SOLID REMOVAL ACROSS PRESSURIZED SAND MEDIA FILTERS FOR DRIP IRRIGATION WHEN USING RECLAIMED EFFLUENTS

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ABSTRACT

Drip irrigation allows a safe and sustainable reuse of reclaimed effluents. However, the general higher loads of salt, nutrients, solid particles, and microorganisms in treated wastewater increase the risk of emitter clogging and pose an additional challenge for keeping the drip irrigation system operating as designed [1].

A key component in any drip irrigation facility is the filtration system since it prevents emitter clogging by removing suspended particles from the irrigation water. The solid particles conveyed by water can not only cause emitter physical clogging, but they can also be the support on which microorganisms attach and grow, and therefore initiate biological emitter clogging. Moreover, solid particles also participate in crystallization, flocculation and aggregation of some chemical substances, which can, in turn, initiate chemical emitter clogging [2]. Thus, filters provide a broad protection against the different sources of emitter clogging. Sand media filters, alone or followed with disc filters, usually show better performances, especially with loaded wastewaters [3].

The filtration process is more efficient with the passing of time because successively smaller particles can be filtered out as the flow paths become smaller. However, with filter operation, resistance to water flow and pressure drop across the filter increase, and there-fore flowrates are reduced [4]. To restore appropriate filtration conditions, the filter is backwashed by reversing the flow for fluidizing the media bed and releasing the retained particles out of the filter bed. Backwashing is a critical part of media filter operation and performance [4], Both filtration and backwashing operation make these filters more complex to operate and, consequently, only suitable for farms with high technological and professional level [5].

Different studies have analyzed the number of solids retained across the sand media filter bed. De Deus et al. [6], Mesquita et al. [7], and Duran-Ros et al. [8] found declining retained solids and removal efficiencies with the media bed height. In addition, the solid removal efficiency increases with higher velocities and smaller sand particle sizes [9,10].

Thus, the main objective of the present study was to assess the efficiency of backwashing in removing suspended solids from the filter bed with two filtration and backwashing velocities using two types of clogging particles.

The experiments were conducted using a cylindrical media filter built in polymethyl methacrylate, with 340 mm height and 110 mm internal diameter. The experimental filter diameter was scaled down from a commercial sand media filter for allowing to conduct the experiments at filtration water velocities common in real practice. A cylindrical diffuser fixed to the filter top distributed homogenously the flow on the bed media surface. The filter underdrain, which was an iron-steel perforated plate placed at the filter bottom, could be raised with a screw system to obtain media bed slices of desired thickness for further analysis. The same experimental filter was used in the tests carried out at the laboratory and at a wastewater treatment plant. Further details on the experimental filter can be found in Duran-Ros et al. [11].

Besides the experimental media filter, the laboratory experimental setup (Figure 1) had a 0.06 m^3 frustoconical tank as water reservoir. By properly changing the fittings, the experiments could be conducted under filtration mode or under backwashing mode (Figure 1). All the components used in the laboratory setup were shifted to the wastewater treatment plant (WWTP) of Celrà (Girona, Spain). In these batch of experiments, the water source was

the reclaimed effluent of a sludge process, which was pumped from the outlet chamber of the settling tanks of this WWTP.

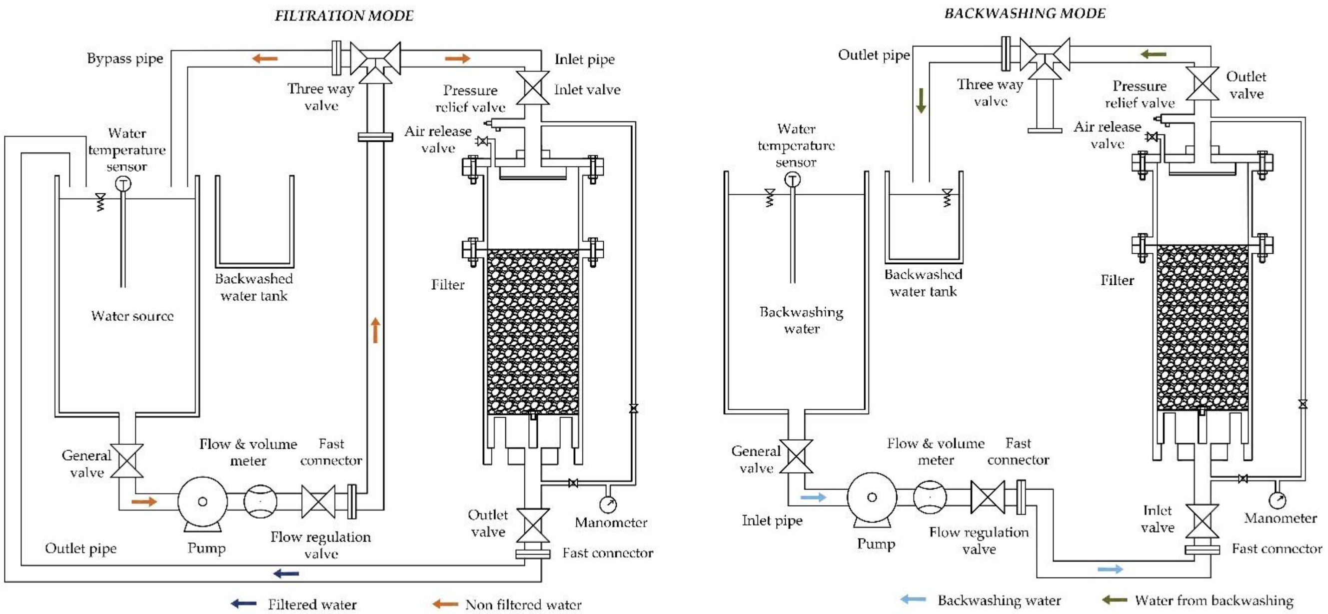

Figure 1. Experimental setup for the filtration and backwashing modes.

The effect of backwashing on the mass of total suspended solid particles retained across the filter bed depth of two water sources with different types of clogging particles (inorganic from A4 coarse sand dust and organic from a reclaimed effluent of a wastewater treatment plant) and two filtration (30 and 60 m h^{-1}) and backwashing velocities (45 and 75 m h^{-1}) was assessed in the present study.

The silica sand used in the experiment had a D_{10} (size of the screen opening which allows 10% of the sand sample mass to pass) of 0.48 mm, a D_{60} (screen size opening that let pass the 60% in weight of the sand) of 0.83 mm, a uniformity coefficient (D_{60}/D^{10}) of 1.73 and a porosity (ratio of the volume of voids versus the total volume occupied by the media) of 0.40

In the laboratory experiments, A4 dust sand was added to the frustoconical tank, for the 30 and 60 m h^{-1} filtration velocities, to maintain the solid load at 0.5 g L^{-1} at filter inlet. The volume, flow rate, inlet and outlet pressures, and temperature were recorded every 2.5 min. When the total pressure drop across the filter surpassed by 50 kPa the initial filter pressure loss, the media bed was clogged and the run was finished. Then, thirteen bed media slices were obtained. In the top 20 mm of the media bed the slices were 5 mm thick, while in the rest 180 mm they were 20 mm thick. The solids retained in each bed slice were measured using the van Staden and Haarhoff procedure [12]. In another batch of experiments, the clogged media beds were backwashed. The same procedure for filtration and backwashing was followed in the experiments conducted in the WWTP, but, in this case, the experimental filter worked with reclaimed effluent in the filtration mode and with tap water in the backwashing mode.

The results of the analysis of variance (ANOVA) of the model for the total suspended solids removal efficiency achieved by backwashing showed that the model, all the independent factors (operation velocity, type of clogging particle and bed depth slice) and two double interactions (operation velocity x type of clogging particle, and type of clogging particle x bed depth slice) were statistically significant ($p < 0.05$). Only the double interaction between the type of clogging particle and the bed depth slice as well as the triple interaction were not significant ($p > 0.05$).

The interaction between the operation velocities and the types of particle filtered is shown in Figure 2. The total suspended solid removal efficiency across the whole filter media bed was around 64% when sand dust was added, without statistically significant ($p > 0.05$) differences observed between both velocities. Other authors [7, 11] reported greater removal efficiencies of inorganic particles at higher filtration and backwashing velocities. On the other hand, with the reclaimed effluent, the removal efficiency was significantly higher ($p < 0.05$) at operation velocities of 60/75 m h^{-1} (filtration/backwashing) (86%) than at 30/45 m h^{-1} (70%). Solid removal efficiencies tended to be better when reclaimed effluent was used, but they were only significantly higher ($p < 0.05$) at 60/75 m h^{-1} operation velocities.

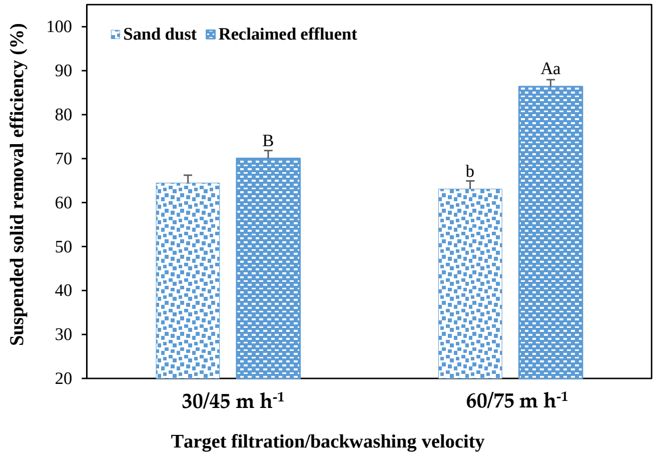

Figure 2. Least square means (± standard errors) of the total suspended solids removal efficiency achieved by backwashing regarding the type of clogging particles added and the target operation velocity. Different lowercase letters show significant differences ($p < 0.05$) between the clogging particles within a same velocity. Different capital letters show significant differences ($p < 0.05$) between operation velocities within a same type of clogging particle.

Figure 3 shows the effect of the type of clogging particle and media bed depth on the total suspended solid removal achieved by backwashing. Overall, the higher removal efficiencies were observed at depths between 5 and 20 mm. More solids were retained at the top of the media [8-10] due the predominant effect of the superficial filtration mechanisms. When reclaimed effluent was used, removal efficiencies from 5 to 20 mm depth (87% on average) were significantly higher ($p < 0.05$) than those from 180 to 200 mm depth (63%). No other significant differences were observed between bed slices, although the second minimum removal efficiency was found in the first 5 mm (68%).

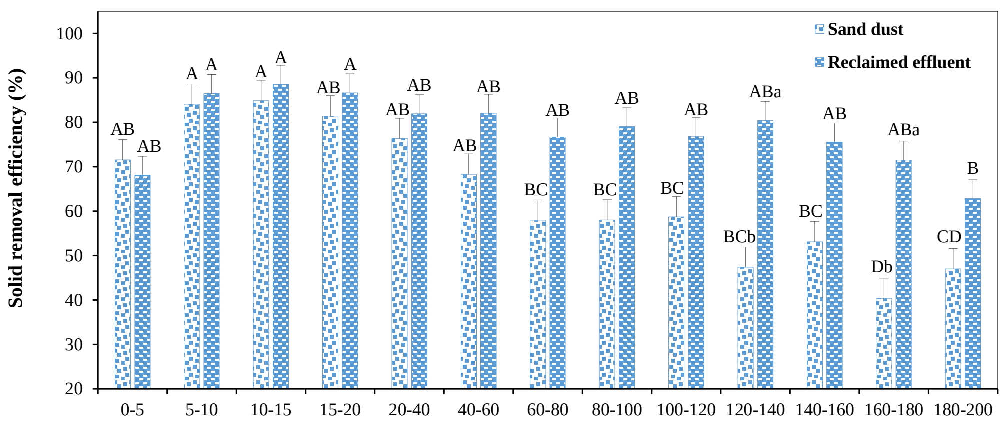

Figure 3. Least square means (± standard errors) of the total suspended solids removal efficiency achieved by backwashing regarding the type of clogging particles and the filter media depth. Different lowercase letters show significant differences ($p < 0.05$) between the clogging particles within a given bed media depth. Different capital letters show significant differences ($p < 0.05$) between bed slices within the same type of clogging particle added.

With sand dust, the efficiencies were significantly higher ($p < 0.05$) in the first 5 – 15 mm (84% on average) than from 60 to 200 mm (52% on average). The lowest efficiency (40%) was observed between 160 and 180 mm, but it was not statistically different than that observed between 180 and 200 mm (47%).

The irregular flow distribution that is usually observed near the filter underdrain reduces the effective area for fluidizing the bed [13] and, therefore, removal efficiencies are lower. Conversely, at the top of the filter bed, the backwash flow is fully developed through all the media surface and, consequently, solid removal efficiencies are better.

Significant differences between the type of clogging particles were only observed for 120 – 140 and 160 – 180 mm slices, being solid removal efficiencies statistically higher ($p < 0.05$) with reclaimed effluent than with sand dust.

In conclusion, the average total suspended solid backwashing efficiencies were greater (73% on average) using reclaimed effluent than when sand dust was added to water (64% on average). The higher backwashing efficiencies were achieved at filtration/backwashing velocity of 60/75 m h^{-1} with reclaimed effluents.

The highest removal efficiencies were observed at depths of 5 – 15 mm and 5 – 20 mm when sand dust and reclaimed effluents were used, respectively. The solid removal efficiency was more constant across the media bed height when the reclaimed effluent was filtered, but it decreased more at the deepest filter layers when sand dust was added. These results suggest that sand media bed depth should not be reduced when filtering reclaiming effluents since all the filter bed removes solids effectively.

REFERENCES

1. Trooien, T. P., Hills, D. J., 2007. Application of Biological Effluent, in: Lamm, F. R., Ayars, J. E., Nakayama, F. S. (Eds.), Microirrigation for Crop Production. Design, Operation and Management. Elsevier, Amsterdam, pp. 329-356.
2. Zhou, H., Li, Y., Wang, Y., Zhou, B., Bhattarai, R., 2019. Composite Fouling of Drip Emitters Applying Surface Water with High Sand Concentration: Dynamic Variation and Formation mechanism. Agric. Water Manag. 215, 25-43. https://doi.org/10.1016/j.agwat.2019.01.009.
3. Triphati, V. K, Rajput, T. B. S., Patel, N., 2014. Performance of Different Filter Combinations with Surface and Subsurface Drip Irrigation Systems for Utilizing Municipal Wastewater. Irrig. Sci. 32 (5), 379-391. https://doi.org/10.1007/s00271-014-0436-2.
4. Nakayama, F. S., Boman, B. J., Pitts, D. J., 2007. Maintenance, in: Lamm, F. R., Ayars, J. E., Nakayama, F. S. (Eds.), Microirrigation for Crop Production. Design, Operation and Management. Elsevier, Amsterdam, pp. 389-430.
5. Capra, A., Scicolone, B., 2007. Recycling of Poor Quality Urban Wastewater by Drip Irrigation Systems. J. Clean. Prod. 15 (16), 1529–1534. https://doi.org/10.1016/j.jclepro.2006.07.032.
6. de Deus, F. P., Testezlaf, R., Mesquita, M., 2016. Assessment Methodology of Backwashing in Pressurised Sand Filters. Rev. Bras. Eng. Agric. Ambient. 20(7), 600-605. https://doi.org/10.1590/1807-1929/agriambi.v20n7p600-605.
7. Mesquita, M., de Deus, F. P., Testezlaf, R., Diotto, A. V., 2019. Removal Efficiency of Pressurized Sand Filters During the Filtration Process. Desalin. Water Treat. 161, 132–143. https://doi.org/10.5004/dwt.2019.24285.
8. Duran-Ros, M., Solé-Torres, C., Ait-Mouheb, N., Molle, B., Arbat, G., Puig-Bargués, J., 2021. Media Filter Fouling Assessment Using Optical Coherence Tomography: New Methodology. Biosyst. Eng. 204, 26–35. https://doi.org/10.1016/j.biosystemseng.2021.01.008.
9. Song, L., Cai, J., Zhai, G., Feng, J., Fan, Y., Han, J., Hao, P., Ma, N., Miao, F., 2024. Comparative Study and Evaluation of Sediment Deposition and Migration Characteristics of New Sustainable Filter Media in Micro-Irrigation Sand Filters. Sustainability. 16, 3256. https://doi.org/10.3390/su16083256.
10. Zhang, W., Cai, J., Zhai, G., Song, L., Lv, M., 2023. Experimental Study on the Filtration Characteristics and Sediment Distribution Influencing Factors of Sand Media Filters. Water. 15, 4303. https://doi.org/10.3390/w15244303.
11. Duran-Ros, M., Pujol, J., Pujol, T., Cufí, S., Arbat, G., Ramírez de Cartagena, F., Puig-Bargués, J., 2023. Solid Removal across the Bed Depth in Media Filters for Drip Irrigation Systems. Agriculture. 13, 458. https://doi.org/10.3390/agriculture13020458.
12. van Staden, S. J., Haarhoff, J., 2011. The Use of Filter Media to Determine Filter Cleanliness. Phy. Chem.Earth. 36 (14-15), 1135-1140. https://doi.org/10.1016/j.pce.2011.07.067.
13. Mesquita, M., Testezlaf, R., de Deus, F.P., da Rosa, L.M., 2017. Characterization of Flow Lines Generated by Pressurized Sand Filter Underdrains. Chem. Eng. Trans. 58, 715-720. https://doi.org/10.3303/CET1758120.