# INNOVATIVE TWO STAGE WATER FILTER

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“Water is life!” this simple sentence shows how important clean drinking water becomes, even in industrial countries. Due to this, the company Grünbeck, as a leader in water treatment solution and the company Hengst, known for leading filtration solutions in industrial and automotive applications, joined to start a cooperation to develop an innovative filter solution for hygienic water treatment applications.

The main target of the development is to find a mobile filtration solution, which can adapt to nearly all drinking water tanks to provide hygienic and pure water.

To ensure a filtration system which is reliable for nearly all drinking water standards a two-stage filter system with a minimum amount of auxiliary materials – for example without any kind of glue within the filter element – has been developed.

The filter element consists of two innovative filter stages with active carbon as, for example, an agent for the removal of chlorine and an additional material for the removing of pathogens and colloids.

Due to the use of the Hengst Energetic concept and ultra-sonic welding processes it is possible to produce a filter element that only consist of the filter materials and plastic components (end cap and inner tube), without any kind of glue or further materials.

The filter element is evaluated by several parameters, especially by retention of chlorine, turbidity and germ reduction.

In figure 1 a chlorine retention curve is shown, comparing the two-stage filter element by benchmarking with a Brand supplier using three stages.

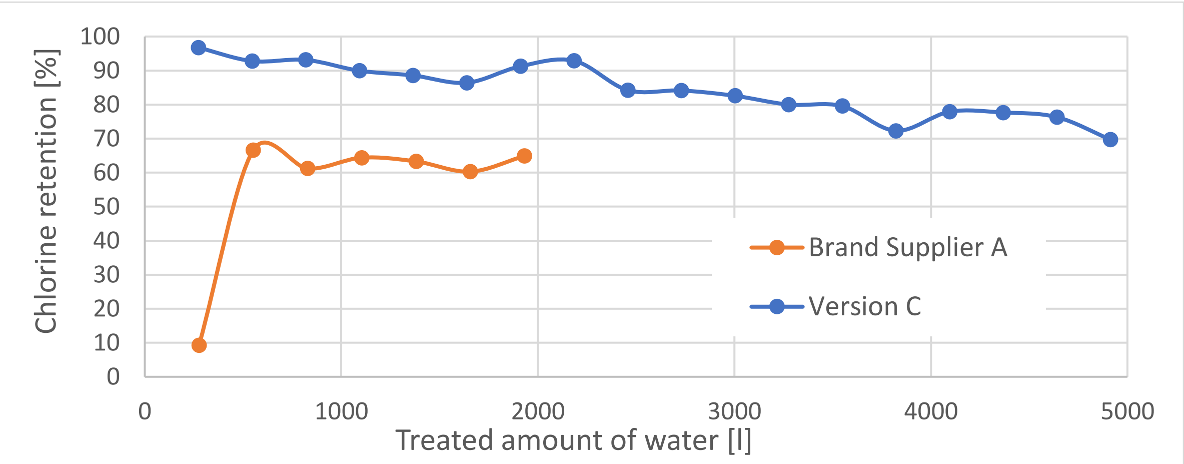


*Figure 1:* *Chlorine retention of raw water with additional free chlorine (A: current at the market available version, C: newly developed version)*

*Keywords: water filtration, water treatment, chlorine retention, pathogens removal, glue free filter*

# 1 Introduction

The filtration of impurities, germs, bacteria and the removal of -for example- chlorine out of drinking water becomes more and more important, due to increasingly strict limits and higher water pollution in all countries.

Following the maxims of the companies Hengst -“making our planet a purer place”- and Grünbeck -“we understand water”- the target of our companies is the protection of people.

According to these maxims Hengst -as one of the leading companies for filter elements in automotive and industrial applications- and Grünbeck -one of the innovative companies for water applications- started a cooperation with the target to develop a mobile filtration solution, e.g. for leisure vehicles. The solution should be adaptable to nearly all drinking water tanks, to provide hygienic and pure water.

Due to the high number of different standards and regulations in water treatment -often depending on the application- a one fits all solution for a drinking water system will not be possible. In the following chapters an overview of the most common standards is given. Furthermore, the production steps and development results of the new two-stage filter system, which fulfils the known standards for systems which are in contact with water, are shown.

# 2 Standards/ Regulations for water treatment

A nearly endless number of standards and regulations for water treatment is worldwide known. Table 1 gives an overview of the most common regulations/ standards for materials in contact with water (with no claim to be complete).

Table 1: Overview regulations for materials in contact with water (non-exhaustive)

| ***Area of validity*** | ***Designation*** |
|---|---|
| *European Union* | • *REGULATION (EC) No 1935/2004 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 27 October 2004 on materials and articles intended to come into contact with food*<br>• *COMMISSION REGULATION (EC) No 2023/2006 of 22 December 2006 on good manufacturing practice for materials and articles intended to come into contact with food*<br>• *COMMISSION REGULATION (EU) No 10/2011 of 14 January 2011 on plastic materials and articles intended to come into contact with food* |
| *Germany* | • *ORDINANCE ON THE QUALITY OF WATER INTENDED FOR HUMAN CONSUMPTION*<br>• *Evaluation Criteria of the German Environment Agency for metallic material. organic materials, cementitious materials enamels and ceramic materials* |
| *United States of America* | • *NSF/ANSI/CAN 61: Drinking Water System Components* |
| *France* | • *Attestation de Conformité Sanitaire (ACS)* |
| *United Kingdom* | • *Water Regulatory Advisory Scheme (WRAS)* |
| *Austria* | • *ORDINANCE ON THE QUALITY OF WATER INTENDED FOR HUMAN CONSUMPTION*<br>• *OENORM series B 5014* |
| *Netherlands* | • *Regeling materialen en chemicaliën drink- en warm tapwatervoorziening* |

## 2.1 Regulation (EC) No 1935/2004 on materials and articles intended to come into contact with food

First, the European Regulation (EC) No 1935/2004 for materials and articles intended to come into contact with food, will be presented in detail. This regulation lays down the basic principles for materials in contact with food. In some member states of the European Union, the regulations for food contact material also apply for water in general. Other member states have laid down more stringent rules on drinking water. Nevertheless, the basic requirements for material in contact with food or drinking water follow the same idea:

Materials in contact with water shall be manufactured and surveyed in a way that they do not transfer their constituents to food in quantities which could

- endanger human health, or
- bring about an unacceptable change in the composition of the food, or
- bring about a deterioration in the organoleptic characteristics thereof.

The necessary processes, tests, certificates, etc. to demonstrate compliance with these basic principles are regulated in further pieces of legislation and technical standards and can be highly individual per country (see Table 1).

## 2.2 Commission Regulation (EC) 2023/2006 on good manufacturing practice (GMP) for materials and articles intended to come into contact with food

The second important European standard from Table 1 is the VO 2023/2006, describing the necessary control systems for the manufacturing of materials/ articles, which are in contact with food. The regulation lays down the basic requirements for a quality assurance system and a quality control system when sourcing, storing, producing and supplying materials and articles in contact with food. Whilst the regulation defines basic principles, detailed and practical rules may rather be found in national standards, in particular for materials in contact with drinking water.

## 2.3 German Ordinance on the quality of water intended for human consumption

One of the most stringent regulations on drinking water is the German Ordinance on the quality of water intended for human consumption. Apart from setting limit values for drinking water to be complied at the point where it emerges from the taps, the German Drinking Water Ordinance lays down requirements for installations for the abstraction, treatment or distribution of drinking water. These general requirements follow the same idea as the basic principles given by Regulation (EC) 1935/2004 (see above), i.e. to ensure that materials in contact with drinking water does not directly or indirectly compromise the protection of human health.

The “translation” of these generic principles into practical requirements for materials in contact with drinking water is done by the German Environment Agency, which has published several so-called Evaluation Criteria, e.g. for metallic and organic materials. These Evaluation Criteria usually provide a positive list on allowed substances/materials and specify the required tests for a material in contact with drinking water prior it can be used in water installations.

## 3 Filter element development and design

The main object of the development was to find a technical high effective filter solution with the lowest possible number of different components to get a robust and error-resistant design, which fulfils all filtration and retention properties (see chapter 3.1.1).

A challenge of this project is the certification of all components for the use in drinking water services. Hereby a production strategy, which is different to the state of the art production technologies, can ensure a minimum number of needed components and parts.

### 3.1 Filter design and material

As the function determining part of the filter element, the biggest focus (beside the design) lies on the filter material. Due to two possible design versions, there are two different filter material versions, type V1 and V2 possible. The different design versions are shown in Figure 2.

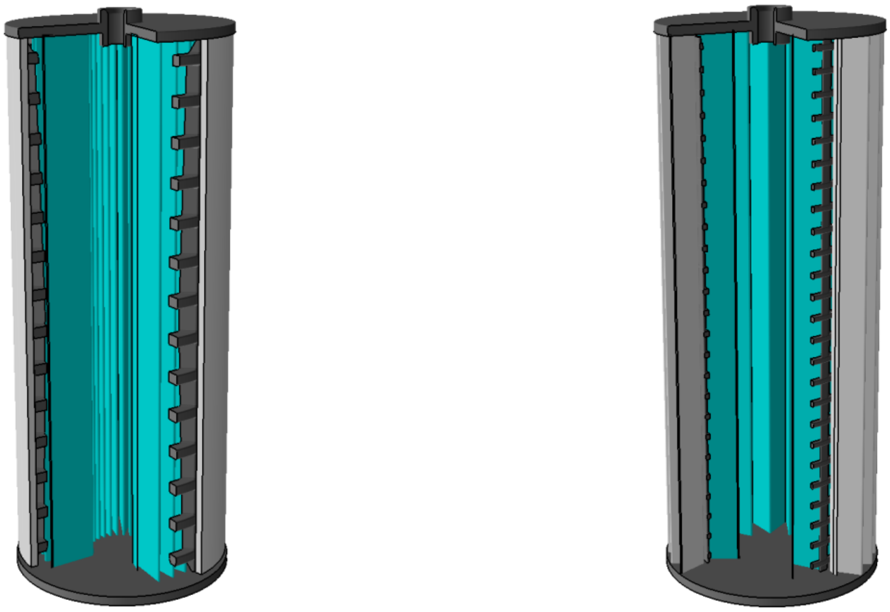

Figure 2: Design version of the filter element. Left: two-stage system with one filter bellow and one active carbon felt layer, type V2; Right: two-stage system with two filter bellows (same filter material), type V1

On the left side of Figure 2 a filter element with two filter bellows, as two-stage system, is shown, called type V1. Both filter bellows have the same filter material as stage 1 and 2, with different filter material areas. The right element consists of a first filter stage with an active carbon felt material and a second stage with the filter material identical to the left version and is further on named as type V2.

The filter material (see Figure 3) is an especially for the water filtration developed material which uses an electro adsorptive filtration technology to realise a high filtration efficiency with a low differential pressure. The adsorptive power is an intrinsic function of the material realized during the production process.

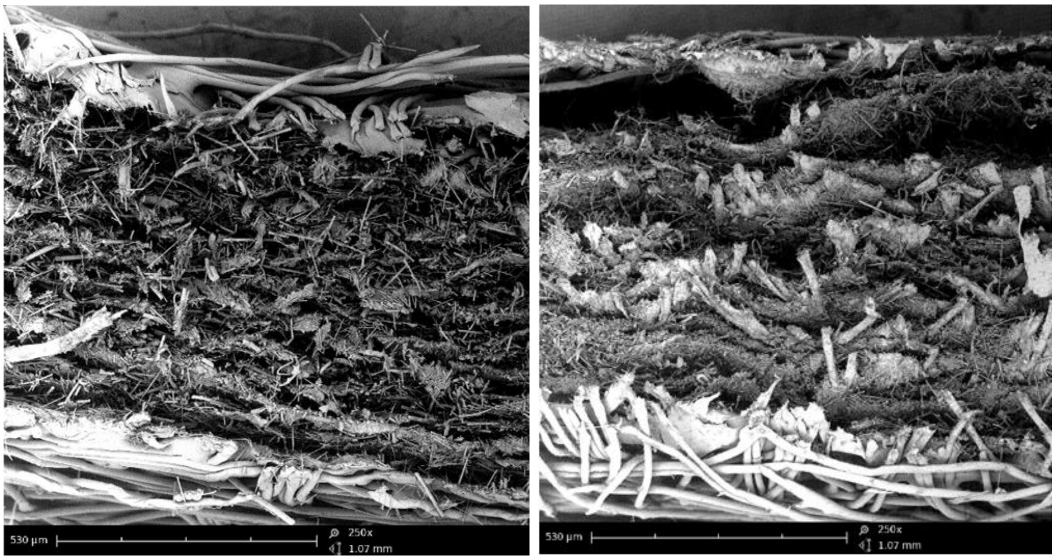


Figure 3: SEM picture of the filter material (cross view)

The material is designed for microfiltration. It's overall efficiency for pathogens and colloids, which are the main impurities in water filtration, are shown for both filter element types in chapter 3.1.1.

Furthermore, the filter material also contains an active carbon system for the removal of, for example, chlorine (see chapter 3.1.1). For the in Figure 2 on type B, the active carbon felt material has in this case as main function the removal of chlorine. The filtration function, especially for germs, is given by the second stage filter bellow.

### 3.1.1 Functional results

During comparative tests of the developed filter elements, the properties concerning chlorine retention, removal of suspended matter (turbidity) and pressure drop are studied.

The process tests are performed at the Grünbeck technical laboratory. Therefore, a test rig is built up, able to use both versions of filter cartridges and run different water qualities. The flow rate and pressure drop are monitored, and the retention was determined by taking analysis of the raw water and treated water on the effluent of the cartridge.

Following figure shows the process scheme of the test bench used for the laboratory testing.

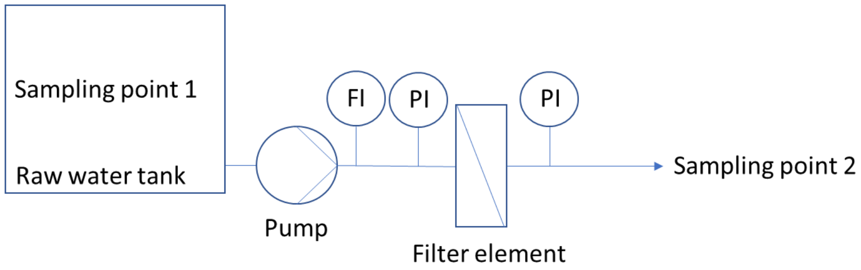


Figure 4: Process flow diagram of the test bench (FI = flow indicator, PI = pressure indicator)

### 3.1.2 Chlorine Retention

Both types, V1 and V2, are tested on their ability to reduce chlorine at a flow rate of 6 litres per minute (300 l/h). The field of application for this filter element is drinking water. The expected chlorine concentration should be below 1 mg/l. To ensure a chlorine retention, even if an overdosing of chlorine is taking place, a high-level concentration of 5 mg/l was taken into account. Both cartridges showed a very good retention of chlorine. After 5.000 litres of water version 1 still has a retention rate of more than 80 % and version 2 at least has more than 60 %. Using an extreme overdosing of 5 mg/l decreased the retention rate faster than expected. In this experiment, also version 1 revealed a higher retention capacity compared to version 2.

The differences in their chlorine retention is related to its different amount and type of active carbon.

The results are shown in the following Figure 5.

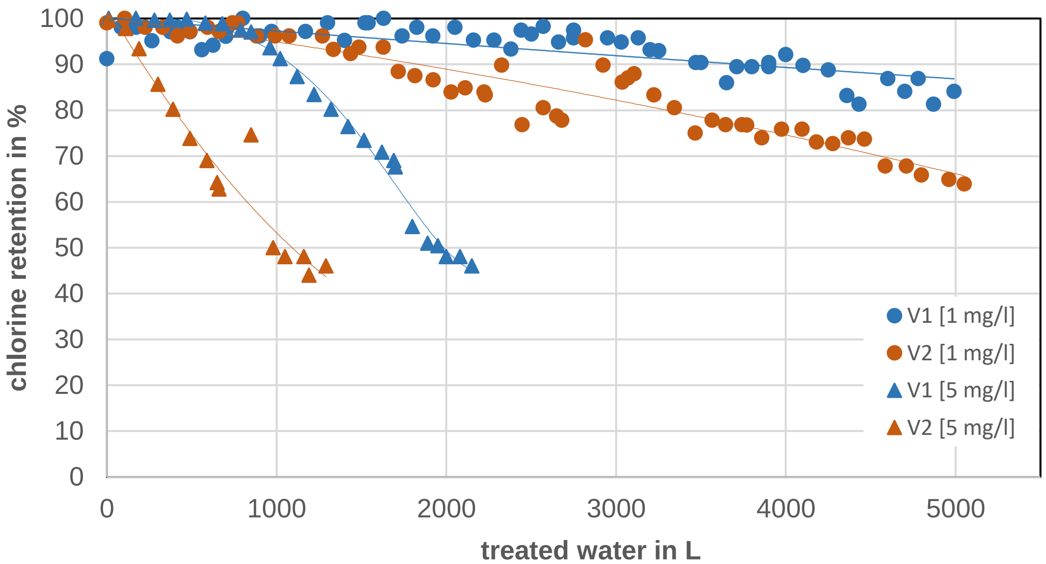


Figure 5: Chlorine retention of the two tested filter elements (V1/blue = two stage system with one filter layer and one active carbon felt layer, V2/red = two stage system with two identical filter material layer)

The differences of the versions of the filter element in their chlorine retention is related to its different amount and type of active carbon. In terms of chlorine retention the Version 1 shows better results.

### 3.1.3 Retention of turbidity

Next to chlorine retention, the threshold of particles is investigated. Therefore, Arizona test dust (particle size distribution 0 – 200 µm) is added to drinking water, to increase its particle content to 2 NTU (Nephelometric turbidity unit). The NTU value is measured with a Nephelometer Turb 550 IR (WTW).

Figure *6* shows, that both cartridge layouts can filtrate those particles over the whole lifetime of 5.000 litres without any decreases. This proves an identical filtration performance, which is independent of its active carbon content and the number of filter bellows.

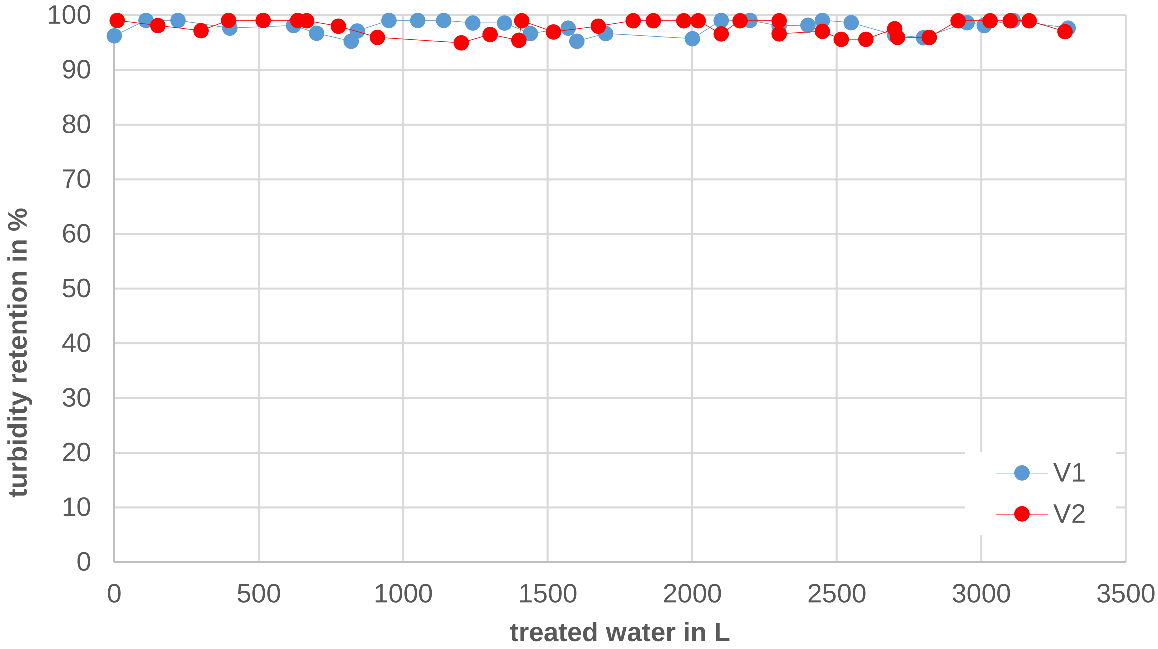


Figure 6: Turbidity retention of the two tested filter elements (V/blue1= two stage system with one filter layer and one active carbon felt layer, V2/red = two stage system with two identical filter material layer)

The filtration of particles is leading to a filter cake causing a pressure drop of the system. During the above-mentioned turbidity retention test the pressure drop is measured.

Figure *7* show that, despite of their identical particle hold performance, both versions build up a different pressure drop. Starting from a lower level the pressure drop on version 1 is increasing slower than in version 2.

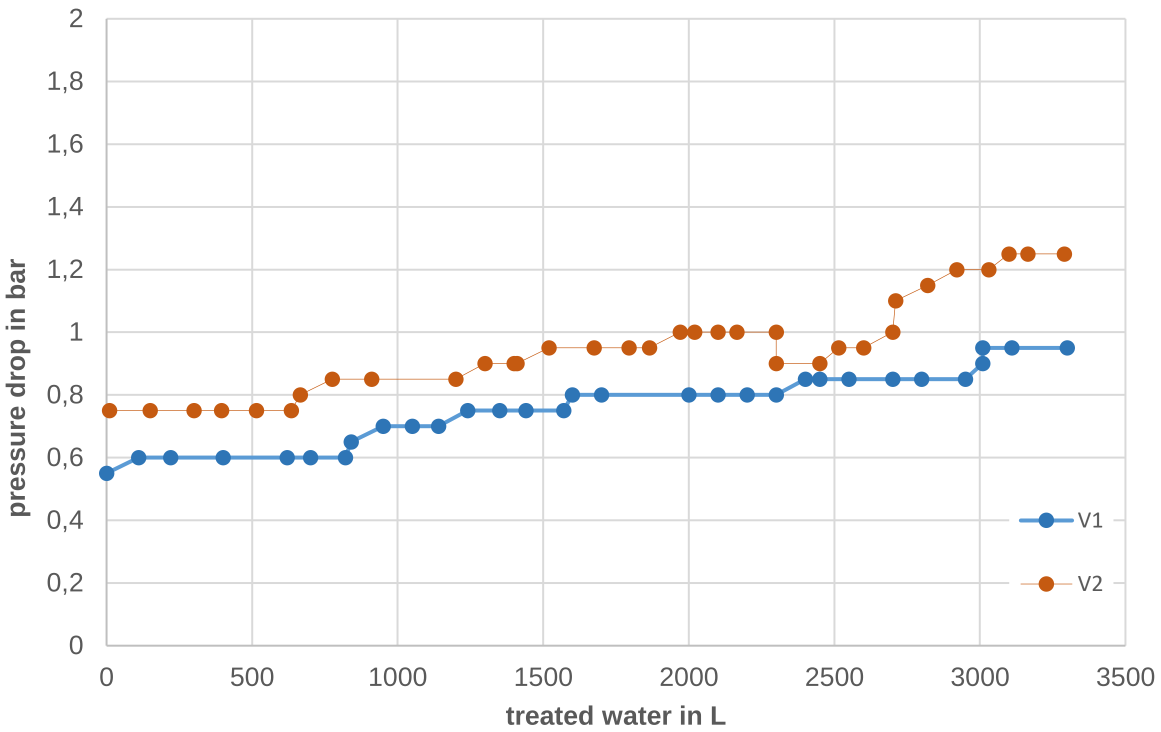


Figure 7: Pressure drop of the two tested filter elements (V1/blue = two stage system with one filter layer and one active carbon felt layer, V2/red = two stage system with two identical filter material layer)

The results of the chlorine retention and the pressure drop properties (see Figure 5 and Figure 7) show, that the filter element V1 (two stage system with one filter layer and one active carbon felt layer) give the best results. The turbidity retention output seems to be equally good with both filter elements.

### 3.1.4 Bacterial Retention

The filter element version V1 shows to have a better chlorine retention and better pressure drop over its lifetime of 5.000 liters in comparison to version V2. Therefore, this cartridge layout is used for testing the bacterial retention. The tests are performed at an external laboratory with experience in water science and microbiology.

For this test, filter element V1 has been fed with unsterile drinking water mixed with a high concentration of Escherichia coli (DSM 1576).

The Escherichia coli concentration is measured with EMB-Agar (cultivated over night at 37°C). The unit for this analytical method is colony-forming units, which stands for the concentration of E. coli. The water flow is set to 200 l/h.

Following Table *2* shows the results of the bacterial retention test.

Table 2: Bacterial retention test of the filter element V1 (two stage system with one filter layer and one active carbon felt layer)

| **Sample** | **Time** | **Treated water** | **Escherichia coli concentration inlet** | **Escherichia coli concentration outlet** | **Retention** |
|---|---|---|---|---|---|
| Unit | Min | l | cfu/100 ml | cfu/100 ml | % |
| 1 | 1 | 3 | $5,5*10^5$ | $< 3,3*10^{-1}$ | > 99,99993 |
| 2 | 5 | 15 | $6,7*10^5$ | $< 3,3*10^{-1}$ | > 99,99995 |
| 3 | 9 | 30 | $6,7*10^5$ | $< 3,3*10^{-1}$ | > 99,99995 |

Figure 8 shows two EMB Agar plates used for counting the amount of E. Coli. The left picture is made by taking the raw water before entering the cartridge. The right picture shows the treated water after passing the cartridge. The red dots on the Agar plate are displaying the colonies formed by the added Escherichia coli.

| Inlet after 9 minutes, diluted 1:10000 | Outlet after 9 minutes, not diluted |
|---|---|

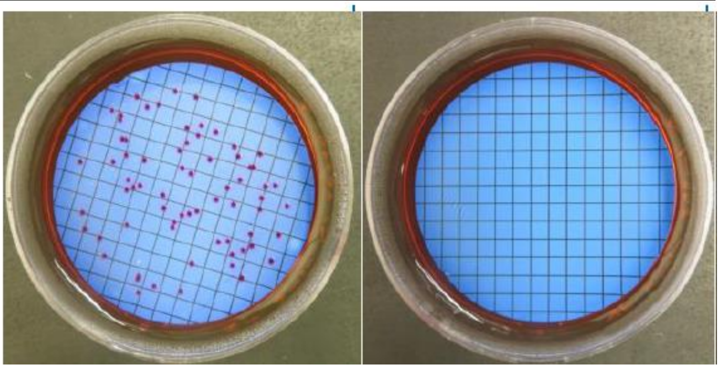

Figure 8: Sample photos of the EMB Agar plates

As expected, the sample on the inlet shows a very high amount of E. Coli, even in a 10.000-fold diluted sample. In contrasts to no detected E. Coli on the outlet sample, even in an undiluted solution.

These results show, that the filter element V1 has a very high bacterial retention capacity for bacterium Escherichia coli of > 99,9999 % (> log 6).

Compared with other bacterial filtration systems, such as ultrafiltration the filter element V1 can compete with these results. At the same time, the filter element V1 has a very low pressure drop. This is a big advantage for practical use in recreational vehicles.

## 3.2 Filter element production

As already indicated, one development target is the use of as less as possible components for the filter element.

State of the art filter elements for water applications have in most cases minimum three different types of basic components (plastic components, filter material, glue). During the development process, a way was found -under the use of already known technologies from air- and fluid-filtration- to reduce the basic components to a number of two.

In Figure 9 a comparison of a “standard” design and the “new” design is shown, with the components: filter material (1), plastic components (2) (end caps, stabilisation tubes etc. (not all components are shown)) and glue components (3) (connection filter material to the end caps, connection of the filter bellow ends).

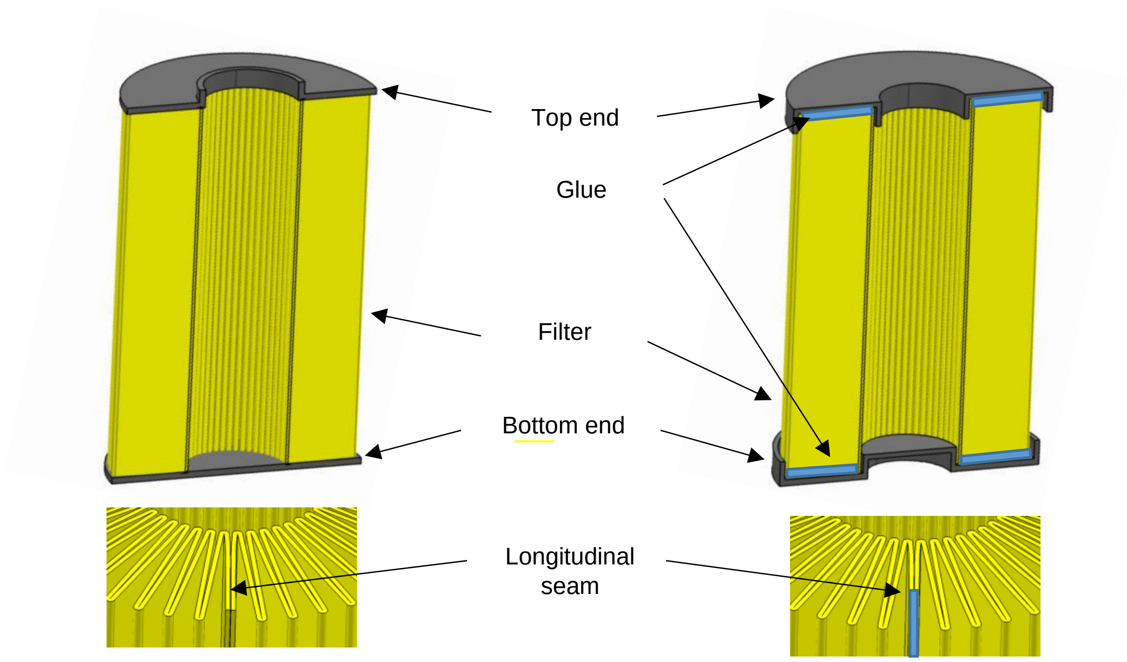


Figure 9: Scheme of an Energetic filter element (left) and a “Classic” water filter element (right). Blue rectangles = glue

The “new” design is a for air filtrations systems and liquid filtrations systems in automotive applications well-known system, called Energetic.

The connection between the end caps and the filter material is based on a heating and melting process of the end caps.

The Figure 10 shows a schematic view of the energetic process.

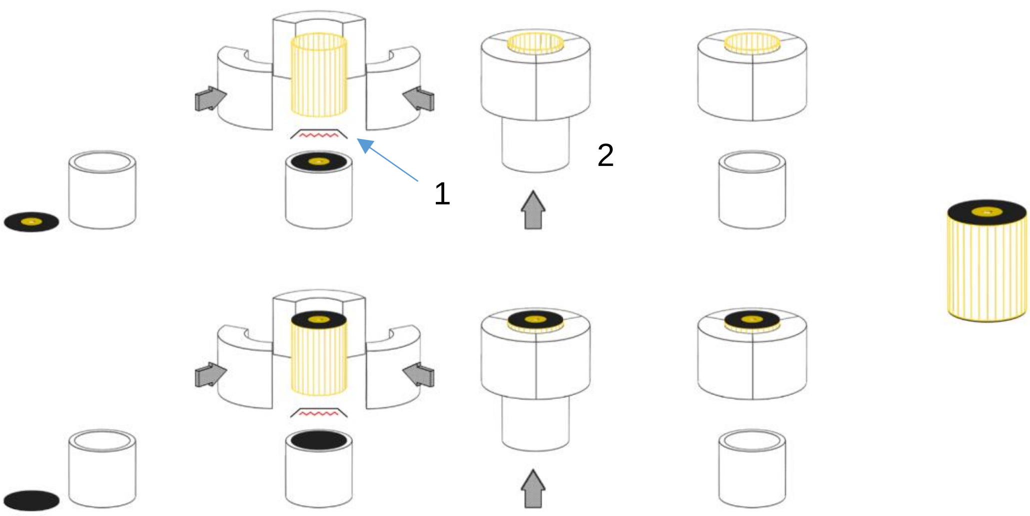


Figure 10: Scheme of Energetic production

The plastic end cap is heated up with a special lamp (1) until the surface of the plastic end cap melts. Once this state is reached, the "soft" end cap is connected to the filter bellow (2). As a result of the cooling down of the plastic end cap, a connection between the filter bellow and the plastic material of the end cap is created. This process is performed twice for both filter element sides.

This kind of production has two main benefits:

1. No glue is needed for the connection between end caps and filter bellow
2. Increasing of the filtration surface due to the missing glue socket

A preceding process of the Energetic process, is the longitudinal seaming of the filter bellow ends and in case of the use of the active carbon felt material (75-089-092) the connection of this material to the stabilisation tube. This can be done by glue or by ultra-sonic welding (see Figure 9). Due to the material reduction target, in this case the ultra-sonic welding is used. The challenge at this point is the material itself. As seen in Figure 3 the material basis of the used filter element is not pure polyester (PES), which is a standard material for using ultra-sonic welding. The same problem can be seen for the active carbon felt material (75-089-092). Both materials are laminated with two thin polyester (PES) layers which need to be welded under special conditions with an especially designed ultra-sonic sonotrode.

As result of this production steps, only the filter material and the plastic granulate have to be certified and handled, which also reduces possible unwanted material entries in the product.

## 4 Conclusion and outlook

In the present study, two different types of filter elements (filter materials/ design versions) are developed, which fulfil a good turbidity retention and chlorine retention. Furthermore, one version is tested against the bacterial retention, were values of nearly 100% retention are reached.

Due to this results and the shown production process, with the lowest possible amount of material components, a "ready to marked" filter element for the filtration of water is developed.