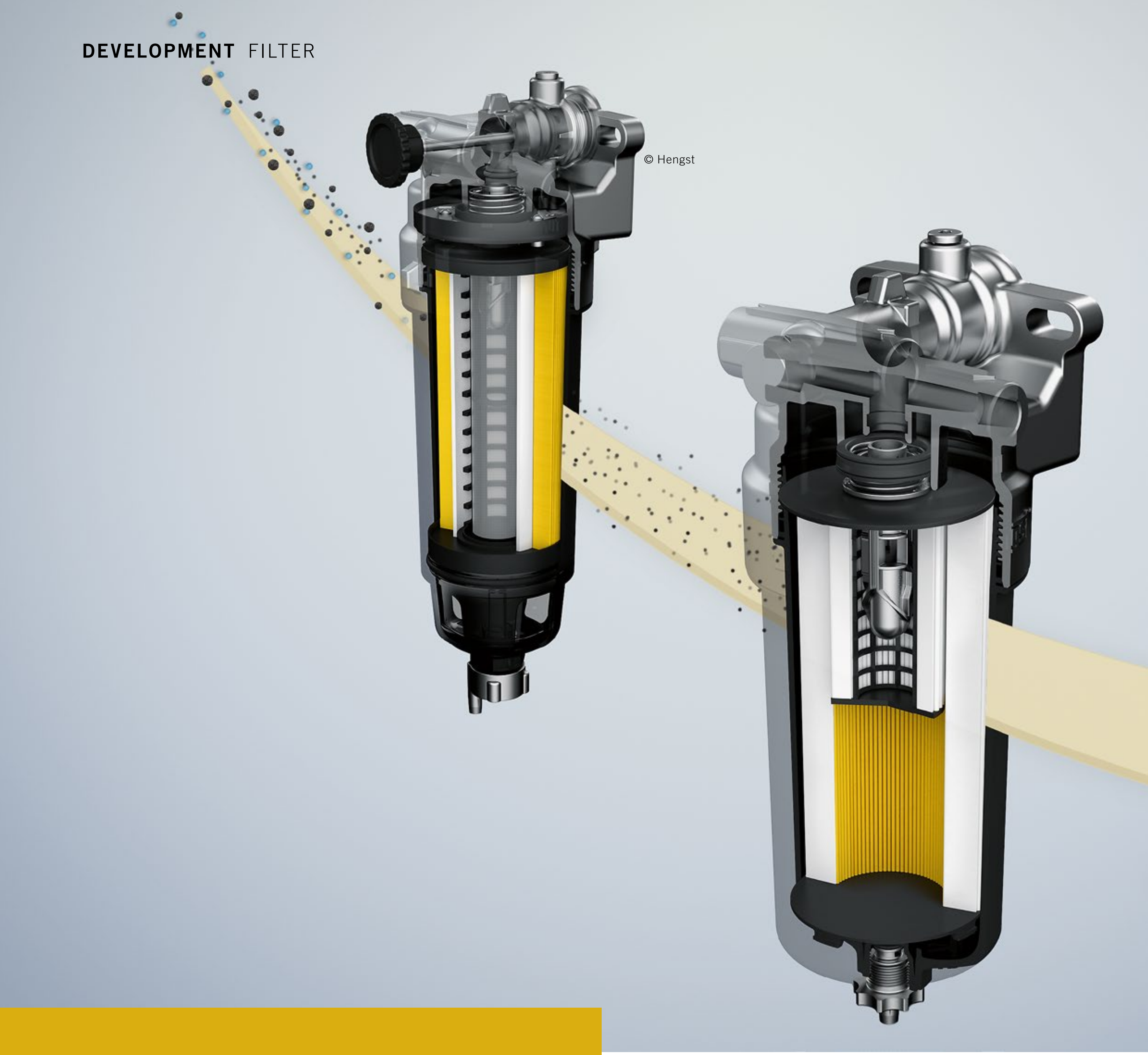
© Hengst

Tailor-made Pre- and Main Fuel Filter Combinations for CV Diesel Engines

Modern diesel engines require highly efficient fuel filter systems. In general, in commercial vehicles, a filter is installed before and after the low-pressure pump. Hengst has dealt intensively with the subject of developing the pre and main filtration as one calibrated overall system. Compared to conventionally designed filters these calibrated systems provide significant performance advantages.

AUTHORS

Dipl.-Ing. Arno Heinen
is Senior Manager Advanced Product Development at Hengst SE & Co.KG in Münster (Germany).

Dipl.-Ing. (FH) Sieghard Pietschner
is Engineer Advanced Product Development at Hengst SE & Co.KG in Münster (Germany).

M.Sc. Moritz Dorschel
is Engineer Advanced Product Development at Hengst SE & Co.KG in Münster (Germany).

Dipl.-Ing. Achim Brömmel
is Chief Technology Officer at Hengst SE & Co. KG in Münster (Germany).

DRIVERS FOR HIGH-QUALITY DIESEL FUEL FILTRATION SYSTEMS

There are few areas in which vehicle filtration has become significantly more complex in the past two decades than in diesel fuel filtration.

The drivers of these requirements were, and are, the impressive technological optimisations of the injection systems. With the objective of increasing efficiency and minimising emissions, components and systems are being further refined and pushed to their technical limits. On the other side, their sensitivity to contamination increases. The system manufacturers are therefore forced to require high fuel purity levels when it enters the injection systems.

In addition, engines in use throughout the world come into contact with highly divergent fuel qualities which are also contaminated, to varying degrees, with particles and water. For many regions in the world, nearly unsustainable upper thresholds for the contamination of the provided fuels can be indicated. The same applies to contamination from solid particles which might come, for instance, from corrosion or wear and tear on upstream fuel provision systems. To a comparable degree, water contaminates the fuels.

Conclusion: The purity requirements for fuel prior to entering the injection system increase while increasingly critical assumptions, with respect to the fuel quality on the raw side, have to be made.

REQUIREMENTS FOR PARTICLE FILTRATION AND WATER SEPARATION

The harmful impact of hard, abrasive particles is particularly critical for the functionality of the injection system components [1]. The contamination of fluids is described in accordance with ISO 4406 by specifying purity classes for the particle sizes from 4, 6 and 14 µm [2]. Today, injection system manufacturers require purity classes between 12 and 16 at 4 µm. On the raw side, the OEMs specify values between 18 and 25 at 4 µm. This means the fuel filter has to fulfil requirements with respect to the efficiency of the particle separation in the range of η (4 µm) = 99 to 99.5 % or even higher.

Alongside the purity requirements with respect to solid particles, focus on the separation of water from the fuel has also increased. On conclusion, it can be stated that insufficient water separation leads to severe damage to the injection system, namely, due to corrosion, cavitation and wear and tear due to insufficient lubrication. In addition, water in fuel serves as the basis of life for micro-organisms and thus promotes microbial contamination.

Diesel fuels have complex designs. They contain bio-diesel components and additives which make water separation effectively more difficult. At the same time, water cannot be completely prevented from getting into the fuel, for instance, due to condensation in the tank. In practice, this is exacerbated in some cases due to an unfavourable layout of the tank ventilation.

Current requirements with respect to the efficiency of the water separation are often in the range of > 95%. In addition, water separation becomes less efficient if the media layers are contaminated by dirt particles after a certain period of use. Ageing effects can also have a negative impact on functionality. Current specifications sheets therefore increasingly demand verification that the water separation function remains constant throughout and beyond the entire service life of the filter or at the very least, does not decrease significantly.

EXISTING SOLUTION CONCEPTS

A fuel filter is installed both before and after the low-pressure pump in various applications with common rail systems in the commercial vehicle segment.

A relatively high hydraulic pressure is available behind the pumps, so a filter with a high filtration efficiency level can be used. This so-called main filter, which is usually installed in direct proximity to the engine, often also performs the water separation function. Due to the complex water separation requirements described above, these systems today comprise several stages: a special media stage is installed on the clean side, behind the particle filter stage, for coalescence, ergo, increasing the size of the water droplets. Then a highly water-repellent sieve is installed as a further media stage which separates the water. **FIGURE 1** shows a schematic diagram of the functions of such a main filter.

The pre-filters which are generally installed on the vehicle frame on the suction side are often added to support the main filter under harsh conditions – as for instance for so-called “bad fuel countries” – or to protect the low-pressure pump. Pre-filters are generally offered in standardised formats and, in the specified cases, selected so their service intervals are not shorter than those of the main filter. At this point, there is significant potential for improvement: consistently designing the pre-filter and the main filter together as a complete system from the beginning significantly increases performance.

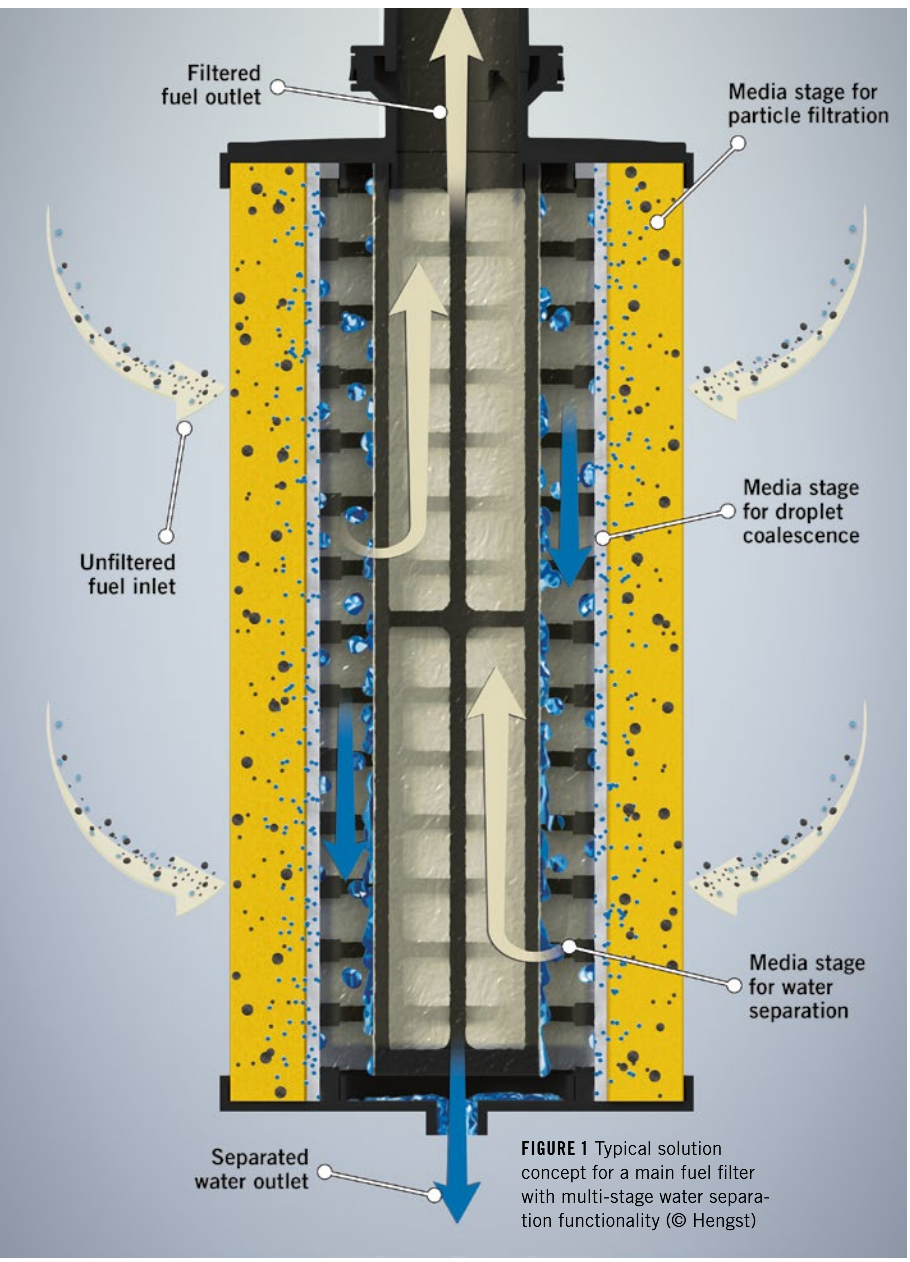

FIGURE 1 Typical solution concept for a main fuel filter with multi-stage water separation functionality (© Hengst)

CASCADE SYSTEMS: DESIGNING THE PRE-FILTER AND MAIN FILTER TOGETHER

The service life of filters is defined by reaching specified differential pressure thresholds throughout the service life due to pores being blocked by dirt particles or other potential mechanisms. The maximum permissible differential pressures for filters installed on the suction side are very low; significantly higher values are permitted for main filters. The objective of the system design is for the differential pressure thresholds of the pre-filter and main filter to be reached approximately at the same time. Thus, the potential of both filters can be developed optimally, **FIGURE 2**. This only works if all media stages are optimally calibrated with respect to evenly storing particles, thus taking advantage of the specific media properties.

If the requirements with respect to filter efficiency and filter service life are high, a cascade layout of several filters or filter stages can be a highly beneficial solution for the task of filtration. The last filter stage on the clean side is generally very fine and therefore has a significant impact on the final fluid purity results. This ultra-fine filter must, however, be protected on the inflow side by one or more coarser upstream filter stages which reduce the number of particles and the size of the particle fractions. A high number of coarse particles for which the ultra-fine filter is not designed would quickly block its fine structure and thus result in premature failure of the filter system.

A modern standard fuel filter medium is already set up like a cascade: the fine-pore cellulose-based filter medium on the clean side is supplemented on the raw side by a synthetic fibre layer which protects the

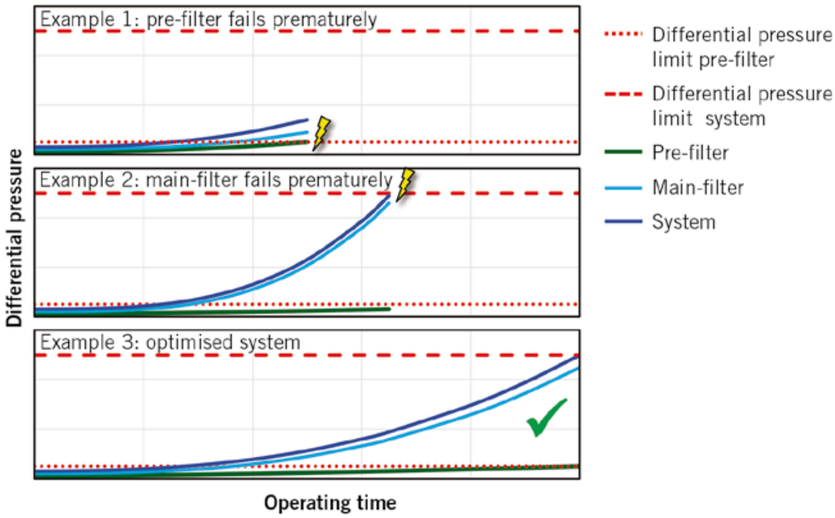

FIGURE 2 Schematic comparison of the differential pressure gradient of systems comprised of a pre-filter and a main filter. Top and centre: System potentials are not being exhausted since one of the two filters reaches its differential pressure prematurely. Bottom: Optimised system with extended service life (© Hengst)

cellulose layer from prematurely clogging.

It is characteristic for cascade layouts that the filtrate of each filter stage is the input size of the subsequent stage. Therefore, the particle distribution in the filtrate has to be analysed and the subsequent filter stage must be precisely designed based on the results. The key to optimising the overall system is to consistently apply this to all filter stages, specify the corresponding filter media and configuring the geometric layout based on this fundamental principle.

FIGURE 3 illustrates the described correlations using an example which is described in more detail below. A three-stage particle filtration system, assuming a particle size distribution corresponding to an ISO medium test dust (MTD) [3] and converted to particle quantities is illustrated. Each of the filter stages results in a modified particle distribution in the fluid to which the design of the subsequent filter stage is specifically adapted. In this manner, a total separation level of η (4 µm) = 99.7 %, measured in accordance with ISO 19438 [4], is achieved.
In the illustrated example, the particles with a minimum size of 4 µm are reduced from purity class 20 (corresponds to 5,000 to 10,000 particles/ml) to purity class 12 (20 to 40 particles/ml), in accordance with ISO 4406.

By consistently applying this method, specific options for achieving optimum results for the filter system with respect to filter efficiency, service life, water separation and construction size open up for any application case. To this end, the boundary conditions for the respective task must be referenced, for example, requirements but also degrees of freedom that result from the vehicle environment and engine design.

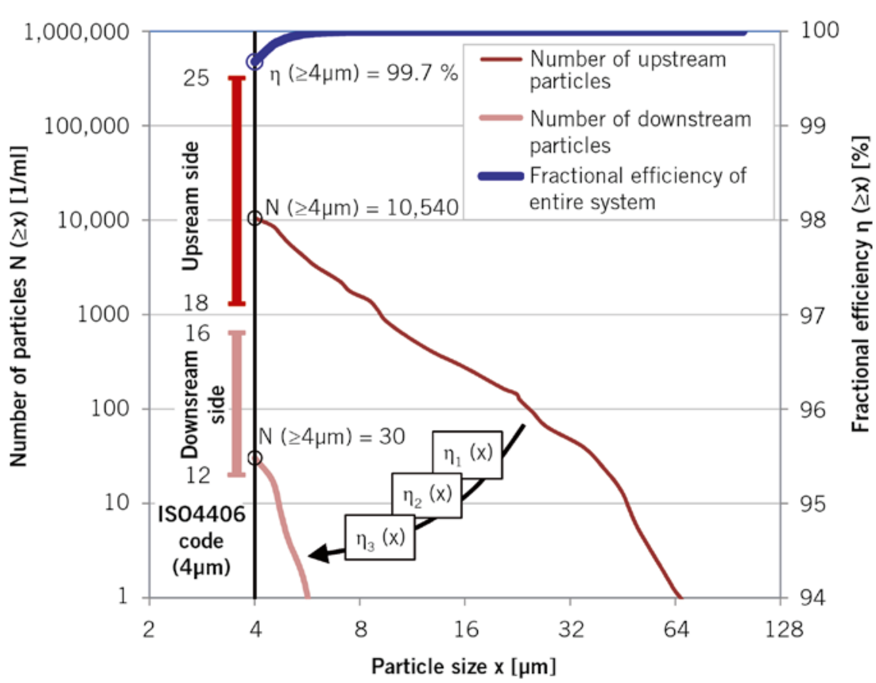

FIGURE 3 Reduction of the particle load via three filter stages arranged in a cascade with different filter efficiencies (© Hengst)

RESULTS OF A DESIGN EXAMPLE COMPARISON

For typical vehicle use, first a system consisting of a pre-filter and a main filter was constructed in accordance with the state-of-the-art. As described above, the core component of this system consists of a main filter, which optimally combines ultra-fine particle filtration and water separation in a small space. In order to take lower fuel qualities into account, a coarse pre-filter, which is selected from a standard, is also installed. In the upper portion of **FIGURE 4** the configuration is illustrated and the achieved functional values are summarised. In order to achieve significantly better values for filter efficiency and dust holding capacity, a fibre-glass filter medium could be installed, but usually many engine manufacturers are sceptical or reject this idea. What they fear is that glass fibers might be released from the filter and cause engine damage as a result of their abrasive properties.

Using the above method, the design was optimised, the results of which can be seen in the lower part of **FIGURE 4**. Initially, the water separation was moved to the pre-filter. This is beneficial since the installation space situation is less critical for the pre-filter than for the main filter close to the engine. In addition, the pre-filter on the frame is highly accessible, for instance, for maintenance. The water

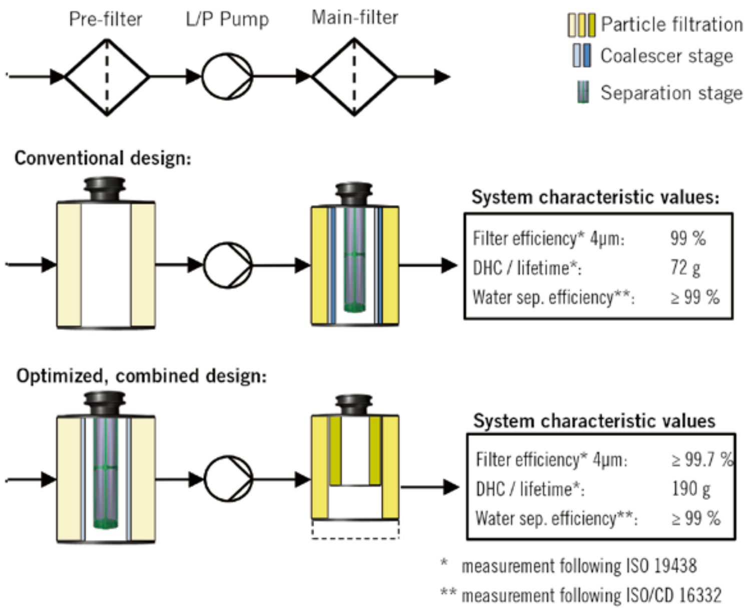

FIGURE 4 Comparison of the functional diagrams and test results of fuel filter systems with conventional designs (pre-filter and main filter functions designed separately, in the figure above) and designed based on the new development method (designed together, in the figure below) (© Hengst)

separator can also be less complex in the pre-filter than if it would be if it had to be integrated in the main filter: before the pump, the water droplets are relatively large on average and can thus be separated more easily. Thus, these media stages can be less fine which significantly reduces pressure losses while on the other hand offering excellent water separation efficiency. The particle filter stage installed on the upstream side was designed so the water separator and the downstream low-pressure pump are effectively protected.

Because the water separation function is no longer in the main filter, additional space is created in which the two-stage, high-efficiency, ultra-fine filtration with excellent dust holding capacity can be installed without glass fibres. A filter efficiency of 99.7 % (4 µm) is achieved as illustrated in **FIGURE 3**. All stages in the five-stage filter system are optimally calibrated in accordance with the method described above. The filter surfaces are balanced so all stages are equally loaded, thus achieving a service life that is significantly higher than the service life of conventional systems.

SUMMARY AND OUTLOOK

Fuel filter systems perform a fundamental protective function for engines in commercial vehicles used throughout the world. Hengst faces the challenge of presumably increasing requirements with multi-stage systems consisting of a pre-filter and a main filter, which are designed based on a consistent development method.

The filter stages are customised and defined in accordance with the respective boundary conditions of each individual application. In comparison to conventionally designed systems, these Hengst fuel filters achieve significantly higher performance benefits with respect to particle filtration, water separation, differential pressure and installation space.

REFERENCES

[1] Verdegan, B. et al.: Case study – Impact of poor diesel fuel quality on an urban fleet. AFS 2013 Spring Conference, Minneapolis , 2013
[2] Norm ISO 4406, 12.1999. Hydraulic fluid power - Fluids - Method for coding the level of contamination by solid particles
[3] Norm ISO 12103-1, 3.2016. Road vehicles – Test contaminants for filter evaluation – Part 1: Arizona test dust
[4] Norm ISO 19438, 11.2003. Diesel fuel and petrol filters for internal combustion engines — Filtration efficiency using particle counting and contaminant retention capacity

THANKS

We would like to thank all of the involved employees at Hengst SE & Co. KG for their participation in this article.