

## Backwashing Characteristics of Pumice as a Sustainable Alternative Granular Filter Medium for Desalination Pretreatment

Selda YİĞİT HUNCE<sup>1</sup>, Cemre KILIÇ<sup>1</sup>, Ege ÇÖLLÜOĞLU<sup>1</sup>,

<sup>1</sup> Department of Environmental Engineering, Marmara University, Istanbul, Türkiye

### Abstract

In this study, the potential use of pumice as an alternative filter medium in granular filters employed for seawater pretreatment prior to membrane processes was investigated in terms of backwashing behavior. Silica sand, activated carbon, and pumice were prepared in different particle size fractions, and their density, equivalent diameter, and water absorption capacities were determined according to ASTM standards. Using synthetic seawater prepared with natural sea salt, fluidization (backwashing) experiments were conducted to evaluate the bed expansion behavior of the materials. As expected, pumice and activated carbon achieved higher bed expansions at lower backwash velocities compared to the primary filter material, sand, due to their lower densities and porous structures. Sand, on the other hand, exhibited limited expansion even at higher velocities because of its dense and less porous structure. This indicates that in dual-layer filters combining sand with a porous medium, achieving effective fluidization for both materials may carry a risk of media loss. The results demonstrate that backwash velocities in dual-layer granular filters should be optimized based on the density and particle size of the selected materials. Considering the characteristics evaluated in this study, pumice may be considered a promising alternative to activated carbon as a filter medium.

**Keywords:** Granular filtration, pumice, activated carbon, backwashing, seawater desalination

### I. INTRODUCTION

Desalination, the process of removing salt and minerals from seawater to produce drinking water, has emerged as a critical solution to the global water shortage crisis. It has been widely adopted in various regions and countries around the world, particularly in arid and water-scarce areas, to expand the availability of freshwater [1]. With the global demand for desalinated water expected to grow, the World Water Council predicts that around 3.9 billion people will live in water-scarce regions by 2030 [2]. In response to this growing demand, desalination technologies are advancing rapidly, with a focus on increasing efficiency, reducing energy consumption and exploring renewable energy sources to power these systems.

Membrane-based desalination, particularly reverse osmosis (RO), is the most widely used desalination method worldwide. This technology uses semi-permeable membranes to selectively remove dissolved salts and minerals from seawater, producing high-quality freshwater [3]. In addition to RO, other desalination techniques such as multi-stage flash distillation and multi-effect distillation are widely used in various parts of the world [4]. While desalination is a viable solution in many regions, selecting an appropriate method depends on factors such as water salinity, energy availability and local environmental conditions. Careful consideration of the location and size of desalination plants, taking into account economic, social and political factors, is essential for optimizing the deployment of these systems [1]. As the global demand for clean drinking and utility water continues to grow, the importance of desalination in increasing water resources will become even more critical.

The pretreatment of seawater is a critical component of the desalination process. One of the commonly used methods involves using granular bed filters to effectively remove microparticles and other contaminants from the feed water. Prior to membrane desalination, granular filtration is essential for removing coarse particles from seawater. This preliminary step protects sensitive desalination membranes and increases the overall efficiency of the system [5].

Granular filtration is carried out by passing the water to be treated through a granular medium such as sand, anthracite, or garnet. In this process, suspended solids, colloids, and microorganisms are retained in the filter bed and removed. The efficiency of granular filtration depends on factors such as the quality of the influent water, the structural properties of the material used as the filter bed, the bed depth, and the flow rate [6,7]. Extensive research has been conducted in the literature on optimizing the design and operational parameters of granular filtration systems, and advanced technologies have been developed to effectively remove organic matter, inorganic salts, and micro-pollutants [6, 8, 9, 10, 11].

One of the fundamental aspects of granular filtration is the need for regular backwashing to maintain filtration performance and system lifespan. The backwashing process reverses the flow direction in the filter bed to remove accumulated contaminants from the medium. Strategies such as air-assisted backwashing or specialized backwashing tanks can be employed during backwashing to enhance filtration efficiency, reduce maintenance frequency, and extend the system's operational lifespan [12].

The design and performance of water filtration systems are critically dependent on the properties of the filter media used. Characteristics such as the type, size distribution, and physical structure of granular filter materials play a central role in determining particle removal efficiency. Beds composed of smaller particle sizes typically provide higher filtration efficiency due to their increased surface area and reduced pore size, enabling more effective capture of fine particles [13]. However, finer media also result in higher filtration resistance and pressure drops, which may lead to operational challenges [13, 14]. In this context, the ability to effectively restore filter performance through backwashing becomes particularly important, as it directly influences both the sustainability of filtration efficiency and the long-term operational stability of the system.

In recent years, the variety of filter media used in granular filtration systems has expanded, with innovative materials such as pumice gaining increasing attention. Pumice, a volcanic rock characterized by its low density and high surface area, offers the potential to improve hydraulic performance while reducing pressure loss in granular filtration. Previous studies have also demonstrated its effectiveness in removing suspended solids, turbidity, and microbial contaminants [12], making it a promising candidate for pretreatment in desalination applications.

In addition to its hydraulic advantages, pumice may offer economic and environmental benefits. Unlike activated carbon, which requires energy-intensive thermal or chemical activation processes [15, 16], pumice is a naturally occurring material that can be utilized with minimal processing [17, 18, 19]. This results in lower production costs and reduced environmental impact. Furthermore, pumice is widely available in Türkiye due to its volcanic origin, making it a locally accessible and cost-effective alternative to conventional filter media [20, 21]. These characteristics highlight its potential as a sustainable material for large-scale water treatment applications.

Given its abundance in Turkey and its cost advantage over conventional media such as sand and activated carbon, pumice represents an economically viable and environmentally sustainable alternative. Accordingly, this study investigates the use of pumice as a replacement for the traditional filter media, activated carbon, in desalination pretreatment, with a focus on assessing its backwashing behavior due to its light characteristics/low density. By exploring the potential of locally available pumice, this work aims to contribute to the suggestion of more sustainable and cost-effective filtration systems

## II. MATERIALS AND METHODS

### 2.1. Filter Materials

Filtration experiments were conducted using silica sand, activated carbon, and pumice with different sizes and densities. The size fractions were determined as 2.00-1.70 mm, 1.70-1.40 mm, 1.40-1.18 mm, and 1.18-1.00 mm for pumice and activated carbon, and 1.40-1.18 mm, 1.18-1.00 mm, 1.00-0.85 mm, and 0.85-0.71 mm for silica sand. Silica sand was preferred due to its high density, common use in drinking water treatment, and easy availability in different fractions. All filter materials were only washed, oven dried at 60 °C, and sieved to obtain the desired size ranges.

Activated carbon is a highly porous material with a large internal surface area, commonly used in water and wastewater treatment. Pumice is a lightweight volcanic rock with a high void ratio, chemically inert and durable, making it suitable as a filtration medium.

### 2.2. Characterization of Filter Materials

Sieve analyses were carried out according to the 2005 ASTM standards using a Retsch AS200 tap sieve shaker [22].

Particle densities were determined according to ASTM C128-12 (2012) standards under saturated surface dry (SSD) conditions using the pycnometer method [23]. For the pumice and activated carbon samples, the SSD condition was checked with the cone test after soaking them in water for 24 hours. Measurements were repeated three times for each fraction.

To measure the equivalent diameter of the particles, 500 particles were counted and weighed for each fraction, and the mean equivalent diameter was calculated from three replicates using the following equation:

$$d_{eq} = \sqrt[3]{\frac{6 \times m}{\pi \times \rho_p}} \quad (1)$$

$d_{eq}$ : equivalent diameter, cm

$m$ : weight of a particle, g

$\rho_p$ : density of particle, g/cm<sup>3</sup>

### 2.3. Preparation of Synthetic Sea Water

To eliminate seasonal and regional variations in natural seawater, synthetic seawater with a salinity of 3.5% was prepared using natural sea salt obtained from a manufacturer. The sea salt obtained has not been processed or treated; it is simply untreated sea salt after the evaporation of seawater. The synthetic seawater was prepared in a 40 liter tank for the backwash experiments.

### 2.4. Water Absorption Tests

The water absorption capacities of the pumice and activated carbon were determined by comparing their dry and wet (SSD) weights. The SSD condition was checked again with the cone test after soaking the samples in water for 24 hours, as was done for the density measurements. The experiment was performed three times to obtain reliable results.

### 2.5. Fluidization Experiments

Fluidization experiments were conducted to determine the behavior of bed expansion during backwashing. Tests were performed using the W3 Permeability/Fluidization Apparatus (Armfield Ltd.) with synthetic seawater. First, a known mass of filter material was placed into the column. Then, the bed was expanded by gradually increasing the flow rate, and the corresponding bed height and flow rate were recorded. The bed expansion ratio, porosity, and backwash rates were then calculated using the obtained data.

## III. RESULTS AND DISCUSSION

### 3.1. Characteristics of Filter Materials

The particle density of pumice, activated carbon, and silica sand for four different size fractions are presented in Figure 1. The measured densities demonstrate distinct differences among these three different filter media. Pumice had the lowest density values, ranging from 1318 to 1370 kg/m<sup>3</sup>, with only slight variation across size fractions. Activated carbon showed slightly higher densities, ranging from 1429 and 1455 kg/m<sup>3</sup>, again with negligible dependence on particle size. However, the densities of silica sand fractions were significantly higher, ranging from 2618 to 2647 kg/m<sup>3</sup>,

which is more than twice the density of pumice and activated carbon as expected. The results indicate that the density of each material is largely independent of particle size within the studied ranges, as variations between fractions were minimal. In contrast, clear material-dependent differences were evident. In desalination pretreatment, where dual-layer filters of porous and non-porous media are commonly applied, such density differences are critical. The backwash rate should therefore be adjusted carefully as high enough to clean the bed but not so high that the lighter, porous media are flushed out.

Figure 2 shows the equivalent diameters of pumice, activated carbon, and sand fractions. The calculated values were consistent with the sieve size ranges. While similar sieve fractions of the three materials yielded comparable equivalent diameters, slight deviations were observed due to differences in particle shape and porosity.

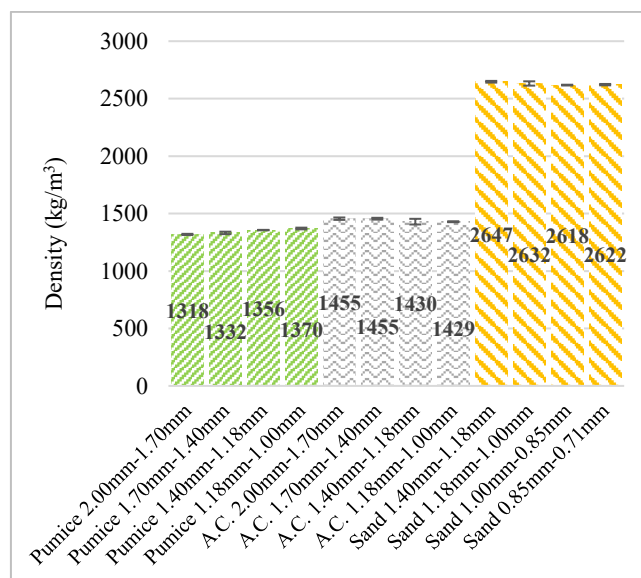


Figure 1. Density Comparison of Material Fractions

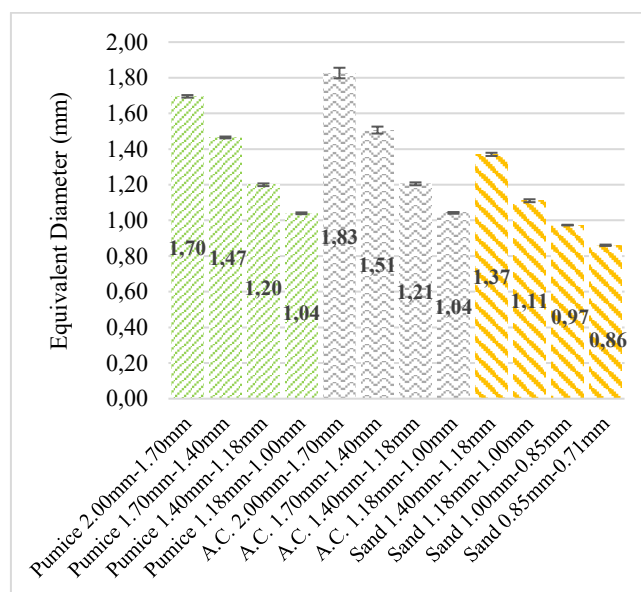


Figure 2. Equivalent Diameters of Material Fractions

Figure 3 presents the water absorption capacities of pumice and activated carbon for four different size fractions. In all cases, pumice showed higher water absorption than activated carbon, with values ranging from 39.0-54.4% compared to 32.8-41.3%. Both materials showed increasing water absorption with decreasing particle size, reflecting the higher specific surface area of finer fractions. The higher absorption capacity of pumice may be attributed to its more porous structure, which is advantageous for filtration applications requiring adsorption and retention of impurities.

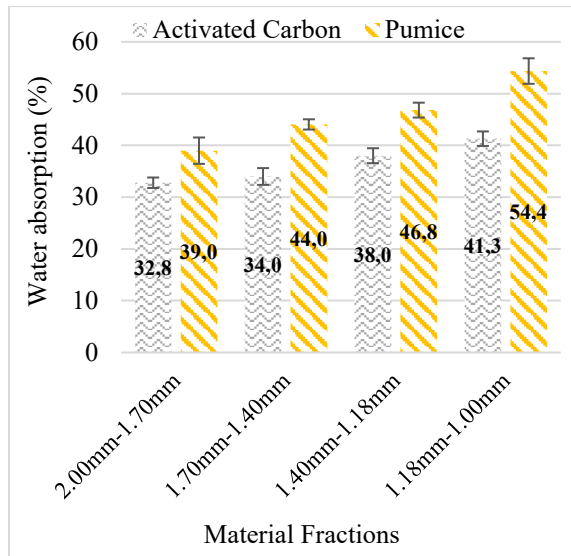


Figure 3. Water Absorption Ratios of Porous Material Fractions

3.2. Backwashing Behavior

In granular filters used for seawater pretreatment, the backwash process relies on adequate fluidization to clean the bed effectively. During backwash, particles are suspended, allowing contaminants trapped between them to be discharged by introducing water from the bottom upwards. Insufficient fluidization can leave contaminated material in some areas of the bed. Excessive backwashing may result in material loss and system instability [6]. Achieving the right balance is therefore essential, both for cleaning efficiency and for minimizing water and energy use.

Figure 4 presents the variation of bed expansion with backwash flowrate for different pumice fractions. In all fractions, percent bed expansion increased progressively with rising backwash velocity, indicating effective backwash behavior. The finer fractions (1.18-1.00 mm and 1.40- 1.18mm) exhibited higher bed expansion at comparable flowrates compared to coarser fractions, due to their lower settling velocity and lighter structure. These results highlight that appropriate backwash rates must be selected depending on the pumice fraction used, as smaller particles are more

susceptible to excessive expansion and potential washout from the filter bed.

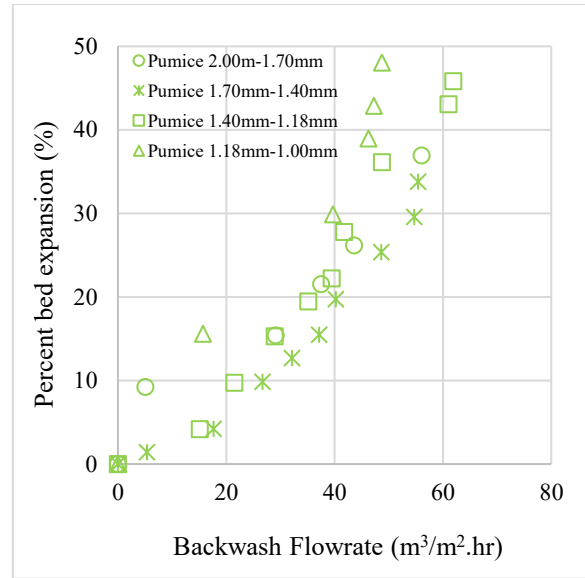


Figure 4. Fluidization of Pumice Fractions

Figure 5 shows the bed expansion behavior of activated carbon under different backwash flowrates. Similar to pumice, bed height increased with increasing flowrate, confirming fluidization. The finer fractions (1.18-1.00mm and 1.40-1.18 mm) of activated carbon expanded more readily than the coarser ones, reaching 67% bed expansion at the highest flowrate. Compared to pumice, activated carbon exhibited lower bed expansion ratios except the finest activated carbon fraction. This indicates that activated carbon beds require relatively higher flowrates to achieve effective backwash without excessive particle loss.

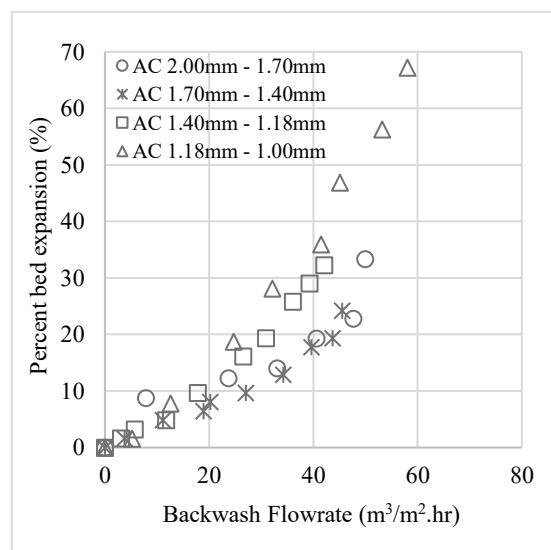
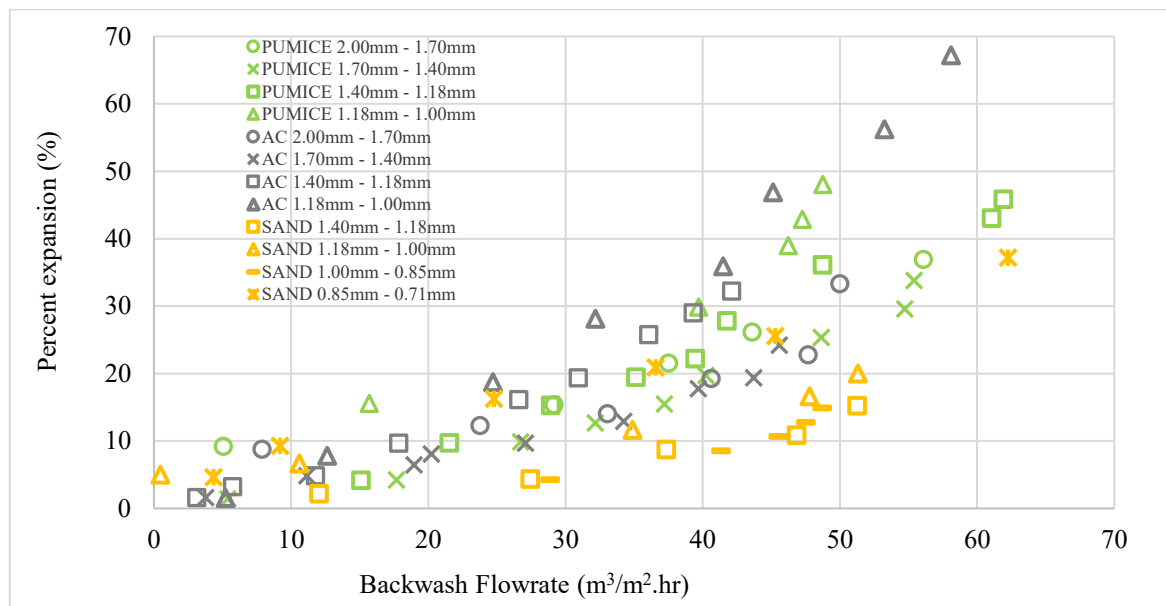


Figure 5. Fluidization of Activated Carbon Fractions

As presented in Figure 6, the pumice, activated carbon, and sand fractions responded differently to increasing backwash flow rates. The general trend indicates that pumice and activated carbon fractions achieved higher bed

expansions at lower flow rates compared to sand. This behavior is consistent with their lower particle densities and higher internal porosity.



**Figure 6.** Fluidization of pumice, activated carbon and sand fractions

Among all tested materials, the activated carbon fraction of 1.18-1.00 mm reached the highest expansion, exceeding 60% at a flow rate of approximately 55 m<sup>3</sup>/m<sup>2</sup>·hr. Such expansion values are considerably higher than the typical design range of 20-50% reported for rapid sand filters [24], highlighting the buoyant tendency of activated carbon. Although high bed expansion improves cleaning efficiency by promoting particle detachment, excessive expansion may cause media loss if not properly controlled during operation [25].

Pumice fractions also demonstrated substantial fluidization, with bed expansions reaching 40-50% at backwash flow rates where sand fractions achieved only about 20% expansion. This clearly indicates that pumice requires considerably lower hydraulic energy to attain effective backwash, owing to its low density and porous structure [21]. The general response curve of pumice closely followed that of activated carbon, suggesting similar hydrodynamic behavior under backwash conditions.

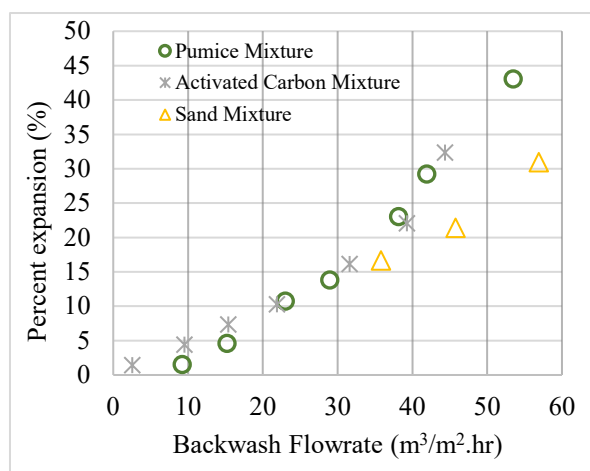
In contrast, the sand fractions exhibited significantly lower expansions under comparable flow conditions. Even the finest sand (0.85-0.71 mm) achieved only around 40% expansion at high flow rates, consistent with its higher density and smooth, non-porous structure. This confirms that sand is inherently more resistant to fluidization, requiring higher backwash velocities (typically 30-50 m<sup>3</sup>/m<sup>2</sup>·hr) to achieve effective cleaning [24].

It is also noteworthy that while sand requires relatively high flow rates to achieve sufficient bed expansion, pumice and activated carbon tend to over-fluidize at similar or higher flow conditions. In dual-media filter

configurations (sand/activated carbon or sand/pumice), this may lead to undesirable separation or loss of the lighter media during backwashing if flow control is not optimized. Therefore, careful selection of backwash rate and media size combination is essential to maintain bed integrity and long-term filter performance.

When analyzing the backwash behavior of pumice, activated carbon, and sand mixtures composed of various size fractions (Figure 7), it was observed that pumice and activated carbon achieved higher bed expansions at lower backwash flow rates due to their lower particle density and porous structure. The pumice mixture exhibited the most pronounced expansion, reaching approximately 40-45% at a flow rate of about 50 m<sup>3</sup>/m<sup>2</sup>·hr, indicating an energy efficient backwashing process. Similarly, the activated carbon mixture demonstrated effective backwashing with relatively low hydraulic input, confirming its suitability for backwashing under moderate flow conditions.

The sand mixture required considerably higher flow rates to initiate and sustain bed expansion, reflecting its denser and less porous nature. This comparative behavior suggests that, while pumice and activated carbon offer advantages in terms of lower backwash energy demand, their excessive expansion at higher flow rates may cause bed instability or media loss if used in dual-media configurations with sand. Therefore, careful control of backwash rate and media size combination is essential to maintain uniform fluidization and prevent the displacement of lighter materials during operation.



**Figure 7.** Fluidization behavior of pumice, activated carbon, and sand mixtures

#### IV. CONCLUSION

In this study, the backwashing behavior of pumice, activated carbon, and silica sand was experimentally investigated to evaluate the potential of pumice as an alternative filter medium for granular filtration systems used in seawater pretreatment. The findings indicated that the physical characteristics of the filter media, particularly density and porosity, play a decisive role in determining bed expansion characteristics during backwashing.

Pumice demonstrated the lowest particle density and highest water absorption among the materials experimented, resulting in a pronounced and energy efficient backwashing behavior. Activated carbon exhibited a similar trend, though with slightly higher density and lower expansion ratios. Conversely, silica sand displayed significantly higher density and limited bed expansion, even at higher backwash velocities.

The experimental results demonstrated that pumice and activated carbon could achieve 40-60% bed expansion at lower backwash flow rates, whereas sand required much higher velocities to reach similar levels of fluidization. These differences indicate that while pumice and activated carbon can be effectively cleaned with lower hydraulic energy, their excessive expansion at high flow rates may cause media loss if not properly controlled.

In dual-media filter configurations like sand/pumice or sand/activated carbon, the lighter media may result in stratification or washout during backwashing. Therefore, the backwash velocity and media size combination must be carefully optimized to achieve uniform backwash and prevent operational instability.

In conclusion, considering its low density, high porosity, natural abundance in Turkey, low cost, and environmental sustainability, pumice emerges as a promising alternative to activated carbon in granular filtration applications. In addition, its natural

availability in Türkiye and the absence of energy-intensive processing steps compared to activated carbon contribute to its cost-effectiveness and lower environmental impact [19, 20, 21]. These characteristics make pumice a sustainable filter material option, particularly in the pretreatment prior to membrane processes. However, further economic analysis and life-cycle assessment studies are recommended to quantitatively evaluate its long-term cost-effectiveness and environmental benefits. Future studies should also focus on long-term filtration and backwash cycles, head loss development, and turbidity removal efficiency to validate the practical performance of pumice media filter systems under real seawater conditions.

#### ACKNOWLEDGEMENTS

This study was supported by the TÜBİTAK 2209-A Research Project Support Program for University Undergraduate Students. The authors gratefully acknowledge this support.

#### REFERENCES

- [1] Mahmoud, M R., Fahmy, H., & Labadie, J W. (2002, March 1). Multicriteria Siting and Sizing of Desalination Facilities with Geographic Information System. *American Society of Civil Engineers*, 128(2), 113-120.
- [2] Saud, A., Saleem, H., & Zaidi, S J. (2022, April 25). Progress and Prospects of Nanocellulose-Based Membranes for Desalination and Water Treatment. *Multidisciplinary Digital Publishing Institute*, 12(5), 462-462.
- [3] Wang, J., Lai, S Y., & He, Y. (2012, November 1). Research on Reverse Osmosis Membrane Materials for Seawater Desalination. *Trans Tech Publications*, 600, 100-103.
- [4] Suárez, F., Río, M B D., & Aravena, J E. (2022, January 28). Water Flux Prediction in Direct Contact Membrane Distillation Subject to Inorganic Fouling. *Multidisciplinary Digital Publishing Institute*, 12(2), 157-157.
- [5] Saavedra, A., Valdés, H., Mahn, A., & Acosta, O. (2021, March 5). Comparative Analysis of Conventional and Emerging Technologies for Seawater Desalination: Northern Chile as A Case Study. *Multidisciplinary Digital Publishing Institute*, 11(3), 180-180.
- [6] Cescon, A., & Jiang, J. Q. (2020). Filtration process and alternative filter media material in water treatment. *Water*, 12(12), 3377.
- [7] Hunce, S. Y., Soyer, E., & Akgiray, Ö. (2018). On the backwash expansion of graded filter media. *Powder Technology*, 333, 262-268.
- [8] Kandra, H. S., McCarthy, D., Fletcher, T. D., & Deletic, A. (2014). Assessment of clogging phenomena in granular filter media used for

- stormwater treatment. *Journal of Hydrology*, 512, 518-527.
- [9] Soyer, E. (2016). Performance comparison of granular media filter beds. *Desalination and Water Treatment*, 57(52), 24867-24881.
- [10] Kim, I., Zhu, T., Jeon, C. H., & Lawler, D. F. (2020). Detachment of nanoparticles in granular media filtration. *Membrane and Water Treatment*, 11(1), 1-10.
- [11] Soyer, E., Hunce, S. Y., & Akgiray, Ö. (2017). Characterization of apricot stone shells as a rapid filter medium. *Desalination and Water Treatment*, 93, 318-323.
- [12] Du, J., Liu, C., Yin, S., Rehman, A., Ding, Y., & Wang, L. (2021). Particle size distribution in a granular bed filter. *Particuology*, 58, 108-117. <https://doi.org/10.1016/j.partic.2021.01.016>
- [13] Kang, S. F., Shieh, C. C., & Chiang, T. H. (1999). Filtration performance of a plastic-sand dual-media filter. *Journal of Environmental Science & Health Part A*, 34(7), 1533-1552.
- [14] Kubare, M., & Haarhoff, J. (2010). Rational design of domestic biosand filters. UWA Publishing, 59(1), 1-15.
- [15] Marsh, H., & Reinoso, F. R. (2006). Activated carbon. Elsevier.
- [16] Babel, S., & Kurniawan, T. A. (2003). Low-cost adsorbents for heavy metals uptake from contaminated water: a review. *Journal of hazardous materials*, 97(1-3), 219-243.
- [17] Öztürk, D., & Şahan, T. (2015). Design and optimization of Cu (II) adsorption conditions from aqueous solutions by low-cost adsorbent pumice with response surface methodology. *Polish Journal of Environmental Studies*, 24(4), 1749-1756.
- [18] Soleimani, H., Mahvi, A. H., Yaghmaeian, K., Abbasnia, A., Sharafi, K., Alimohammadi, M., & Zamanzadeh, M. (2019). Effect of modification by five different acids on pumice stone as natural and low-cost adsorbent for removal of humic acid from aqueous solutions-Application of response surface methodology. *Journal of Molecular Liquids*, 290, 111181.
- [19] Quesada-Rodríguez, J., Ledezma-Espinoza, A., Roa-Gutiérrez, F., & Romero-Esquivel, L. G. (2022). Evaluation of pumice stone as an alternative low-cost adsorbent for atenolol removal, an emerging contaminant. *International Journal of Environmental Science and Technology*, 19(4), 3177-3188.
- [20] Gündüz, L. (2008). The effects of pumice aggregate/cement ratios on the low-strength concrete properties. *Construction and Building Materials*, 22(5), 721-728.
- [21] Çifçi, D. İ., & Meriç, S. (2016). A review on pumice for water and wastewater treatment. *Desalination and Water Treatment*, 57(39), 18131-18143.
- [22] ASTM C136. (2005). Standard test methods for sieve analysis. ASTM International.
- [23] ASTM C128-12. (2012). Standard test method for density, relative density (specific gravity), and absorption of fine aggregate. ASTM International.
- [24] Kawamura, S. (2000). Integrated design and operation of water treatment facilities. John Wiley & Sons.
- [25] Turan, M. (2023). Backwashing of granular media filters and membranes for water treatment: a review. *AQUA—Water Infrastructure, Ecosystems and Society*, 72(3), 274-298.