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Performance Recovery Following Upward and Downward Flushing of Up-flow Sand Filter

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Abstract. The up-flow sand filter (USF) is an excellent alternative to conventional downward sand filters, reducing susceptibility to clogging. Two methods of cleaning the USF are upward flushing and downward flushing. The efficiency of both methods towards water quality was investigated by comparing the recovery of turbidity, total suspended solids (TSS), dissolved oxygen (DO), and pressure drop. The results obtained after upward flushing include turbidity levels of 22.64 NTU, TSS levels of 33.13 mg/L, DO levels of 4.78 mg/L (top layer), 5.20 mg/L (middle layer), and 4.20 mg/L (bottom layer), as well as a pressure loss recovery difference of 6.05 cm. Meanwhile, downward flushing obtained turbidity levels of 27.84 NTU, TSS levels of 34.5 mg/L, DO levels of 6.12 mg/L (top level), 6.38 mg/L (mid-level), and 5.48 mg/L (bottom level), as well as a pressure drop recovery difference of 12.87 cm. The ripening period of a filter refers to the stage where the sand filter matures and reaches its optimum filtration ability. In this research, the ripening period achieved after upward flushing was 11 hours, while after downward flushing was 8 hours. This was obtained by measuring the time it took for water parameters to stabilize after flushing. Overall results showed that upward flushing was more efficient due to higher turbulence during upward flushing, allowing contaminants to dislodge from gaps or surfaces of sand particles.

Keywords: Up-flow Sand Filter, Sand Filter Ripening, Sand Filter Cleaning, Sand Filter Backwash, Sand Filter Flushing

INTRODUCTION

An up-flow sand filter (USF) operates with water flowing from the bottom to the top, reversed compared to the slow sand filter. The USF comprises three main filtering media layers: coarse gravel, fine gravel, and sand media (De Souza *et al.*, 2021). In some USFs, a buffer area beneath the gravel layer (separated via a diffuser) acts as a sedimentation chamber to reduce pollutant load, increase removal efficiency, and elongate the filter lifespan (Lahin *et al.*, 2022). Media stratification and pore size distribution from bigger to small from the bottom to the top of the filter also reduce the frequency of clogging.

However, in the event of clogging, the pressure drop of the USF elevates, increasing energy requirements and reducing production capacity. Therefore, the USF must be cleaned. Unlike the scraping method for

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cleaning slow sand filters, the USF requires flushing the filter with clean water. Two available configurations are upward and downward flushing (De Souza *et al.*, 2021). Upward flushing involves water being flushed upwards from the bottom of the filter and exiting at the top, fluidizing the sand media. For this method, it is important to determine the suitable inlet flow rate to prevent over-fluidization and overflowing of sand media. During upward flushing, the flow rate of the water is excessively increased, where the bed expansion ratio and the contaminant particles will behave randomly. When sand media gets fluidized, the accumulated matter in the filter can be removed as it gets dispersed (Turan, 2023). The main force operating in this stage is the drag tension between filter media and fluid, which will drag attached particles out of the filter. After being fluidized, this tension reduces. Research has shown that upward flushing minimizes the impairment of water quality. A 4-minute backwash improved the turbidity parameter to <1.0 NTU and coliform removal to >80 %, indicating the filter was sufficiently cleaned De Souza *et al.*, (2021).

Downward flushing is a simple process where water is flushed from the top of the filter, and contaminants are removed from the filters to an effluent outlet at the bottom of the USF. Unlike upward flushing, this process can eliminate the risk of losing sand particles from fluidization. This may retain the efficiency of the sand filter, given the same cleaning performance as upward flushing. According to De Souza *et al.*, 2021, studies showed that the detachment of impurities in the filter could occur from the disturbance and increased flow rate. However, this study concluded that downward flushing was insufficient in cleaning the USF. It was further explained that the flushing did not clean the filter bed, and the initial head loss could not be achieved after cleaning. It was deduced that the USF required fluidization due to the insufficient agitation of filter media to clean the filter bed and support layer. Hence, the study found upward flushing more efficient than downward flushing. However, this was also due to the flushing run time, which affects the downward flushing efficiency (De Souza *et al.*, 2021).

Therefore, to study the effects of the two cleaning methods, this research focused on assessing the efficiency of the upward and downward flushing by comparing the recovery of effluent water quality parameters: TSS, DO, and microbial attachments on sand particles. The recovery of pressure drop after flushing was also monitored.

MATERIALS AND METHODS

Raw Water Preparation

The experiment utilizes augmented raw water feed, as described in previous research (Lahin *et al.*, 2022). A higher dosage of contaminants was used to facilitate USF clogging.

USF Setup

The USF setup is depicted in Figure 1. The USF operation was facilitated with a gear pump for continuous flow. At any event, the USF was idle, all valves were shut, and water in the USF remained to retain the conditions of the USF. The experiments were conducted at room temperature (≈28°C).

Flushing of USF

The upward flushing was conducted at 18 L/h for 25 minutes. The efficiency of the cleaning method regarding the pressure drop was assessed based on the amount of head loss recovered within 25 minutes (Ranjan, P., and Prem, M., 2018). Downward flushing was conducted at a flow rate of 12 L/h for 25 minutes. After flushing, the USF was allowed to rest for 30 minutes before operating as usual.

Parameters Analysis

All samplings were conducted before and after flushing was conducted. The turbidity level was measured using the HACH 2100AN Turbidimeter. The TSS level was measured using standard test methods for filterable and nonfilterable matters (ASTM D5907-18, 2018). The pressure drop was measured by head loss, observed through a manometer attached to the P1 and P2 valves in Figure 1. The DO levels were measured using the HANNA H19142 Dissolved Oxygen Meter. Sampling points for DO are depicted in Figure 1.

Microbial Attachment

The microbial attachment within USF media was compared before and after the flushing. The attachments on sand particles were observed through Field emission scanning electron microscopy (FESEM) analysis. Samples were taken from the USF's top, mid, and bottom levels.

RESULTS AND DISCUSSION

Turbidity and TSS Removal Recovery

The USF required 11 hours of operation to achieve a stabilized turbidity and TSS removal level after upward flushing (see Figures 2 and 3). Turbidity stabilized at 22.64 NTU, where the initial turbidity level before clogging occurred was 22.50 NTU. The TSS level stabilized at 33.13 mg/L compared to 45.0 mg/L before clogging. The interparticle collision, fluidization, and buoyancy effects during upward flushing contribute to efficient turbidity (Aboelkhair *et al.*, 2022). The dislodgement of trapped particles occurs due to fluidization within the filter bed (Calixto *et al.*, 2020). Furthermore, buoyancy forces act on the suspended particles as the water flows upward, causing them to rise and separate from the filter media. This separation helps reduce turbidity as the particles are carried toward the surface and can be flushed out (Turan, 2023).

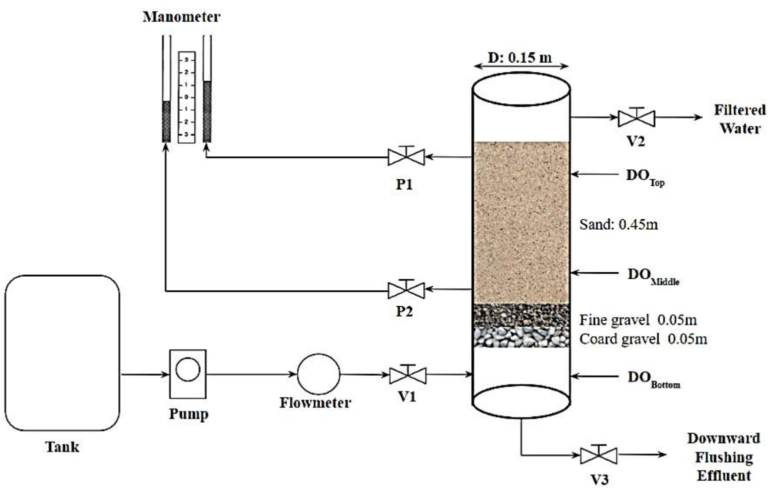

Fig. 1: Schematic diagram of experimental setup

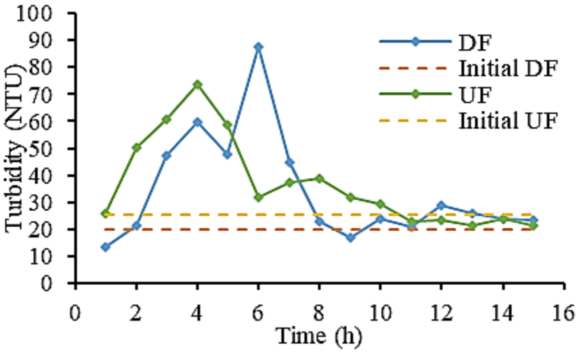

Fig. 2: Turbidity recovery after flushing

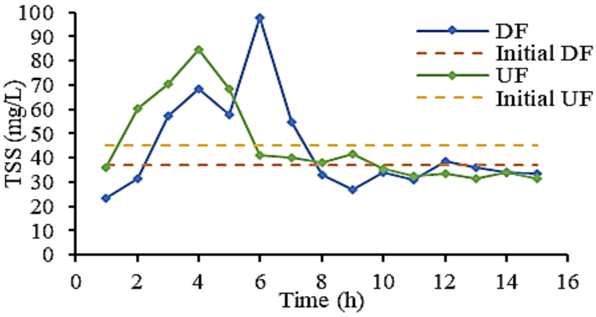

Fig. 3: TSS recovery after flushing

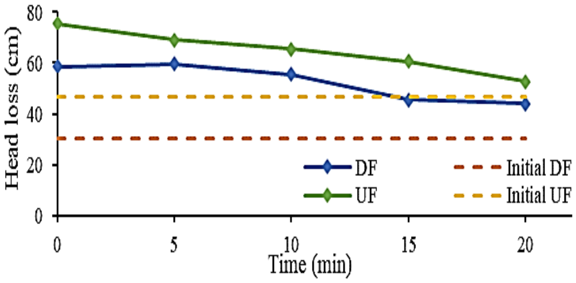

Fig. 4: Head loss recovery after flushing

Meanwhile, the USF required 8 hours of operation for downward flushing to achieve a stabilized removal performance. The average turbidity level achieved was 27.84 NTU compared to 20.10 NTU before clogging occurred. The TSS level after flushing was at 34.5 mg/L as compared to 37.0 mg/L before clogging occurred. Downward flushing at a high flow rate allows particles to be washed out as the water flows downward through the filter media. However, the flow direction does not provide the same agitation and dislodgement of trapped particles as in upward flushing (De Souza *et al.*, 2021). In addition, the flow velocity is decreased, causing suspended particles to settle and deposit onto the filter media bed. Contaminant particles are then captured and retained within the filter media. As the water flows downward through the filter media, particles larger than the media pores get trapped within the sand bed. Compression of the sand bed due to gravity flow can decrease the permeability of the sand filter. Consequently, the filter media may function as a physical barrier, limiting the removal of trapped contaminant particles during flushing (Aboelkhair *et al.*, 2022).

Head Loss Recovery

Monitoring of head loss was extended post-flushing of the USF (see Figure 4). Results showed a regular trend of head loss recovery with time. However, it could not reach initial head loss (measured at steady state before clogging occurred), with a 6.05 cm head loss difference after upward flushing. According to De Souza *et al.*, 2021, 15-25 minutes flushing could be sufficient. Still, it may vary depending on the filter size, the flushing flow rate, and the degree of contamination.

Hence, it is possible that the initial head loss could be achieved if the duration of flushing was extended. A lower recovery rate of the head loss was observed after downward flushing with a 13.87 cm head loss difference. When the initial head loss is not achieved, this would indicate that the sand filter was not fully cleaned. This is due to the lack of agitation during downward flushing.

DO Concentration

The DO levels were taken at three areas of the filter bed: the top, middle, and bottom of the sand bed (See Figure 1). Since USF operates similarly to the slow sand filter, it was worth noting that area with the most biofilm growth could have higher oxygen levels (Fitriani, 2020). The biological layer may degrade due to the height of the sand bed, which includes shallow depth. Besides that, it was stated that degradation of the biolayer for deeper sand levels may also occur due to insufficient oxygen supply to the biolayer. Therefore, this shows that the height of the sand filter may influence biological growth (Lamon *et al.*, 2021).

DO level monitoring was conducted at normal USF operation post-flushing for 15 hours. The average DO concentration in the three zones of the USF bed is summarized in Table 1. After upward flushing, the DO level did not change significantly compared to before clogging, which occurred in the 4.2 – 5.2 mg/L range.

Meanwhile, a higher DO level was observed after downward flushing was conducted. This may be due to insufficient cleaning of biological growth in the sand bed. Compared to upward flushing, the upward flow creates turbulence and agitation for cleaning, allowing water to carry away the dislodged particles, including the biological layer. Downward flushing, however, may generate a different level of turbulence, making it less effective in detaching and removing biological growth. Hence, the presence of retained biological growth was indicated through higher DO concentrations.

Table 1. DO conc. at varied zone after flushing (mg/L)

Layer zone	Upward Flushing	Downward flushing
Top	4.78	6.12
Middle	5.20	6.38
Bottom	4.20	5.48

**Initial DO before clogging was 4.5 mg/L for both experiments*

Microbial Attachments on Sand Particles

Figure 5 presents the FESEM micrographs taken before upward flushing, revealing thick clusters of bacteria with jagged edges, indicating apparent colonies adhered to the surfaces of sand particles. Analysis of the sand bed's top, middle, and bottom sections before upward flushing confirms successful biological growth during the USF operation. Notably, larger bacterial clusters are observed in the middle and bottom sections compared to the top. This pattern is attributed to the upward flow configuration of the USF, where the lower sections receive higher oxygen concentrations before reaching the upper layers.

Figure 6 shows the results after upward flushing. Upward flushing could eliminate biological growth on sand particles. This can be determined by identifying the smoother surfaces of sand particles compared to those before flushing. This is due to the high turbulence of sand media during upward flushing. However, some bacterial colonies could still be observed adhering to the sand particle surfaces due to the short duration of upward flushing (Calixto *et al.*, 2020).

According to Figure 7, thick clusters of bacteria can be observed adhering to sand particle surfaces. Figure 8 shows results after downward flushing, eliminating biological growth on sand particles. However, more bacterial colonies could still be observed adhering to the sand particle surfaces compared to the upward flushing experiment. This may be due to the lack of turbulence and agitation of sand particles, such as through fluidization, which helps to dislodge contaminants and biological growth from sand particle surfaces (Aboelkhair *et al.*, 2022).

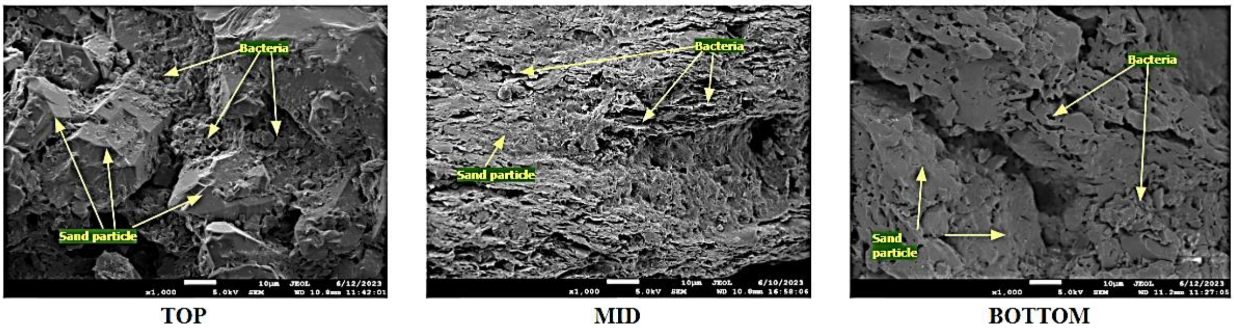

Fig. 5. FESEM micrographs x1000: Microbial attachments before upward flushing

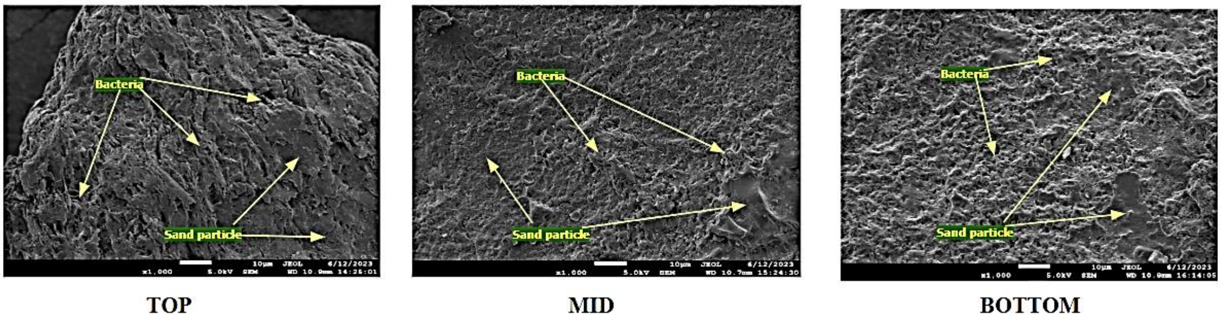

Fig. 6: FESEM micrographs x1000: Microbial attachments after upward flushing

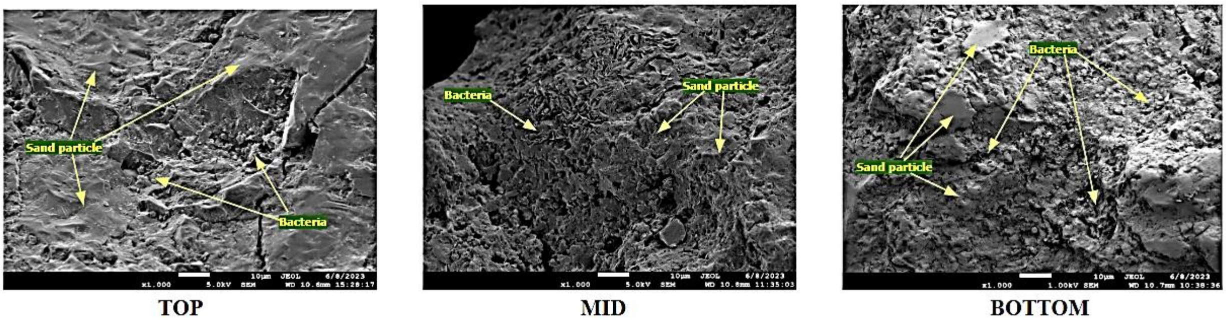

Fig. 7: FESEM micrographs x1000: Microbial attachments before downward flushing

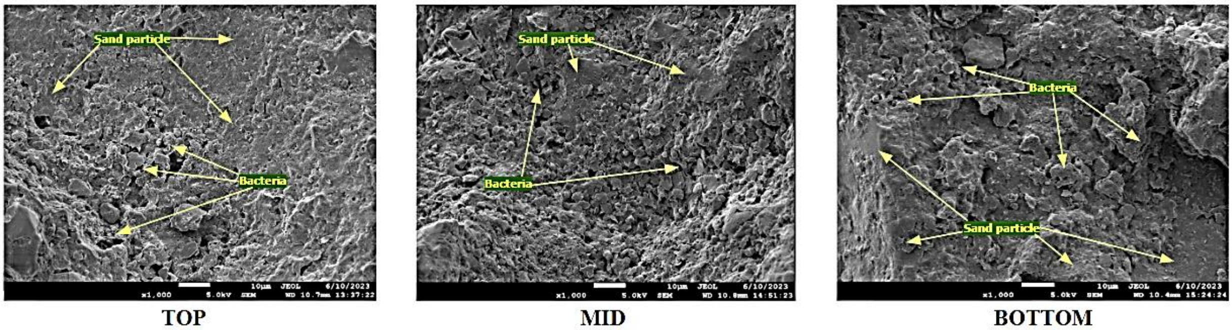

Fig. 8: FESEM micrographs X1000: Microbial attachments after downward flushing

CONCLUSION

Upward flushing showed superior outcomes in particle removal and head loss recovery although it required a longer time to recover TSS and turbidity removal performance. Lack of fluidization and less agitation during downflow flushing resulted in more microorganisms remaining within the USF. Physical observation of micro-organisms' spatial attachments after flushing further implies upward flushing with higher cleaning optimization as well as post-cleaning efficiency recovery

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