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Effect of organic loading rate and retention time on pollutant reduction in a batch process for graywater treatment

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ABSTRACT

Graywater (GW) is the term given to all used water discharged from a house, except for toilet water. Among the different sources, laundry and kitchen sink are the main contributors to the total GW load of organic carbon and suspended solids; these sources can also be called dark GW, whereas bathtub and handbasins are the less polluted sources of GW known as light GW. The main aim of this study was to evaluate the effect of organic loading rate (OLR) (0.27, 0.49, and 0.82 COD kg/m^3/d) and retention time (RT) (8, 16, and 24 h) on sand filters. The performance of coarse and fine sand filter was monitored by monitoring the reduction in biochemical oxygen demand (BOD), chemical oxygen demand (COD), oil and grease (O&G), and turbidity. The experimental results showed that increase in OLR and RT increase the removal efficiency. The maximum removal efficiency was observed in BOD was 78%, COD was 77%, O&G was 75%, and turbidity was 81% at 24 h RT and OLR 0.82 kg/m^3/d.

Keywords: Graywater; Light graywater; Dark graywater; Batch reactor; Retention time; Organic loading rate

1. Introduction

It is pertinent to note that Mother Earth has blessed us with many natural resources which are key to our survival. But human beings have a tendency to misuse and waste such precious resources. This has led to a scarcity of available resources. Among all natural resources, water is an important and the most crucial natural resource that is used every day by human beings. Other than consuming water for survival, human beings also use it for a wide variety of purposes, ranging from maintenance of hygiene to the production of energy. Other than these uses, human beings also use water for washing, food processing, recreation, and other purposes. Additionally, it is used in agriculture for irrigating farmlands.

Graywater (GW) is wastewater which is generated from domestic activities such as laundry, dishwashing, and bathing, while blackwater (BW) is water generated from toilets [1,2]. In a household, the proportion of GW flow is around 50%–80% of the total wastewater flow [3,4]. The use of GW results in lower freshwater use, less strain on septic tanks or treatment plants, less energy and chemical use, and reclamation of wasted nutrients [2–5]. All of these benefits equal savings in energy and the natural resource that is water [2].

GW is not suitable for direct use but can be useful for nonpotable reuse such as irrigation and toilet flushing [5]. Domestic water consumption can be reduced up to 50% and achieves nearly "zero emission" when BW and GW are treated separately [1,6]. Separating GW from BW reduces the danger posed by pathogens [4].

GW bifurcated into light graywater (LGW) as well as dark graywater (DGW) [2]. The sources of LGW are bathroom and washbasin, contains soaps, shampoos, toothpastes, body care products, shaving waste, skin, hair, body fats, lint, and traces of urine and feces [7]. The sources of DGW are originating from the kitchen and laundry, contains food residues, high amounts of oil and grease (O&G), dishwashing detergents [4,7,8], bleaches, oils, paints, solvents, and non-biodegradable fibers from clothing [2,7]. DGW was polluted with food particles, oils, fats, and also contain chemical

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pollutants such as detergents and cleaning agents which are alkaline in nature and contain various chemicals. Due to this reason, DGW is discarded for treatment and reuse purpose because it takes more effort to maintain the system than with those for other GW sources. On the other hand kitchen GW contributes about 10% of the total GW volume. Wastewater from kitchen promotes and supports the growth of microorganisms, which is helpful in biological treatment [8].

This study was an attempt to evaluate the effect of organic loading rate (OLR) and retention time (RT) on sand filters fed with DGW and LGW.

2. Materials and methodology

2.1. Graywater

GW was collected from a student's hostel located at Sardar Vallabhbhai National Institute of Technology (SVNIT), Surat, India. LGW and DGW were collected daily at 8 am in the morning. GW collected from bathroom, handbasin was considered as LGW, and GW collected from the hostel mess (kitchen) was considered as DGW. Around 60 L GW was collected for the experiments. GW was passed through the screen of aperture size 1 mm to remove floating impurities. GW was collected in a collection tank, which was washed daily before use with clean potable water to avoid any carryover of contaminants.

2.2. Feed

DGW and LGW were homogeneously mixed with altered ratios in three different samples (A, B, and C), which correspond to OLR. OLR can be calculated by multiplying the influent concentration of COD with the amount of water poured in the reactor and dividing by the reactor volume. For the experiment 20 L total sample for each (Samples A, B, and C) was prepared. Sample A consisted of 25% DGW and 75% LGW which corresponds to OLR of 0.27 COD kg/m^3/d. Sample B consisted of 50% DGW and 50% LGW with an OLR of 0.49 COD kg/m^3/d. Sample C consisted of 75% DGW and 25% LGW corresponds to OLR of 0.82 COD kg/m^3/d.

$$\text{OLR}=\frac{\text{COD}\left(\text{mg/L or kg/m}^3\right)\times\text{Quality of sample poured in the reactor}\left(\text{L}\right)}{\text{Reactor volume}\left(\frac{\text{L}}{\text{d}}\right)} \tag{1}$$

2.3. Media

Naturally available river sand (coarse and fine) was used as a media for preparation of filters. The grain size distribution ranged from 2 to 4.75 mm (coarse sand) and 0.750 to 2 mm (fine sand). It provides adequate filtration by retaining particles and allowing water to flow across the media due to its inherent porosity of 40% coarse sand and 30% fine sand. Coarse and fine sand was sieved and washed several times with tap water until the clear water was obtained.

2.4. Experimental reactors

A polyvinyl chloride hopper bottom shape container having the volume 20 L was used for the fabrication of reactor. The reactor had 25 cm inner diameter and 45 cm height in which cylinder was 30 cm and hopper bottom was 15 cm (Fig. 1). Two identical reactors fabricated for coarse and fine sand which had pore volume 7 and 5 L, respectively. Both reactors were operated in batch mode. Both reactors were attached in series. Raw GW was manually fed into the coarse sand filter and effluent was collected and manually fed into the fine sand filter.

The performance of both the reactors was monitored at three different OLR and RT (0.27, 0.49, and 0.82 COD kg/m^3/d) and (8, 16, and 24 h), respectively. Total RT equally divided into the coarse and fine sand. The RT 8 h means 4 h RT for coarse sand followed by 4 h RT for a fine sand filter and similar methodology is followed for 16 and 24 h. The performance of the reactors was monitored by analyzing, monitoring parameter biochemical oxygen demand (BOD), chemical oxygen demand (COD), O&G, and turbidity.

2.5. Analytical procedures

All the parameters were analyzed according to the procedure mentioned in the standard method (APHA). BOD at 20°C test was analyzed as per the Winkler method with azide modification. COD was analyzed by an open reflux method using potassium dichromate ($K_2Cr_2O_7$) as an oxidizing agent. O&G was analyzed by a partition gravimetric method using petroleum ether (40°C/60°C). Turbidity was analyzed by using Systronics μc turbidity meter 135.

3. Result and discussion

3.1. Characterization of GW

Characteristics of DGW and LGW and the three prepared samples are presented in Table 1. According to the results, the average pH in DGW is from 6.5 to 7.7, whereas LGW is from 7.1 to 7.6, pH of GW highly depends on the pH of the water supply and the chemicals used in several activities (with more pronounced examples of those used in laundry and dishwasher). These values are very close to the ones reported by other researchers for kitchen sink range of pH 6.5–7.7

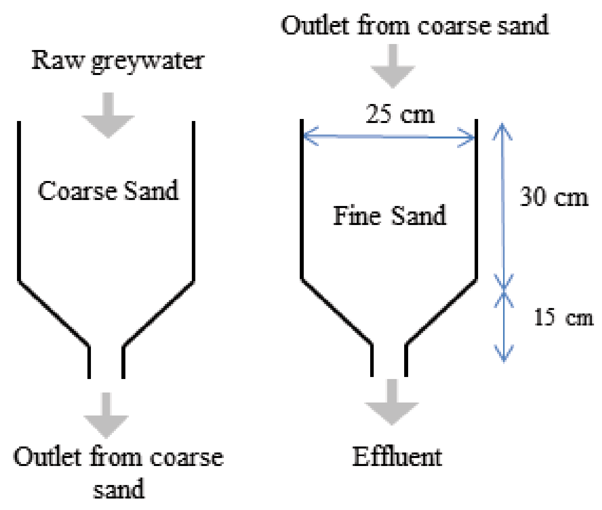

Fig. 1. Batch reactor coarse sand and fine sand.

Table 1
Characteristics of dark graywater (DGW) and light graywater (LGW) at different organic loading rate

Parameter	*n*	DGW	LGW	Sample A	Sample B	Sample C
OLR COD (kg/m^3/d)				0.27	0.49	0.82
pH	16	6.9 ± 0.4	7.1 ± 0.5	–	–	–
TS (mg/L)	16	380 ± 120	145 ± 90	–	–	–
BOD_5 (mg/L)	16	400 ± 150	150 ± 80	119 ± 18	226 ± 58	485 ± 81
COD (mg/L)	16	750 ± 250	320 ± 100	272 ± 77	493 ± 53	819 ± 95
O&G (mg/L)	16	825 ± 450	100 ± 55	161 ± 11	318 ± 108	539 ± 171
Turbidity (mg/L)	16	350 ± 150	130 ± 55	137 ± 6	205 ± 18	269 ± 88

Notes: *n*, number of samples.

considered as DGW and washbasin 7–7.3, bath 7.1–7.6, and shower 7.3–7.5 considered as LGW [2].

In this study, average COD concentrations of DGW varied from 750 ± 250 mg/L, whereas BOD concentrations varied between 400 ± 150 mg/L. As per the previous studies, in DGW (GW from the kitchen) the value of COD was 1,119 ± 476 mg/L and BOD was 831 ± 358 mg/L [2,9]. LGW exhibits the lower COD and BOD concentration with values 320 ± 100 and 150 ± 80 mg/L, which are almost half than the respective ones from DGW. Previous studies reveal the value of LGW from the bathroom concentration of COD and BOD ranged between 390 ± 125 and 263 ± 83, respectively [2]. These values are very close to the ones reported by other researchers for LGW [2].

If COD/BOD ratio is more than 2 it cannot be treated biologically [10]. In this study, COD/BOD ratio of DGW is 1.8 which is less than 2 which was an indication that it can be treated biologically.

In this study, concentration of O&G in DGW was 825 ± 450 mg/L, which was eight times higher than that of LGW 100 ± 55 mg/L. Turbidity concentration of DGW was 350 ± 150 mg/L and LDW was 130 ± 55 mg/L, similar type of results were reported in previous studies [2,8,11].

3.2. Effect of OLR and RT

In this study, Samples A, B, and C have the OLR 0.27, 0.493, and 0.82 kg/m^3/d (calculation of OLR presented in Eq. (1)) in which concentration of BOD was 119 ± 18, 226 ± 58, and 485 ± 81 mg/L. These values are very close to the ones reported by other researchers [2]. BOD removal efficiency of 50%, 67%, and 68% were observed at OLR 0.27 kg/m^3/d for 8, 16, and 24 h RT, respectively. At OLR 0.49 kg/m^3/d BOD removal efficiency was 52%, 60%, and 73% for 8, 16, and 24 h RT, respectively, and 54%,76%, and 78% at OLR 0.82 kg/m^3/d for 8, 16, and 24 h RT, respectively. As shown in Fig. 2, RT had an impact on the reduction of BOD. As RT increased from 8 to 24 h removal efficiency was increased 18% to 24% at different OLR. Influent COD concentration of 272 ± 77, 493 ± 53, and 819 ± 95 mg/L was observed for 0.27, 0.49, and 0.82 kg/m^3/d OLR, respectively. These values are very close to the ones reported by other researchers [2].

COD removal efficiency was observed as 50%, 62%, and 70% at OLR 0.27 kg/m^3/d for 8, 16, and 24 h RT, respectively. At OLR 0.49 kg/m^3/d the COD removal efficiency was 55%, 57%, and 71% for 8, 16, and 24 h RT, respectively, and 50%, 67%, and 77% at OLR 0.82 kg/m^3/d for 8, 16, and 24 h RT, respectively. As shown in Fig. 2, RT had an impact on the reduction of COD. As RT increased from 8 to 24 h removal efficiency of COD was observed between 16% and 27% for 0.27, 0.49, and 0.82 kg/m^3/d. The previous studies by Katukiza et al. [12,13] reported 70% COD removal for sand filters. The maximum removal of COD was observed as 77% at 24 h RT and 0.82 kg/m^3/d OLR.

The sand filters were influenced by changes in RT. An increase in RT resulted in increased wetted surface and a higher percentage of the pore volume become accessible to the water suggested in the literature [13–16]. Increased RT enlarged the adsorption potential, which increases the BOD and COD reduction. Increasing RT lengthen the residence time [14,15] thus contact time of the water with the media increased results in increased oxygen diffusion into filters, triggering biological oxidation of the adsorbed organic matter the same trend was reported by the other studies [14]. With increasing RT in sand filters the wetted area probably increased, which improved the conditions for biofilm coverage and allowed the media to achieve higher organic matter degradation reported in the previous studies [14].

In this study, maximum reduction of organic matter was observed with 0.82 kg/m^3/d OLR. As reported in the previous studies that sand-based filters can achieve about 85% removal of organic matter from higher strength GW [13].

In this study, the COD/BOD ratio of the raw effluent was 2.3, 2, and 1.7 for 0.27, 0.49, and 0.82 kg/m^3/d OLR, respectively. In the previous literature, it had been cited that if COD/BOD ratio is more than 2 it cannot be treated biologically [10]. Lower COD/BOD ratio increases the biological growth on media which help in reduction of organic matter. Increasing OLR reflects higher impurities accumulated on the top layer of the media was due to straining phenomena which resulted in the development of biomass on the top layer. As a result of this, biofilm became thicker and also holds more water. Prolonged contact time between water and biofilm results in more removal efficiency for organic matter.

Concentration of O&G for OLR 0.27, 0.493, and 0.82 kg/m^3/d was 161 ± 11, 318 ± 108, and 539 ± 171 mg/L, respectively. The removal efficiency of O&G observed for OLR 0.27 kg/m^3/d was 51%, 59%, and 70%, for OLR

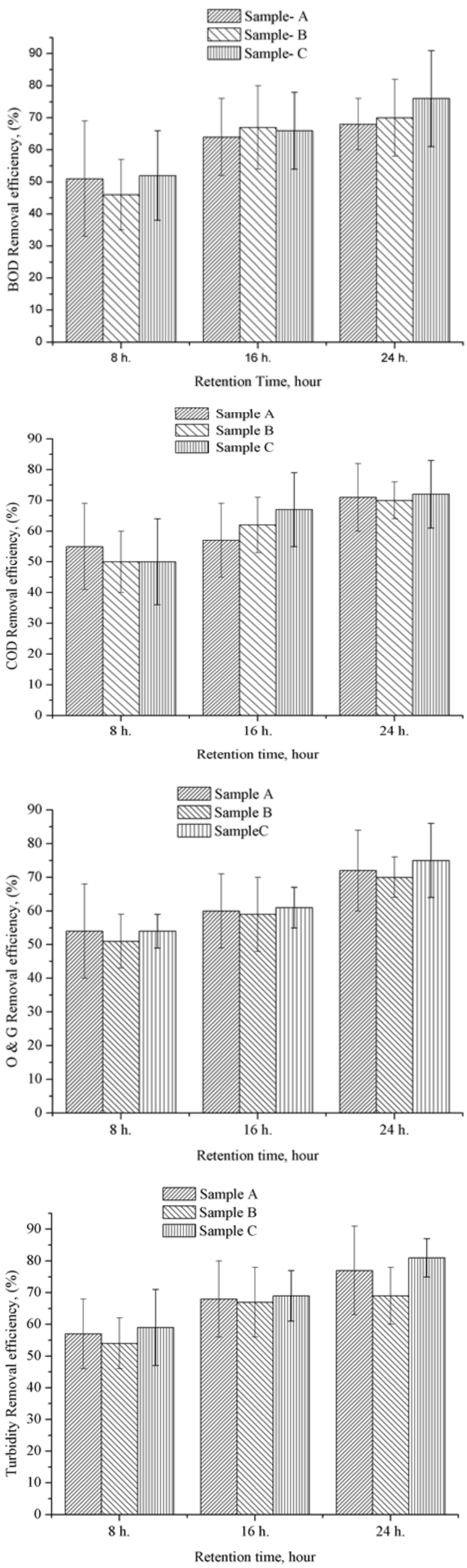

Fig. 2. Removal efficiency in different retention time. Organic loading rate for Sample A, 0.27 kg/m^3/d; Sample B, 0.49 kg/m^3/d; and Sample C, 0.82 kg/m^3/d.

0.49 kg/m^3/d was 54%, 60%, and 72%, and for OLR 0.82 kg/m^3/d was 51%, 61%, and 75% in 8, 16, and 24 h RT, respectively. In previous studies, Katukiza et al. [13] reported 72% O&G removal for sand filters.

Concentration of turbidity for OLR 0.27, 0.493, and 0.82 kg/m^3/d was observed 137 ± 6, 205 ± 18, and 269 ± 88 mg/L, respectively. Maximum concentration of turbidity was observed for OLR 0.82 kg/m^3/d because DGW consist of the high amount of turbidity (mainly due to the presence of cooking oil and left over food residuals), similar type of results were reported in previous studies [2,10,15]. Turbidity removal efficiency observed for OLR 0.27 kg/m^3/d was 54%, 67%, and 69%, for OLR 0.49 kg/m^3/d was 57%, 68%, and 77%, and for OLR 0.82 kg/m^3/d was 59%, 67%, and 81% in 8, 16, and 24 h RT, respectively.

Maximum removal was observed with OLR 0.82 kg/m^3/d at 24 h RT. Increasing RT resulted in accumulation of suspended solids and O&G on the top layer of the media as straining phenomena was taking place which results in increasing the removal efficiency [2,10,13,15].

3.3. Performance of individual media

The performance of individual media was studied to know the role of coarse and fine sand. Fig. 3 illustrates the removal efficiency of BOD_5, COD, O&G, and turbidity in a separate experimental system with 24 h RT for OLR 0.27, 0.49, and 0.82 kg/m^3/d, which is showing removal efficiency for two different media. In the previous section, higher removal was observed at 24 h RT (12 h for coarse sand and 12 h for fine sand). Total removal of BOD was 70%, 75%, and 85% in which coarse sand was giving 32%, 32%, and 38% removal and fine sand was giving 38%, 43%, and 47% removal for all the three OLR 0.27, 0.49, and 0.82 kg/m^3/d, respectively. BOD removal efficiency difference of coarse and fine sand was observed between 6% and 11% at different OLR.

Total removal of COD was 76%, 77%, and 86% in which coarse sand is giving 32%, 32%, and 40% removal for OLR 0.27, 0.49, and 0.82 kg/m^3/d, respectively. Fine sand is giving 44%, 45%, and 46% for OLR 0.27, 0.49, and 0.82 kg/m^3/d, respectively. COD removal efficiency difference of coarse sand and fine sand was observed between 6% and 13% at different OLR.

According to the result, total removal of O&G was 60%, 75%, and 85% in which coarse sand is giving 25%, 35%, and 40% removal, whereas fine sand is giving 35%, 40%, and 45% at different OLR 0.27, 0.49, and 0.82 kg/m^3/d, respectively. O&G removal efficiency difference of coarse sand and fine sand was observed between 5% and 10% for all the three OLR.

Total removal of turbidity was 65%, 70%, and 80% in which coarse sand is giving 25%, 28%, and 35% removal, whereas fine sand is giving 40%, 42%, and 45% for all the three OLR 0.27, 0.49, and 0.82 kg/m^3/d, respectively. The difference in turbidity removal efficiency of coarse sand and fine sand was observed between 10% and 15% at different OLR.

Higher removal was observed in the fine sand filter because coarse sand filter was receiving raw GW and fine sand filter was receiving effluent from coarse sand for all the

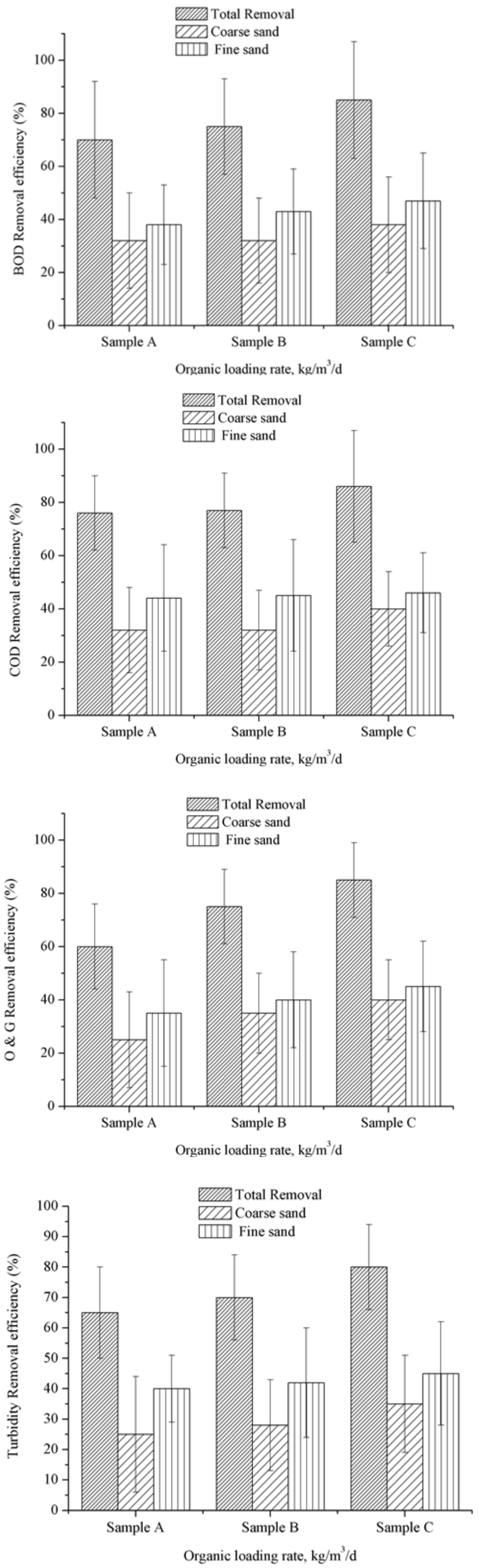

Fig. 3. Removal efficiency of media (coarse and fine sand).

three samples. Fine sand had a porosity of 32%, which is less than that for the coarse sand filter of 40%.

Grain size of fine sand is less compared with grain size of coarse sand (i.e., 0.75–2 mm) and the partials are next to one another, there are little spaces between them, liquid can pass slowly through these tiny spaces and some of the partials get trapped. The smaller the particles, the smaller the spaces will be in the layer and the smaller the dirt particles that can be trapped.

4. Conclusions

GW characteristics are highly variable as they depend on the living standards, the activities and habits of the residents. Among different sources, laundry and kitchen sink are the main contributors to the total GW load of organic carbon and suspended solids generally known as DGW, whereas bathtub and handbasins are the less polluted sources of GW known as LGW.

- The experimental results showed that increase in OLR and RT increases the removal efficiency. This study was an attempt to evaluate the effect of OLR (0.27, 0.49, and 0.82 COD $kg/m^3/d$) and RT (8, 16, and 24 h) on sand filters.
- The maximum removal efficiency observed in BOD was 78%, COD was 77%, O&G was 75%, and turbidity was 81% at 24 h RT and OLR 0.82 $kg/m^3/d$.

The study reveals that lower COD/BOD ratio improves the removal efficiency of the sand filter.

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