Keeping the oil in the engine

New, highly effective systems separate oil droplets from the blow-by gas and ensure the efficient functioning of engines

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Each time the fuel-air mixture is ignited in petrol and diesel engines a small portion of the gases flows from the combustion chamber into the crankcase as leakage current. For the engines to function optimally, it is necessary to dissipate these so-called blow-by gases and separate the engine oil droplets contained within them. This reduces the pollutant emissions and oil consumption of the engines. For modern, higher-compression engines, researchers have developed new and effective separation systems that undercut the more stringent emission limits for oil mist.

Downsizing is the current task of modern combustion engines: smaller, higher-compression engines achieve high outputs out of less cylinder capacity. As a result, significantly smaller oil particles are to be separated from the blow-by gas in the crankcase ventilation. Depending on the available installation space, passive separation systems, such as simple impact separators, can also be used in vehicles for crankcase ventilation in combination with, for example, fleece materials for enlarging the surface of the baffles or cyclones. Actively driven separators, such as disc stack centrifuges, are also already being used in the commercial vehicle sector. The challenge for the developers was to design separation systems, in particular for very fine oil droplets, that have a better separation performance than the simply constructed passive systems. In addition, the new system should be inexpensive to produce and need as little energy as possible for the drive.
The treatment of the blow-by gases largely prevents oil droplets dripping into the intake system. These would soil engine components such as intercoolers

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and valves and impair the function of catalytic converters. Oil droplets settling on the blades of the turbocharger are decreasing its efficiency. The power density of the internal combustion engine decreases, the efficiency drops and the fuel demand increases.

High performance engines need more efficient separation systems

Very fine droplets are partly created in highly turbocharged engines as a result of the high mean pressures during combustion. This is where the passive oil mist separation systems used today, such as impactor-fleece separators which are often integrated into cylinder head covers, reach their limits. This is why new, active separation concepts need to be developed for modern, highly-charged engines. The currently available active systems such as disc stack centrifuges, with which even oil droplets smaller than 0.5 µm are separated with high efficiency, have until now been limited to use in the commercial vehicle sector owing to their space requirements.

For this reason, researchers from the ElringKlinger AG component manufacturing company and the Institute of Mechanical Process Engineering (IMVT) at Stuttgart University developed two physically different, active separation concepts: a centrifuge and a wet scrubber. These are more efficient than existing systems and take up less space. It is intended that they can be used in the future for a wide variety of applications. While the centrifuge reliably separates fine droplets with a droplet diameter $d50 < 0.5$ µm due to the high speeds that can be generated either by a hydraulic drive or an electric motor, the wet scrubber is used for applications where only a small pressure loss may be generated with simultaneously limited installation space. Both concepts promise high separation efficiency and thus a significant reduction of the oil droplet entry into the intake system of gasoline or diesel engines.

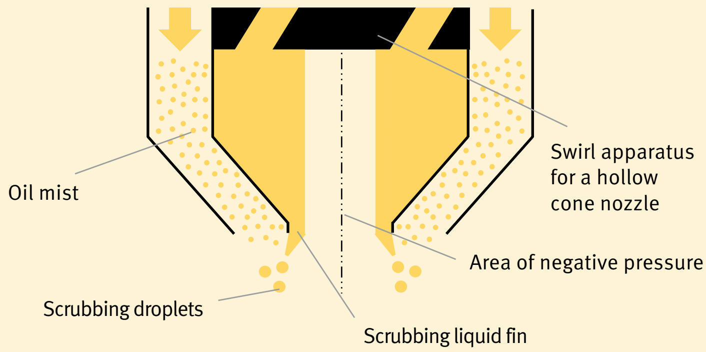

Fig. 1 *Schematic depiction of the operation of a wet scrubber*

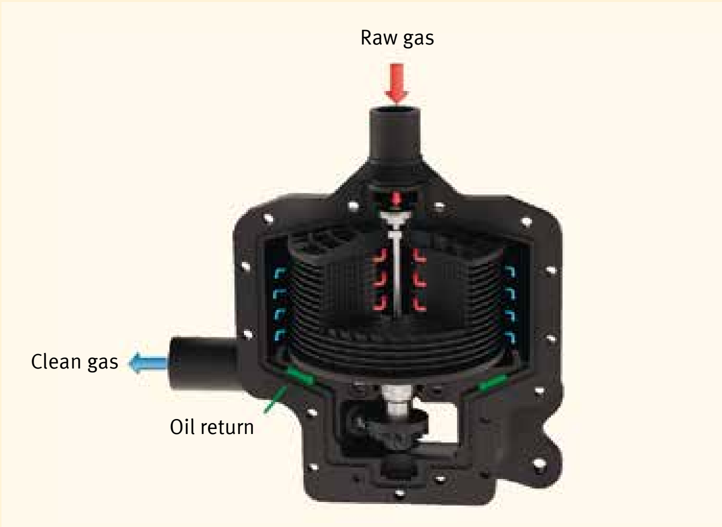

Fig. 2 *Flow of raw and clean gas in a centrifuge with hydraulic drive*

Oil mist separation systems protect engines and the environment

At IMVT, the researchers in particular studied the flow and pressure behaviour of the separation units since this affects how much energy the separation process requires. For the design of the separation units and atomisation elements for the new separation system, they developed mathematical-physical models as well as simulation methods.

At ElringKlinger, the focus was on how such systems can be manufactured in a mass production-oriented and cost-effective manner. In particular, they were looking at how the design could be further developed for its space-optimised use in cars. Intermediate stages were tested on engine test rigs for the further development and optimisation. The researchers investigated the separation concepts with a test aerosol. The particle size distributions measured before and after the separation process enable them to evaluate the separation performance under different operating conditions.

Wet scrubber – big droplets collect smaller ones

For the first time, a compact wet scrubber concept for oil aerosols was tested in the research project that is also suitable for passenger cars. A newly developed model enables the researchers at IMVT to predict the necessary flow rate as well as the mean droplet size of the atomisation process. At the same time, they conducted basic experiments and developed design models to investigate the effects of the relevant spray-side parameters on the separation process. They optimised the wet scrubber concept by comparing the separation efficiency of sprays achieved by different nozzles. Using Computational Fluid Dynamics and physical models they described the decay behaviour of nozzle sprays from hollow cone nozzles. With this data, they adapted the concept in terms of the size and design for separating oil aerosols (Fig. 1). In addition to a high relative velocity between scrubbing droplets and aerosol particles, a high oil flow rate is also advantageous because this increases the concentration of the scrubbing droplet spray and the probability of its contact with the aerosol particles.

ElringKlinger developed an improved wet scrubber geometry and integrated the new wet scrubber into the cylinder head cover of a 4-cylinder diesel engine. Here the engine's pressurized oil is used to create an oil aerosol inside the oil separator by atomising the oil through a hollow cone nozzle. The oil aerosols within the blow-by gas are deposited on the larger oil droplets (scrubbing droplets) formed by this atomisation process. The functionality of the wet scrubber was checked by taking gravimetric and particle size measurements on an engine test bench. Experiments with practice-based oil pressure and oil flow rates showed that these as well as the size of the scrubbing zone and the residence time of the blow-by gas flow are decisive factors for efficient separation.

Figure 3 compares the degrees of separation of a standard impactor-fleece separator and a scrubber calculated from the measurement of droplet size distributions on a 4-cylinder diesel engine from a German OEM. Both

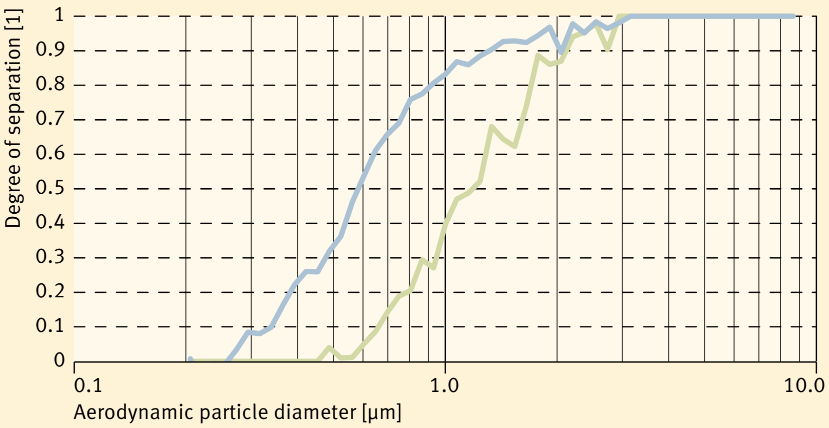

Fig. 3 *Comparison of the separation efficiency of a scrubber and a standard impactor-fleece separator, measured on a 4-cylinder diesel engine.*

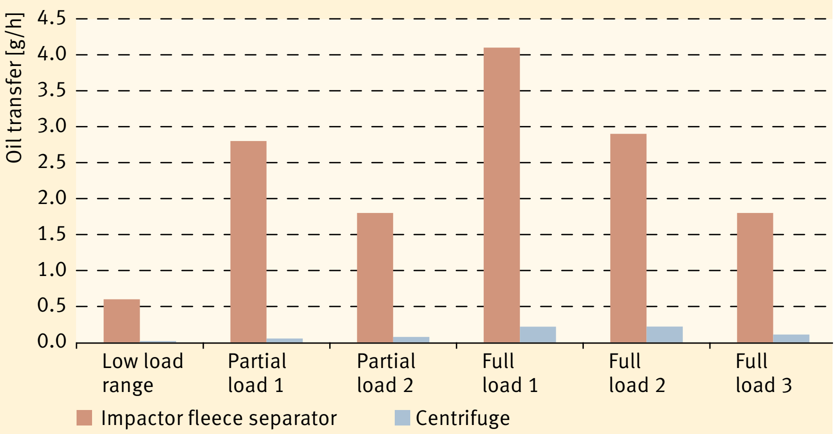

Fig. 4 *Comparison: Separation performance of a disc centrifuge and standard impactor-fleece separator, oil discharge measured on a 4-cylinder diesel engine.*

systems are integrated into the cylinder head cover and are operated in the same pressure loss range of approximately 1.6 mbar. Impactor fleece separators are normally operated in ranges between 10 and 20 mbar to achieve very good separation performance. It has been shown that for applications where only very low pressure loss is available, the scrubber concept provides a greatly improved separation efficiency with a simultaneously low space requirement.

Disc centrifuge – and the oil mist rotates out

The main components of the disc centrifuge are parallel, synchronously rotating discs on which there are diverse ducts within which the separation takes place. The discs have a central borehole through which the aerosol is fed to the ducts on the discs (Fig. 2).

Researchers at IMVT investigated how the housing and discs for the centrifuge can be optimally designed. In this case, an involute shape was determined as the optimum shape for the channels on the individual discs. Based on extensive CFD calculations with experimental validations, they developed a reduced numerical model that can estimate the separation at different operating points within the ducts very quickly. In experiments, they determined the limits and decisive factors for integrating this concept into an application-suitable apparatus. In this several discs are arranged one above the other, resulting in a disc package. The aerodynamic seal concept used here improves the friction and long-term performance.

Based on these findings, ElringKlinger developed separator discs with narrow involute channels and narrow, delimiting ribbed structures, and tested how these can be manufactured out of plastic for the later series product. The aim here was to assess and evaluate the ability to manufacture the injection moulding tool and fill the mould with plastic melt.

In order to design the centrifuge‘s hydraulic drive, the researchers performed flow simulations and experiments. The aim here was to detect pressure losses from various nozzle shapes and to achieve the most efficient possible fluid guidance on the turbine blade. The possibility of electrically driving the disc separator was also investigated. This is supported by higher degrees of freedom in regulating the centrifuge speed over the entire operating map of the combustion engine. Figure 4 shows the oil discharge values of a centrifuge, measured on a 4-cylinder diesel engine relative to a standard impactor-fleece separator. The high separation efficiency of the disc centrifuge significantly reduces the oil discharge to values less than 0.5 g/h of oil for the entire engine operating map.

Systems reducing oil consumption and increase efficiency

Powerful oil mist separation systems can also increase the overall efficiency of engines, especially in the passenger car sector. These reduce fuel consumption and total emissions. Better oil mist separators can also help increase efficiency with stationary engines in combined heat and power plants.

At ElringKlinger the different concepts have now been developed to readiness for serial production. Both, disc centrifuge and wet scrubber were requested for serial production in passenger and commercial vehicles from different OEM. ElringKlinger is currently conducting series tests on the disc centrifuge in cooperation with a German car manufacturer.

Blow-by gases in the crankcase

When the combustion engine ignites the gas-fuel mixture, the expanding combustion gases push the piston down the cylinder. When this happens part of the blow-by gas flows over the piston rings into the crankcase. In order to prevent inadmissibly high pressure here the gas is directed into the intake system. The gas carries very fine oil droplets that are considerably smaller than 1 µm (mass-average diameter 0.8 ‹ d50.3 (µm) ‹ 1.1). It also contains soot, water and unburned fuel. The oil components need to be separated from the flow stream as these will otherwise be deposited in the intake system and impair the function of turbochargers, intercooling or intake valves. Inertial separators such as cyclones or impact separators (impactors) are currently mainly used for this demanding separation task, which aims to reliably separate oil droplets with limited pressure loss in both full load and idle modes.

Separation systems also for industry

In addition to motor vehicles, the active separation systems developed for removing fine particles or droplets are also suitable for other applications. For example, they can be used in stationary engines in combined heat and power plants or for separating oil aerosols from industrial production processes and compressed air systems. Machining processes require the need, for example, to separate cooling lubricant aerosols.

The separation concept utilised by the innovative disc centrifuge can also be deployed for separating suspensions and emulsions as well as for separating solids from gases. It therefore offers potential for handling a variety of tasks and problems in mechanical separation technology.
In addition to the reuse of coolants and lubricants, a more efficient separation system reduces the air pollution caused by fine particles and aerosols in factories, thus improving the working conditions for the employees.

Since the removal of oil mist from exhaust gases can both reduce emissions and save energy and resources, various research organisations and companies are working to develop suitable separation systems.
For example, researchers from the Institute of Mechanical Process Engineering at Stuttgart University are developing an innovative, hybrid counterflow impactor. By optimising the flow pattern, along with a miniaturisation of the separation structures, they want to achieve a significant increase in efficiency compared with conventional impactor separators. The development is being carried out using modern numerical methods in conjunction with complex multi-scale modelling. The focus is on separating oil aerosols that arise in compressed air and vacuum generation. During the course of the project they will produce prototypes and test them under real, industrial conditions.

Project participants

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Links

- ElringKlinger information brochure on lightweight plastic components and oil mist separation: https://www.elringklinger.com/sites/default/files/brochures/downloads/elringklinger_lightweight_plastic_components_en_201708_kopierschutz.pdf

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Fig. 1: University of Stuttgart, Institute of Mechanical Process Engineering

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