

Assessment of up-flow and down-flow dual media filters for secondary treated wastewater

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Received: 24 October 2023; Accepted: 09 April 2024

The present research study has investigated the effectiveness of vertically down-flow and up-flow dual media filters in secondary treated domestic wastewater. Dual media filters, incorporating gravel, sand, and granular activated carbon, have been designed to overcome the challenges of tertiary wastewater treatment, such as the removal of fine suspended solids, microbial contaminants, odors, and nutrients. The up-flow dual media filter has achieved higher removal efficiencies for suspended solids and organic matter, resulting in effluent that meets discharge standards. Specifically, the up-flow configuration has enhanced contact time between the wastewater and the filter media, thereby improving the adsorption and filtration processes. Additionally, up-flow filter has exhibited reduced clogging issues and lower operational and maintenance requirements, as accumulated contaminants tend to settle at the bottom, facilitating ease in removal as compared to down-flow dual media filter.

Keywords: Tertiary treatment, Dual media filter, Up-flow, Sand, Activated carbon

1 Introduction

Water shortages have become one of the most pressing issues for many countries due to growing populations and a lack of freshwater resources. In order to address this problem, new water resources need to be developed. A common approach in this trend is to reuse wastewater from tertiary treatment for irrigation¹. In the final stage of treating wastewater derived from secondary treatment unit effluent, tertiary treatment systems use a variety of physical and chemical methods to completely eliminate all pollutants². There are several physical methods used in tertiary treatment, including sand filtration, activated carbon, nanofiltration, ultrafiltration and reverse osmosis. Various chemical treatments are also well-known, including, ultraviolet disinfection, photocatalysis, coagulation and flocculation, ozonation, and others. The process of filtering with sand and adsorbing with activated carbon does not require the use of chemicals and are considered to be eco-friendly³⁻⁶. The treatment efficiency of sand filtration in combination with activated carbon is directly correlated with hydraulic loading rates⁷. Filtration attains better treatment efficiency when the hydraulic loading rates range from 0.05 to

0.4 m/h. Recent studies have shown that slow sand filtration reduces suspended solids better than rapid filtration in secondary effluents. A slow sand filtration system offers a low capital and operating cost, as well as simplicity of operation and maintenance⁸⁻¹⁰. In recent decades, the use of activated carbon adsorption for wastewater treatment has gained popularity because of its more surface area and higher porosity¹¹. In the tertiary treatment of municipal and industrial wastewaters, Granular Activated Carbon (GAC) is most commonly used. To maximize the adsorption effectiveness, factors to consider include the specific sorption capacity of the GAC, the dosage and physico-chemical properties of the activated carbon, and the composition of the effluent obtained from secondary treatment¹². Processes for activated carbon adsorption are effective at removing recalcitrant compounds from wastewater, including heavy metals, aromatic hydrocarbons, bisphenols, alkylphenols, pesticides and pharmaceuticals¹³⁻¹⁵.

By designing and implementing powerful tertiary treatment methods, this goal is often achieved, allowing a safe discharge of treated effluents back into the natural environment¹. Furthermore, tertiary treatment should be performed on the discharge effluents as well as the biological processes required for the deputation of such waste streams to ensure that

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residual pesticides have been removed and that the legislation is met. Additionally, tertiary treatment systems have the potential to have positive impacts on irrigated agriculture by reducing chemical levels in water footprints and minimizing the environmental impact of wastewater disposal. Microbiological contaminants must be effectively removed from domestic and commercial wastewater to ensure safe discharge into the environment or reuse and recycle. Cost-effective and advanced tertiary treatment methods, such as filtration with sand and adsorption with activated carbon, can achieve this level of purification³.

The objective of this study is to design and evaluate a tertiary treatment system for removing minute organic matter and suspended solids from secondary treated domestic wastewater. The research study demonstrates up-flow and down-flow filters with gravel, sand, and activated carbon to identify the most effective filtration configuration.

2 Materials and Methods

2.1 Dual media

By the time wastewater reaches the tertiary treatment stage, fine particulates and suspended matter are still present. Furthermore, it contains microbes and odor, as well as a high level of nutrients like nitrogen and phosphorus. A dual media filter is the most economical way to remove all these contaminants. Activated carbon and quartz coarse sand are used in these filters to filter suspended solids and absorb/adsorb pollutants. The filtration and absorption materials used in this experiment are coarse quartz sand and granular activated carbon, respectively, and they are supported on a bed of gravel. The physicochemical properties of these materials are shown in Table 1. Granular activated carbon adsorbs organic contaminants better than any other commercial carbon due to its large internal surface area and high bulk density. During the filtration and adsorption

processes, a normal temperature was maintained. A filtration with sand and activated carbon system was used under continuous operation with a hydraulic retention time of 24 hours maintained both vertically down-flow and vertically up-flow for 1KLD of secondary treated wastewater.

2.2 Design and Demonstration




The filter unit is designed as a pressure vessel, which is constructed with a straight cylindrical shell and convex dish-shaped ends that are welded together at the top and bottom. This type of filter vessel is typically engineered to tolerate a pressure of around 5 kg/cm². It is common for small diameter filter vessels to include a bolted dish at the top, which simplifies maintenance. At the top of large filters, manholes typically measure more than 0.6 meters in diameter. To facilitate media removal from the vessel during service, a 200 mm diameter handhole is provided at the bottom of the cylinder. In smaller treatment facilities, the shell height of the filter vessel typically ranges from 1.2 meters to 1.5 meters. The bottom layers of the filter are filled with graded pebbles ranging in size from 10 mm to 20 mm, with a depth of nearly 0.5 to 0.6 meters. The top layers of the filter consist of Quartz's sand media, which includes both coarse and fine sand/granular activated carbon, with a depth of 0.6 to 0.7 meters. Additionally, a freeboard of approximately 0.3 meters above the sand level may be included to allow for sand expansion during backwashing.

An effective filtration rate to use as a basis for designing wastewater treatment plant filters is 12 m³/m²/hr of filter cross-sectional area. Consequently, the majority of filters utilized in sewage treatment plant applications are designed using this rate as a standard procedure with 20 hours of filtration and 4 hours of rest. The details of media depth column – I and column – II are explain in Table 2.

To carry out the tertiary treatment of domestic wastewater containing minute concentration of

Table 1 — Physicochemical properties of quartz coarse sand and granular activated carbon.

Parameters	Quartz coarse Sand	Parameters	Granular Activated Carbon
Effective size	2.2–3.5 mm	Effective size	5–8 mm
Particle shape	Sub-angular	Bulk density	500±30 kg/m ³
Particle density	2.5 g/cm ³	Ash content	<6%
Color	Yellowish-grey	Iodine number	1050 mg/g min
Content	96% SiO ₂	Surface area	1050 m ² /g
Solubility in water	Negligible	Dechlorination half-value length	<4.8 cm
Respirable quartz	<1%	Hardness	98%
Aqueous solution pH	5–8	Activation method	Steam
Melting point	>1610 °C	Moisture Content	5%

Table 2 — Filling material or media depth in dual media filter tank			Filter Media
Type of Media	Column –I Gravel +Sand	Column –II Gravel + Sand + GAC	
Crushed Gravel (10-20 mm)	10 cm	5 cm	
Quartz Coarse Sand (2-3 mm)	60 cm	5 cm	
Granular Activated Carbon (5-8 mm)	-	60 cm	
Free Board + Water Depth	10 cm	10 cm	

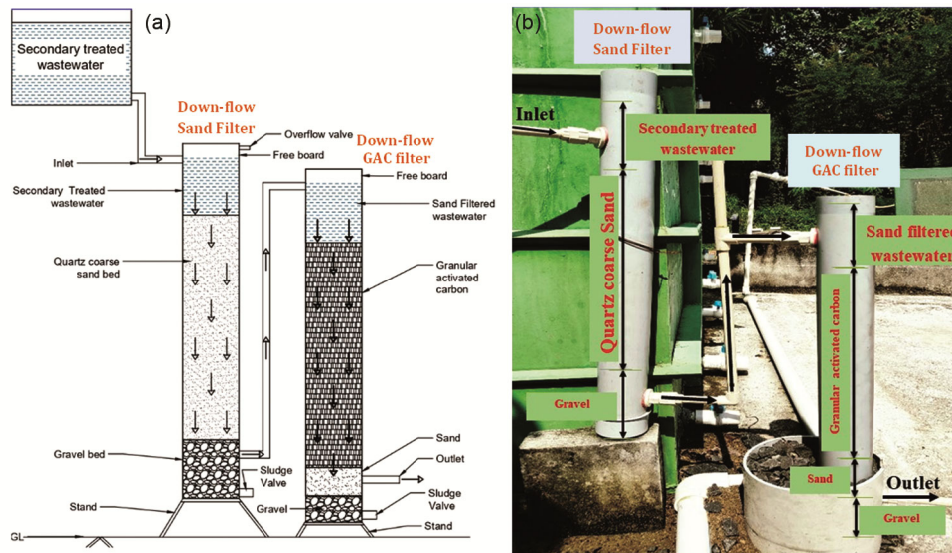


Fig. 1 — Down-flow dual media filter: (a) Schematic diagram, and (b) field photograph.

organic matter, developed and installed a laboratory-scale dual media filter consisting of gravel, sand and a granular activated carbon column. The combined system has a capacity of 3.5 liters of each column and operates in series manners. Columns made of cylindrical Unplasticized Polyvinyl Chloride, Soil, Waste and Rainwater Pipes (UPVC, SWR) contained sand and granular activated carbon. The column under consideration had an approximate internal diameter of 7.5 cm, a usable height of 70 cm, and a freeboard height of 10 cm as presented in Table 2. The bottom

of the sand filter was filled with 10 cm of gravel, while the top layer was filled with 60 cm of quartz sand. Before adding granular activated carbon (GAC) at the top of the column, a layer of gravel (5 cm high), quartz sand (5 cm high), and GAC (60 cm high) was placed at the bottom of the GAC column filter. The downward flow of secondary effluent took place in the sand column, while the treated filtrate started at the top and flowed downward in the activated carbon column as shown in Fig. 1. Secondary effluent was flowed vertically up-ward in the sand column, and

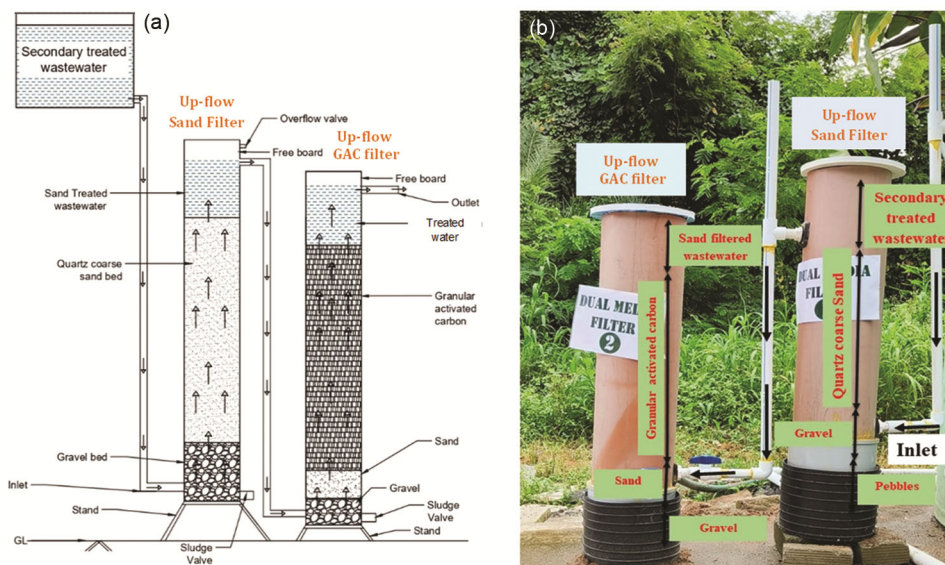


Fig. 2 — Up-flow dual media filter: (a) Schematic diagram, and (b) field photograph.

treated filtrate started at the bottom and flowed upward in the activated carbon column as shown in Figure 2.

2.3 Experimental analysis

In order to evaluate the quality of tertiary treatment, physical and chemical parameters were determined according to "Standard Methods for Examining Water and Wastewater". Hanna HI 98191 pH meters were used to determine pH. Whatman GF/C glass microfibre filter paper was used to measure Total Suspended Solids (TSS). Chemical Oxygen Demand (COD) was assessed by employing the open reflux method. Steam distillation and Kjeldahl methods were used to determine the concentration of total Nitrogen (TKN). The measurement of Total Phosphorus (TP) was conducted using a spectrophotometer. To count *Escherichia coli* (*E. coli*), 100 mL of sample was permeated through a filter paper with a pore size of 0.45 μm , and then the membrane filter culture was incubated on Chromocult Coliform Agar plates for 24 hours at 44 degrees Celsius.

2.4 Secondary treated wastewater characteristics

Samples of secondary treated wastewater were taken from a constructed wetland based STP installed in CSIR-NEERI campus (Table 3). The secondary treated wastewater was collected in an overhead tank for continuous supply to down-flow and up-flow dual media filters.

Dual media filter was fed with biologically treated wastewater containing microbiological contaminants,

Table 3 — Water quality of secondary treated wastewater

Sr. No.	Parameter	Secondary treated wastewater		
		Min	Max	Average
1	pH	7.2	7.9	7.5
2	TSS (mg/L)	32	48	40
3	COD (mg/L)	64	80	68
4	TN (mg/L)	11.4	16.4	13.1
5	TP (mg/L)	2.6	4.8	3.3
6	FC (CFU/ 100mL)	8×10^4	2×10^5	1×10^5

and the filtrate from the sand column was then fed into activated carbon for the absorption of organic matter. The columns were continuously fed evenly throughout the experiment. There was no need for any pump to generate pressure because the system worked by maintaining hydraulic through gravity flow.

3 Results and Discussion

The performance of up-flow and down-flow dual media filters was compared based on water quality parameters. In addition, it is observed that the parameters of the permeate changed in activated carbon, but pH did not significantly affect either the sand columns or the activated carbon columns. It was found that the pH of the activated carbon permeate with up-flow was slightly higher than that of the biologically treated secondary wastewater and sand filtrate, with values ranging from 7.5 to 7.6. However, with down-flow water in the filter, pH values did not vary much in either the sand column or the activated carbon filter column, ranging from 7.4 to 7.5 (Fig. 3(a)). This rise in pH can be attributed to

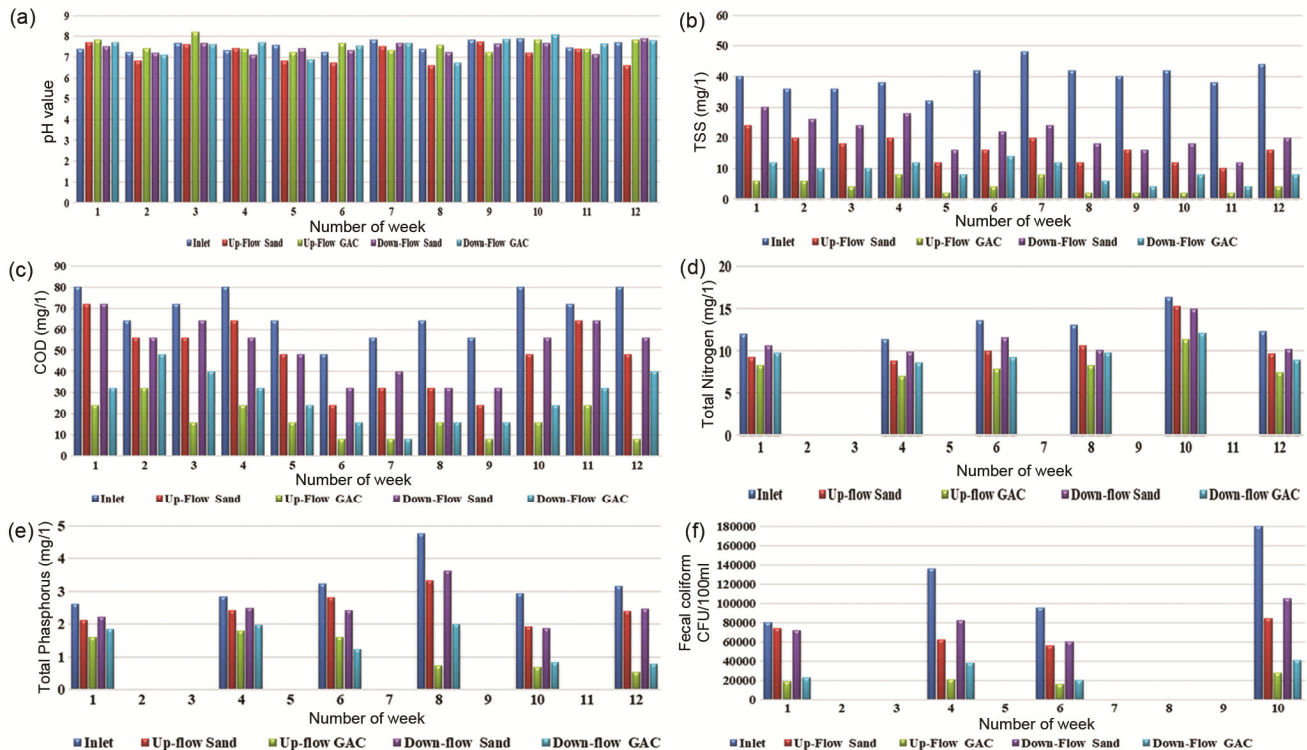


Fig. 3 — Performance of dual media filter in terms of water quality parameters (a) pH , (b) TSS, (c) COD, (d) TN, (e) TP, and (f) FC.

interactions between anions in the wastewater and activated carbon surfaces. These interactions occur due to an ion exchange process whereby activated carbon adsorbs anions after surface ionization¹⁶. Overall, the findings suggest that the use of activated carbon filters in wastewater treatment may help to alleviate low pH levels caused by the presence of trace elements and salt solutions in domestic wastewater.

The secondary treated wastewater with an initial TSS concentration of 40 mg/L was reduced to around 15 mg/L through sand filtration and finally 4 mg/L through granular activated carbon filtration, in the up-flow filter. The removal of TSS in the down-flow sand and activated carbon filters was 24 mg/L and 9 mg/L, respectively. These removal results indicate that the filtering process was highly effective in reducing TSS levels and enabling the reuse of wastewater parameters (Fig. 3(b)). However, a clogging issue was identified in the down-flow filter due to clogging of fine sand layer on top of the sand filter. This resulted in the accumulation of particles in the top 2 cm of the sand filter layer, leading to a drop in filtration capacity. To ensure optimal performance, it is recommended that the top layer of the sand be replaced every 2-3 months. In contrast, up-flow dual

media filters did not experience such problems. Any solids that accumulated at the bottom of these filters were in the form of sludge, which could be easily removed using sludge removal valves. Overall, the results demonstrate that up-flow dual media filters are an effective solution for reducing TSS levels in secondary treated wastewater, without the risk of clogging. However, to maintain optimal performance of downward flow filters, regular maintenance is required to prevent the accumulation of particles and ensure the longevity of the filtering system.

The results of the 12-week analysis showed a significant decrease in COD in the up-flow dual media filters. The initial COD concentration of 68 mg/L (average) from biologically treated wastewater was reduced to 50 mg/L (average) from the sand filter column (Column I) and further decreased to 16 mg/L from activated carbon column (Column II) in the up-flow filter. The removal of COD in the dual-media filters with vertically downward flow was 55 mg/L (average) and 27 mg/L (average) in the filtrate of Column I and Column II, respectively. The results indicate that the flow pattern had an impact on the removal efficiency, with the up-flow water column providing more contact between the organic matter and the granular activated carbon,

resulting in enhanced removal efficiency of organic matter from the activated carbon (Fig. 3(c)). Both the activated carbon column treatments achieved the highest COD removal efficiency. Based on these results, activated carbon was found to make a significantly higher contribution to the removal of organic matter than sand filters. Therefore, the use of activated carbon as a filter media is recommended for the effective removal of organic matter in wastewater treatment systems.

The experimental results indicate that the sand filtration process had a negligible effect on the total nitrogen removal (Fig. 3(d)). The total nitrogen concentration in the treated wastewater decreased only slightly from 13.1 mg/L to 10.6 mg/L after passing through the up-flow sand filter. In contrast, the activated carbon permeate with up-flow dual media filter significantly reduced the total nitrogen concentration to 8.3 mg/L, indicating the effective removal of organic nitrogen content. The down-flow sand filter removed only a small portion of the total nitrogen, with the effluent total nitrogen concentration being 11.2 mg/L. A total nitrogen concentration of 9.7 mg/L was obtained from the effluent after installation of a down-flow activated - carbon filter. The sand filter was not so effective in removing both organic and inorganic nitrogen. The experimental approach involved passing the secondary treated wastewater through a dual-media gravel, sand filter, followed by an activated - carbon media filter. The sand filter was utilized to filter and absorb contaminants on its surface, whereas the activated carbon filter was designed to adsorb and remove organic and inorganic contaminants from the wastewater. The findings of the study suggest that sand filtration may not be the optimal treatment process for the removal of total nitrogen from organic-containing wastewater. Activated carbon can remove both organic and inorganic nitrogen. Nonetheless, further studies are required to identify the optimum conditions for using activated carbon in the removal of nitrogen from wastewater.

The results of the study indicate that the use of dual media filters comprising sand and granular activated carbon can effectively reduce phosphorus concentrations in wastewater. The study employed two different filters with vertical flow along the saturated sand and activated carbon profile every alternate week to evaluate the effect of the dual media filters on phosphorus retention (Fig. 3(e)). The

analysis of the effluent concentrations in comparison to the influent concentrations of phosphorus allowed the evaluation of the treatment efficiency. The average influent phosphorus concentration during the study period was 3.3 mg/L, which was slightly reduced after passing through the dual media sand filters. The vertically up-flow sand and granular activated carbon filters produced an average concentration of 2.5 mg/L and 1.5 mg/L, respectively. The final concentrations of phosphorus after passing through the sand and GAC were 2.5 mg/L and 0.8 mg/L, respectively, in the down-flow filter. The results demonstrate that the use of granular activated carbon in conjunction with sand filters can significantly improve the removal efficiency of phosphorus in wastewater treatment. This is likely due to the high adsorption capacity of activated carbon, which can effectively adsorb phosphorus from wastewater. During the filtration process, particulate phosphorus (mineral and organic) is physically retained on the surface of the filter bed. In addition to adsorption and precipitation, physico-chemical methods can remove dissolved phosphorus.

In this study, two filtration systems were compared to reduce fecal coliform in secondary treated wastewater: sand filtration and activated carbon filtration with vertically down-flow and up-flow dual media filters. The results showed that sand filtration reduced the fecal coliform concentration by 46%, from 1×10^5 CFU/100 mL to 7×10^4 CFU/100 mL in the up-flow filter. However, activated carbon filtration was more effective in removing fecal coliform with an up-flow direction. The removal efficiency of activated carbon for the fecal coliform was 83%, with a residual concentration below 2×10^4 CFU/100 mL (Fig. 3(f)) in the up-flow filter. In terms of the direction of flow, the study found that the down-flow filtration resulted in higher fecal coliform concentrations in both the sand and activated carbon filters, with concentrations of 8×10^4 CFU/100mL and 3×10^4 CFU/100 mL, respectively. However, there was no statistically significant difference in fecal coliform concentrations between the down-flow activated carbon filtrate and the up-flow activated carbon treated wastewater. The study also highlighted the importance of considering the adsorption capacity of activated carbon over time. While it may become less effective as time passes, activated carbon can enhance its adsorption capacity with proper maintenance and reactivation.

Table 4 — Performance of dual media filters

Parameter	Inlet	Down-flow (Outlet)		Up-flow (Outlet)		Discharge Standards
		Sand Filter	GAC Filter	Sand Filter	GAC Filter	
pH	7.5 ± 0.25	7.2 ± 0.25	7.5 ± 0.4	7.5 ± 0.3	7.6 ± 0.3	6.5 - 9
COD (mg/L)	72 ± 8	56 ± 16	32 ± 16	48 ± 16	16 ± 8	≤ 50
TSS (mg/L)	24 ± 4	22 ± 6	8 ± 4	16 ± 4	4 ± 2	≤ 20
Total Nitrogen (mg/L)	13.14 ± 1.8	11.2 ± 1.8	9.74 ± 1.6	10.6 ± 2	8.38 ± 1.5	≤ 10
Total Phosphorus (mg/L)	3.25 ± 0.8	2.5 ± 0.5	0.85 ± 0.6	2.5 ± 0.5	0.62 ± 0.6	≤ 1
Faecal Coliform (CFU/100 mL)	1 × 10 ⁵ ± 4 × 10 ⁴	8 × 10 ⁴ ± 1.5 × 10 ⁴	3 × 10 ⁴ ± 1 × 10 ⁴	7 × 10 ⁴ ± 1 × 10 ⁴	2 × 10 ⁴ ± 0.5 × 10 ⁴	< 230 MPN/ 100 mL

Evaluation of the quality of treated wastewater from down-flow and up-flow dual media filters was performed with pH, TSS, COD, TN, TP, and fecal coliform. In order to ensure treated wastewater compliance, these parameters are compared with discharge standards as per National Green Tribunal (NGT) norm April 2019. All the parameters complied with the standards except fecal coliform; therefore, disinfection must be provided before discharge into water bodies or reuse/recycle for various purposes. As a result of measuring and monitoring on a regular basis, the concentrations of required parameters from the dual media filters are provided in Table 4 with treated sewage discharge standards.

4 Conclusions

A dual media filter has been evaluated considering gravel, sand and granular activated carbon through down-flow and up-flow movement of secondary treated domestic wastewater. Both vertically up-flow and down-flow dual media filters allow the effluent to comply with discharge standards except for fecal coliform (FC). It has been observed that the removal efficiency of suspended and dissolved organic matter with activated carbon is enhanced in the up-flow dual media filter due to the up-flow movement of wastewater, which provides more contact between wastewater and filter media. Based on physico-chemical, and biological water quality analysis, the up-flow dual media filter performs better than the down-flow dual media filter. Another advantage of the up-flow dual media filter is the reduced clogging problem as pollutants settle at the bottom and do not travel along the wastewater movement. Up-flow dual media filter requires minimal backwashing at regular intervals as compared to the down-flow dual media filter. This allows the treated water to be discharged directly into the environment or recycled after disinfection for floriculture, road washing, flushing, gardening, and other useful purposes.

Acknowledgement

Authors would like to acknowledge Director, CSIR-NEERI, Nagpur for providing the infrastructure and necessary support to carry out this research. Authors acknowledge the efforts taken by Knowledge Resource Centre, CSIR-NEERI, Nagpur, India, for plagiarism check (KRC No.: CSIR-NEERI/KRC/2023/MAY/WWTD/2). Authors are also thankful to CSIR-HRDG for GATE-SRF fellowship. Authors also would like to thank Shradhanjali Sethi for bacteriological analysis.

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