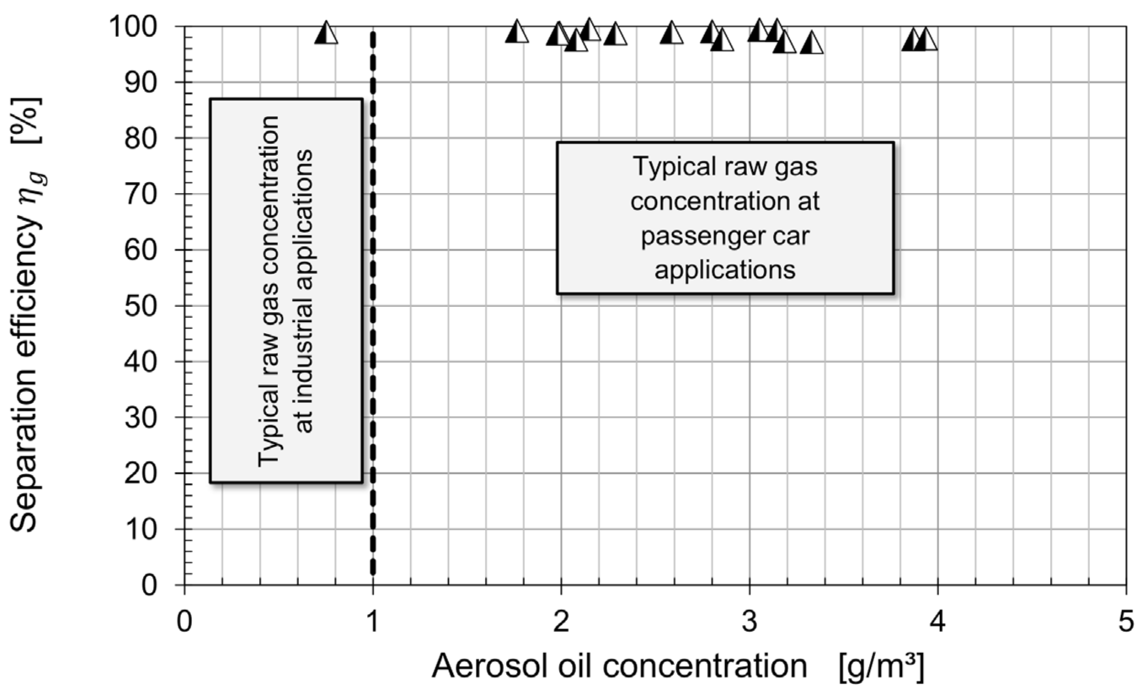


Figure 14: Influence of the raw gas oil concentration on gravimetric separation efficiency η_g.

6. Summary and outlook

MANN+HUMMEL propose a new high efficiency fiber demister for passenger car applications. The presented results demonstrate the capacity of the new separation concept to fulfil the upcoming needs of new engine technologies resulting in the requirement to efficiently separate very small particles with d_{50} << 1μm. Being flexible in designing round, flat and also curved elements, ideal package utilization can be achieved. The results show a very good separation efficiency and stable separation performance under relevant operating conditions regarding filtration velocity and aerosol oil concentration for realistic package-fitting dimensions of the new fiber demister.

The verification of a continuously high performance over lifetime and of a realistic feasible service interval is scope of ongoing investigations in endurance tests on different kind of Diesel and Gasoline engines. First results already demonstrated the constant performance and indicate a promising service interval of at least 100.000 km.

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