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PERFORMANCE EVALUATION OF A SMALL-SCALE TRICKLING FILTER: AN EXPERIMENTAL STUDY

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ABSTRACT

Trickling filters are one of the widely used biological treatment process of sewage, for its effectiveness in removing organic pollutants, constructional simplicity and low energy consumption. Unlike many studies that use commercial or synthetic media, this study demonstrates the performance of a low-cost, small-scale trickling filter using locally available materials for decentralized domestic sewage treatment under controlled conditions. Sewage was collected from a local source and treated in the filter under standard experimental conditions. Key parameters such as pH, chemical oxygen demand (COD), BOD_5, total suspended solids (TSS), total dissolved solids (TDS) and phosphate removal were monitored throughout the operation to measure its performance. The removal efficiency was found to be 2.02, 21.41, 85.33, 65.45, 62.54 and 77.08% for pH, TDS, TSS, COD, BOD_5 and Phosphate respectively. Our results suggest that small-scale trickling filter with locally available stone chips can be used as single/detached and community scale, as an efficient option for treatment of sewage, locally. The results of this investigation can be able to generate real field data that is often unavailable.

Keywords: *Trickling filter, biofilm growth, sewage treatment efficiency*

1. INTRODUCTION

In developing nations, particularly Pakistan, India, Bangladesh, and numerous African regions, water pollution remains a major barrier to improving public health (Haider et al., 2017; Qureshi & Mastoi, 2011). Poor water management and increasing water emissions are fueling global human and environmental health problems. Population growth, urbanization, unsustainable consumption, and inadequate sanitation are further stressing water resources in terms of both quality and availability (WWF, 2007). The selection of an appropriate treatment system is often constrained by several factors, including financial limitations, high energy consumption, skilled manpower, technical compatibility, and difficulty in operational activities (Bouabid & Louis, 2015). Selecting an appropriate and practical technology is necessary due to economic constraints and the implications of the decision (Tănase et al., 2017). As conventional treatment plants are often costly to construct and maintain, there is growing interest in low-cost, decentralized systems that can operate efficiently with minimal energy and technical supervision (Ventura et al., 2024). Although many local research groups are working on selecting sewage treatment systems for developing countries, but the amount of research is still very low. (Imran et al., 2017). At present, the trickling filters are commonly known for an effective option for domestic sewage treatment. Its key advantages are simplicity, low sludge production, non-mechanized process, and lower energy use compared to physical and chemical methods (Ismail et al., 2008). In this system, high microbial activity is maintained over a long duration where microbes degrade the pollutants (Yeh et al., 1997; Joseph & Christopher, 2000). Here, in the aeration basin, sewage is continuously circulated, allowing the microbial community to aerobically metabolize organic compounds and synthesize new biomass. The microbial cells build a sludge, which settles in a secondary clarifier (Peter et al., 1999). A trickling filter typically contains three parts i.e. distribution system for monitoring hydraulic load rates, filter media for the development of biofilm, and under drain system for collecting effluent sewage and accumulated sludge from filter (Michael, 1999). In this study, a small-scale trickling filter was operated in aerobic condition to treat a sample domestic sewage. The trickling filter performance was evaluated throughout this experiment by testing key parameters such as pH, Chemical Oxygen Demand (COD), Five-day Biochemical Oxygen Demand (BOD_5), Total Suspended Solids (TSS), Total Dissolved Solids (TDS) and Phosphate.

2. METHODOLOGY

2.1 Trickling filter configuration and operation layout

A small-scale Trickling Filter was constructed, having a height of 18” and inner diameter of 12”, using steel sheet. An under-drain system was constructed having height of 12” where an outlet was positioned at top to collect treated sewage. The supporting material for bacterial growth was locally available small stone-chips. Different sizes of stone-chips were used in different layers for different purposes as mentioned in Table 1. The influent sewage was applied to the system intermittently, four times daily at 7:00 a.m.,11:00 am, 3:00 p.m., and 7:00 p.m. at a rate of 10L/day. The trickling filter had an effective hydraulic retention time of approximately 3 days, based on reactor volume and influent flow rate. The sewage was collected from a septic tank beside canteen-3, Chittagong University of Engineering & Technology, Bangladesh. We made sure that the sample sewage was collected using proper safety protocol. We constructed our trickling filter setup near the sewage source for ease of collection and minimum disturbance during transportation. A plastic container was used to hold treated sewage and also, act as a secondary clarifier. Figure 1, shows the configuration of trickling filter developed in field case in this investigation.

2.2 Biofilm growth on filter media

Initially, the sewage was circulated in the filter for four weeks. A small amount of locally available cow dung was mixed with the influent sewage during one distribution period to accelerate biofilm development. After four weeks of circulation, small biofilm was observed on the upper layer of filter. Sewage was distributed evenly over the top surface of filter in this initial period. From previous research articles, the initial biofilm development in the fixed-film reactor required 3-60 days to commence the treatment processes for sewage (Moore et al., 2001; Nacheva et al., 2008; Yu et al., 2008).

2.3 Collection of sewages

Sewage samples were collected using High-density polyethylene (HDPE) plastic bottle (250 mL) and put through laboratory analysis which was performed under 24 hours. In order to perform physicochemical analysis, around 150 mL sewage was collected and all the tests were conducted within 6 hours.

2.4 Physicochemical characterization of sewage

For evaluating the efficiency of the constructed trickling filter setup, physicochemical analysis of both influent and effluent sewage was performed. The physicochemical parameters analyzed included pH, Chemical Oxygen Demand (COD), BOD_5, Total Suspended Solids (TSS), Total Dissolved Solids (TDS) and Phosphate. We used high-range COD vials and Hach DR6000 spectrometer to determine the Chemical Oxygen Demand (COD) value accurately. We also used the same Hach DR6000 spectrometer to determine phosphate value using proper reagents. We also determined the pH and Total Dissolved Solid (TDS) value using digital multiparameter for precise value. We determined Total Suspended Solid (TSS) value using standard gravimetric oven-drying method. The treatment efficiency of the trickling filter was found by using formula below.

Treatment Efficiency (%) = 100 × [(Influent Pollutant Concentration) – (Effluent Pollutant Concentration)] / (Influent Pollutant Concentration)

Table 1. Stone chips size distribution for different layers

Layer	Stone Size Range	Purpose	Thickness
Top	12 – 25 mm	Highest biological activity, fine surface area	12 inches.
Middle	25 – 38 mm	Transition zone for drainage and biofilm support	1.5 inches.
Bottom	38 – 50 mm	Drainage support layer, prevents clogging of underdrain	4.5 inches.

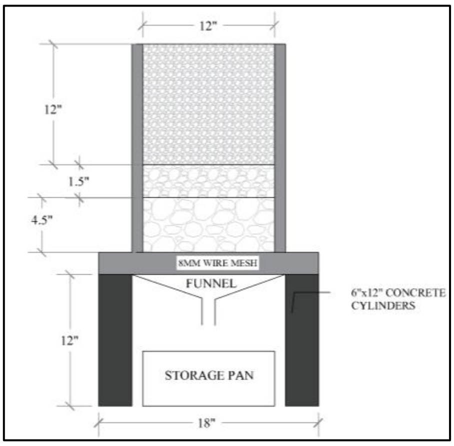

Figure 1. Schematic diagram of small-scale trickling filter setup

3. RESULTS AND DISCUSSIONS

The efficiency of the trickling filter during the research period is presented in a box-plot, as shown in figure 2. After the initial 4 weeks period for biofilm growth, the trickling filter was operated for 8 weeks. Additionally for better clarification, Table 2 shows the influent and effluent pollutant concentration of the constructed trickling filter. Using influent and effluent sewage pollutant concentrations of the trickling filter, removal efficiencies of each parameter were calculated using the formula mentioned above. The "×" in figure 2 represents the mean efficiency of the corresponding parameters.

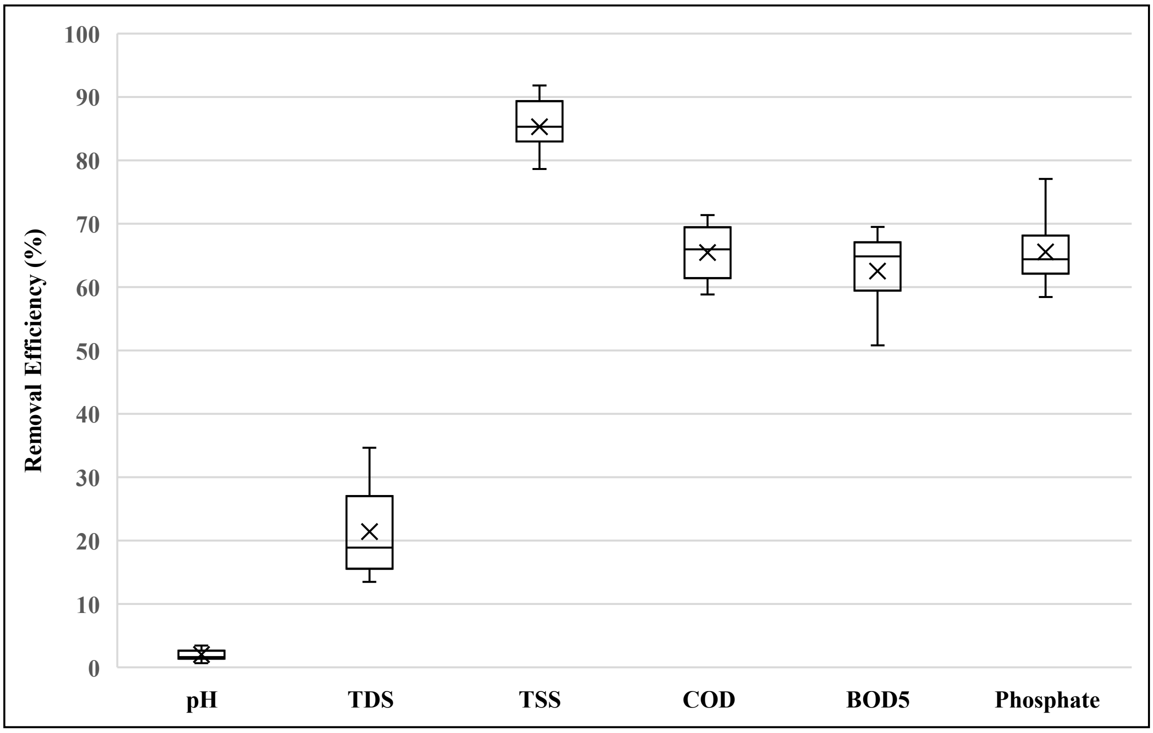

Figure 2. Pollutants removal efficiency of small-scale trickling filter during research period

Table 2. The characteristics of influent and effluent samples

Sample No.	**Sample Type**	**pH**	**TDS (mg/L)**	**TSS (mg/L)**	**COD (mg/L)**	**BOD$_5$ (mg/L)**	**Phosphate (mg/L)**
1	Influent	7.45	750	1360	1530	600	260
	Effluent	7.2	500	200	630	211	108
2	Influent	7.49	740	2300	1820	660	288
	Effluent	7.23	600	300	550	216	66
3	Influent	7.3	760	1200	1850	624	280
	Effluent	7.2	540	250	530	253	78
4	Influent	7.27	750	1320	1590	432	266
	Effluent	7.22	640	180	540	198	96
5	Influent	7.35	770	1240	2230	720	272
	Effluent	7.18	610	210	670	240	103
6	Influent	7.4	740	1800	1740	480	246
	Effluent	7.3	540	180	620	188	91
7	Influent	7.44	790	1960	1930	580	284
	Effluent	7.25	610	160	770	177	111
8	Influent	7.39	770	1420	2070	588	264
	Effluent	7.27	650	240	720	188	104
9	Influent	7.29	760	1500	1470	468	278
	Effluent	7.2	620	320	460	216	98
10	Influent	7.33	740	1820	1650	616	256
	Effluent	7.22	640	300	590	210	86
11	Influent	7.3	760	1530	1540	488	266
	Effluent	7.18	620	260	520	240	76
12	Influent	7.49	750	2100	1970	668	276
	Effluent	7.33	490	200	670	220	94
13	Influent	7.6	740	1850	1840	520	294
	Effluent	7.4	560	350	710	184	106
14	Influent	7.42	790	2070	1670	490	306
	Effluent	7.2	680	220	510	196	109
15	Influent	7.54	760	1920	1800	626	270
	Effluent	7.43	640	230	720	218	86

In general, as seen in figure 2, the highest removal of TSS has been found in the range of above 80%, while the other parameters studied falls within 20 to 70%. The results obtained from the developed trickling filter are found in consistent with other studies elsewhere (Iffat et al., 2015; Khan et al., 2015). A detailed parametric results and discussions are as follows.

3.1 pH Removal

pH indicates whether the solution is acidic or alkaline. It is a measure of the hydrogen ion concentration, more accurately reflecting hydrogen ion activity. Deviation from the recommending range (6.5-8.5) might influence the biological organisms in water (WHO, 2004). The results showed that the influent pH value is decreased by 0.69 to 3.47% (Figure 2, Table 2). The denitrification process in the filter may have resulted in the slight decrease of pH (Sakuma et al., 2008).

3.2 TDS and TSS Removal

In this experiment, mean TDS and TSS concentration before treatment was 758 and 1693 mg/L respectively (Table 2). After treatment process, mean reduction of 21.41 and 85.33% was found for TDS and TSS respectively (Figure 2, Table 2). The trickling filter obtained high TSS removal efficiency (78.67 to 91.84%) as a result of physical filtering of the stone media and filtering action of the biofilm layer at the top surface (Maheesan et al., 2011). So, the treatment process is highly effective in removing particulate matter like suspended solids. The lower reduction of TDS may be the result of lower contact time in the trickling filter (Iffat et al., 2015).

3.3 COD Removal

COD reflects the amount of organic pollutants in water and typically reported in milligrams per liter (mg/L) (Sehar et al., 2011). In this experiment the average COD value of influent sewage was found to be 1780 mg/L (Table 2). After treatment, the COD value reduced by 58.82 to 71.35% (Figure 2, Table 2). This indicates that micro-organisms of biofilm are responsible for degrading carbon-containing compounds (Sa´& Boaventura, 2001). The process of nitrification in the trickling filter has also enhanced the reduction of COD (Maciejewski et al., 2024). The gradual stabilization of COD levels between the samples at Table 2 indicates that the microbial layer at the top surface matured over time and became more effective (Khan et al., 2015).

3.4 BOD$_5$ Removal

BOD$_5$ represents the total amount of oxygen requirement for micro-organisms to aerobically break down organic wastes. BOD is commonly expressed in mg of oxygen per liter of water or wastewater (mg/L). The influent mean BOD$_5$ value was 571 mg/L which is quite high due to having large amount of contaminants (Table 2). The effluent quality shows that trickling filter has significantly reduced the BOD$_5$ content by up to 69.48% (Figure 2, Table 2) which indicates that sufficient amount of oxygen was available for the micro-organisms of biofilm to break down organic pollutants in sewage. The micro-organisms of biofilm layer broke down the organic contaminants and transformed them into biofuel (Soontarapa & Srinapawong, 2001).

3.5 Phosphate Removal

Polyphosphates out of washing powder, living organism, and feces into sewage, are the key supplier of phosphates. Phosphate is extracted out of sewage by the microorganisms through absorption process for metabolism and biomass growth (Szogi et al., 1997). In this experiment, the average phosphate content for the influent was 274 mg/L (Table 2). After treatment, around 58.46 to 77.08% efficiency was found for phosphate removal process (Figure 2, Table 2). From previous studies, it is reported that as the sewage passed through the biofilm layers, the enhanced contact between microorganisms and nutrients resulted in the rapid uptake of orthophosphate into microbial biomass (Meng et al., 2024).

4. CONCLUSIONS

This study, the mean removal efficiency of the constructed small-scale trickling filter was found to be 2.02, 21.41, 85.33, 65.45, 62.54 and 77.08% for pH, TDS, TSS, COD, BOD$_5$ and Phosphate respectively. This experiment results concluded that the constructed small-scale trickling filter is an effective option for organic contaminants removal. The overall system performed adequately. A notable reduction in phosphate content was found in the treatment process which indicates the presence of phosphate-accumulating microorganisms in the biofilm layer of filter media. This study suggests that small-scale trickling filter can be used in developing countries for an efficient option for treatment of sewage and removing chemical impurities and also, removing microbial concentration. Furthermore, larger scale trickling filter can be adopted for widespread uses.

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