WATER FILTRATION – DRAINAGE SYSTEMS AND THEIR USE IN LABORATORY MODELS

Filip Mečíř*,1, Renata Biela[1], Aleš Haška[1]

*filip.mecir@vutbr.cz
[1]Brno University of Technology, Faculty of Civil Engineering, Veveří 331/95, Brno, Czech Republic

Abstract

The article focuses on the use of various drainage systems for water filtration. The aim is to analyse and compare the available technologies and their potential application in the construction of filters. The paper deals with the design of laboratory models that allow the testing of filtration processes. An innovative approach is employed in terms of the use of 3D printing in the development of drainage systems for these models. The results provide new insights that can help to optimise filtration systems.

Keywords

Filtration, drainage system, laboratory model

1 INTRODUCTION

Water filtration is a key process in water purification that allows the removal of mechanical impurities and microorganisms. In the water industry, it is usually used as a primary separation stage or as a secondary stage. Drainage systems are an important part of this process, as they ensure the even passage of water. They also allow the filter media to be flushed - either with water alone or with air, or a combination of both. There are a number of drainage technologies that affect filtration efficiency, as well as initial and operating costs.

In this article we will look at traditional and modern drainage systems and their applications. We will also look at laboratory filtration models. Special emphasis will be placed on the options for optimising filtration processes using innovative technologies such as 3D printing. Laboratory models play a crucial role in analysing and testing the performance of different types of drainage systems, allowing for a better understanding of filtration dynamics and their subsequent optimisation.

Description of the present state

In two-stage water treatment, the second separation stage currently involves rapid filtration, which has evolved from slow filtration. The first slow filters were designed in 1829 in England. The treatment of water by slow (biological) filtration is analogous to surface water purification processes that occur in nature. In slow filtration, a top layer of sand (1 to 2 cm thick), referred to as a 'biological membrane', is technologically most effective, with intensive revival by aerobic microorganisms and algae [1].

The first rapid filters were put into operation in Somerville (New Jersey, USA) in 1885, and in Europe at the water treatment plant for the city of Zurich (Switzerland) in 1895. These high-speed filters had the same flow arrangement as the slow filters, i.e. water flowed through the flooded sand layer from top to bottom under gravity. The vast majority of current designs are based on the same principle. Fast filters differ from slow filters in their higher filtration rate, the coarser grain size of the cartridge and the smaller surface area of the cartridge [2].

There are two basic design variants of rapid-speed filters, namely European and American.

The more widespread of these are the European quick filters, which are built with or without an intermediate bed and washed with air and water, usually from below. The American quick filters have been under development for longer, are without an intermediate bed, and are washed from above and below. Silica sand is most commonly used as a filter media [3].

The rapid filters with an intermediate bed are equipped with a concrete intermediate floor, which is usually fitted with straining heads.

Received 07/02/2025/Accepted 15/04/2025/ Published 30/09/2025 DOI 10.13164/juniorstav.2025.26088

During renovations it is usually advantageous to replace the intermediate drainage system. This solution saves structural height in the filter. Drainage systems are offered by various manufacturers - in the Czech Republic, the most common systems are made by Leopold, Triton and Aquafilter [4]. One of Triton's drainage systems is shown in Fig. 1.

Fig. 1 Construction of a Triton drainage system segment [5].

In previous experiments simulating a rapid filter via a laboratory model, a drainage system was used that utilised a spiked aggregate supplemented with three layers of glass beads of different sizes. This design was chosen not only to provide stability to the filter bed but also to prevent the leakage of the filter material into the drain. The use of a multi-layered arrangement of glass beads allowed the creation of a sufficiently permeable but stable base for the filter media itself [6], [7].

Although this system effectively prevented clogging of the drainage layer with filter material, some complications were encountered when backwashing the media. Satisfactory results were achieved with the use of water backwash, as the water was able to effectively remove the trapped contaminants and partially restore the original filtration properties of the bed. However, when attempting to backwash using air, undesirable mixing of the drainage layers with the filter media itself occurred. This phenomenon was probably caused by the different densities and sizes of the individual particles, which led to their uneven movement in the turbulent environment created by the air flow.

This fact suggests that while the layering of glass beads of different sizes alone may prevent filter material from entering the drainage system, it may not be optimal for all types of backwashing. Air scouring, which is commonly used to loosen and remove settled particles from the filter bed, did not work as expected in this case, as the individual layers were destabilised and mixed.

2 METHODOLOGY

For the purpose of the experiment, four different drainage system variants were designed, each with different geometry and drainage hole size. The aim was to determine how the different design parameters would affect the backwash efficiency and stability of the filter bed.

The proposed models were created using CAD software and then printed on a 3D printer using a material resistant to water and mechanical stress. The use of 3D printing allowed precise control over the shape and size of the individual components, ensuring the comparability and reproducibility of the experiments. A PLA filament was used for 3D printing. The prototypes are shown in Fig. 2. A comparison of the original filter system and the variant with the proposed filter system using a PLA drainage ring is shown in Fig. 3.

After printing and assembling the individual drainage systems, we conducted a series of backwash experiments, testing both water and air washing. Each experiment was conducted using a laboratory model of a rapid filter, in which the ability to remove sediment and the extent to which the original structure of the filter bed was retained after the process was completed was monitored.

DOI 10.13164/juniorstav.2025.26088

Evaluation of backwash was focused on:

1. Backwash efficiency,
2. The stability of the drainage system during the flushing process,
3. The speed and uniformity of the passage of air and water through the drainage layer.

The data obtained was analysed and compared for the different drainage system options to identify the most effective design solution for practical application.

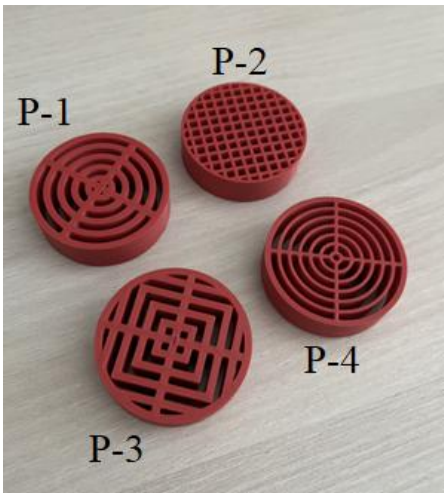

Fig. 2 Four different prototypes for a lab-scale drainage system.

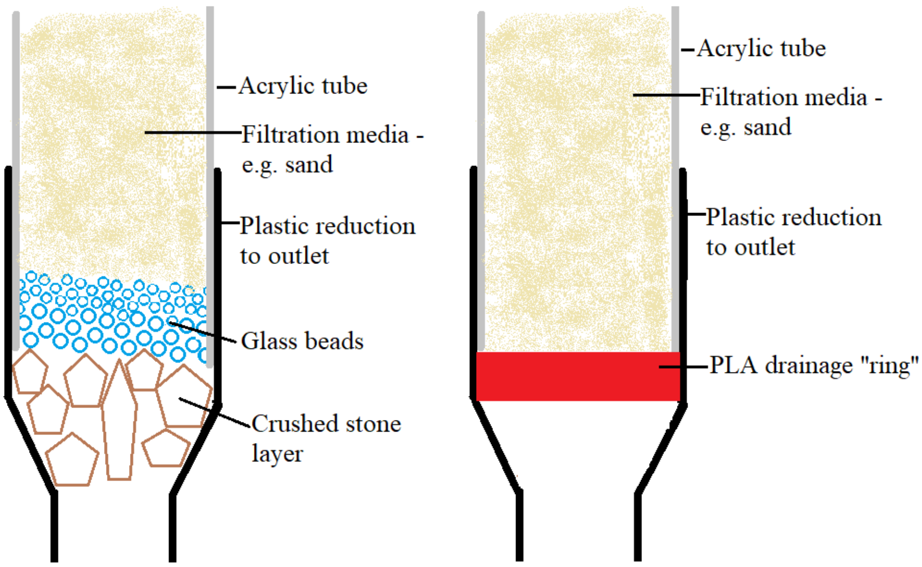

Fig. 3 Comparison of a drainage system with crushed stone and glass beads with the proposed system with a PLA "ring".

DOI 10.13164/juniorstav.2025.26088

3 RESULTS

Fig. 4 shows the turbidity of the water when backwashing the filter after clogging. Four lines are plotted for the four prototypes shown in Fig. 2.

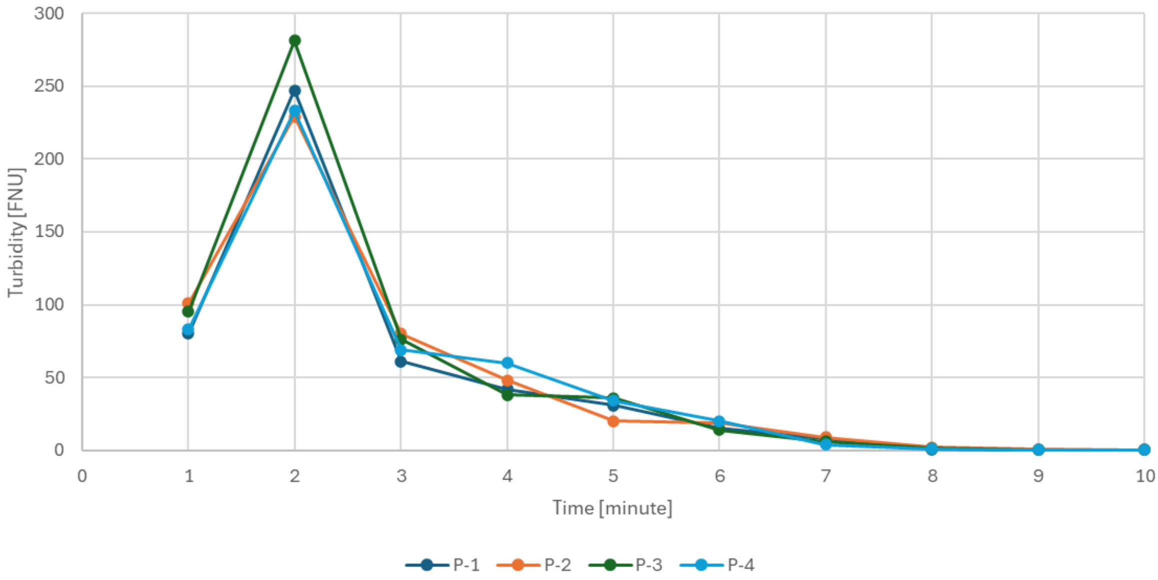

Fig. 4 Turbidity of backwash water during backwash.

During the washing process, there was no observable difference between the proposed prototypes within the model. Prototypes P-2 and P-3 had a problem with leakage of the filter media during filtration. During washing, the drainage system was stable for all prototypes.

4 DISCUSSION

Although holes with smaller dimensions than the lower limit of the filter material dimensions were chosen, some prototypes still displayed leakage of the filter medium. This could be due to both printing inaccuracies and variations in the filter material. Another possible cause of filter media leakage is the use of rectangular holes in variants P-2 and P-3. No leakage was observed for variants P-1 and P-4.

The air and water washing process was similar for all variants, and due to the dimensions of the filter column there was no observable difference between the drainage system designs.

5 CONCLUSION

This study looked at the effectiveness of different drainage systems in rapid filtration, focusing on their ability to support effective backwashing. The results confirmed that while traditional multilayer drainage configurations provide sufficient stability to the filter bed and prevent the loss of filter material, stability issues are experienced during air washing. The instability of layered drainage systems during air backwashing points to the need to improve their design to ensure a balance between permeability and structural integrity.

The use of 3D printing allowed precise control over the geometric parameters of the drainage systems and facilitated their comparative testing. Differences in efficiency were observed between the four proposed variants depending on the shape and size of the drainage holes. The findings suggest that optimised drainage system geometry can improve backwash efficiency and minimise the unwanted mixing of layers.

Future research should focus on alternative drainage system structures and material compositions that better resist both water and air scour without compromising filter bed stability. Further use of computational fluid dynamics

DOI 10.13164/juniorstav.2025.26088

(CFD) modelling could provide a deeper understanding of flow behaviour in drainage systems and help to develop more efficient filtration systems. The continued integration of innovative technologies, such as 3D printing, represents a promising route to optimising water filtration processes both under laboratory conditions and during real world operations.

References

[1] CHEREMISINOFF, Nicholas P. *Liquid filtration*. 2nd ed. Boston: Butterworth-Heinemann, c1998. ISBN 07-506-7047-9. Available at: http://www.sciencedirect.com/science/book/9780750670470.

[2] MALÝ, Josef and MALÁ, Jitka. *Chemie a technologie vody*. 2nd ed. Brno: ARDEC, c2006. ISBN 80-86020-50-9.

[3] CRITTENDEN, John C.; TRUSSELL, R. Rhodes; HAND, David W.; HOWE, Kerry J. and TCHOBANOGLOUS, George. *Stantec's water treatment: principles and design*. Updated third edition. Hoboken, New Jersey: Wiley, [2023]. ISBN 978-1-119-81996-7.

[4] HLAVÁČ, Jaroslav and Milan LÁTAL. Racionální přístup k inovacím úpraven vod. In Voda Zlín 2012. 1. Zlín: Moravská vodárenská, a.s., 2012. s. 91–96. ISBN: 978-80-260- 1468-3.

[5] RIVET, Christian, Fabrice COURAGEOT and Zdeněk HRADIL. Nerezové drenážní systémy Triton ve filtrační technologii pitných vod. In: Voda Zlín 2008. 1. Zlín: Moravská vodárenská, a.s., 2008. s. 51-59. ISBN 978-80-254-1348-7

[6] CÍSAŘOVÁ, Monika. Removal of micropolutants during drinking water treatment. Brno, 2024. Master's thesis. Brno University of Technology, Faculty of Civil Engineering Available at: https://www.vut.cz/studenti/zav-prace/detail/152758

[7] HALAŠTA, Tomáš. Heavy metals in drinking water sources and possibilities of their removal [online]. Brno, 2023. [accessed 07/01/2025]. Master's thesis. Brno University of Technology, Faculty of Civil Engineering Available at: https://www.vut.cz/studenti/zav-prace/detail/143443

DOI 10.13164/juniorstav.2025.26088