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Performance evaluation of a single household anaerobic packaged system for onsite domestic wastewater treatment

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ABSTRACT

The present study evaluated the performance of a uniquely configured compact anaerobic packaged system as an alternative to the conventional septic tank for a single household. The system consisted of two bioreactors, a septic tank followed by an upflow anaerobic filter. Both reactors were accommodated within a single compact unit. The treatment efficiency of the system was identified on the basis of its pollutant removal efficiency and desludging interval over a period of 12 months. The system was fed with actual onsite wastewater with large fluctuations in the flow throughout a day. The average removal efficiency for COD, BOD, TOC, TSS and faecal coliform was observed as 70.9, 68.7, 62.1, 78.1 and 86.5% (1.1 log), respectively. A hydrodynamic study revealed a low dead volume (19.8%) with plug flow regime within the system. Based on a significantly better performance than the septic tank, the present system has a good potential for application in the unsewered rural and peri-urban areas of the developing countries like India.

Keywords: Flow characterization; Hydrodynamic characteristics; Onsite system; Packaged system; Septic tank; Single household

1. Introduction

In most of the developing countries, it is not practically feasible to construct centralized sewage treatment plants (STPs) everywhere due to the rapid growth in the population, scarcity of space and financial limitations. Hence, there is need to develop efficient as well as economically affordable decentralized/onsite domestic wastewater treatment systems [1]. The conventional septic tank is the oldest and the most popular mode of onsite domestic wastewater treatment due to a simple design, low-cost involvement and electricity-free operability, especially in the rural and peri-urban areas of the developing countries [2,3]. As per the Census of India 2011, the total sanitation coverage in the rural areas is 32.7%, out of which 14.7% people depend on the septic tank, while only 2.2% of the population has access to the sewerage system [4]. The rest of the population depends on the other traditional systems, such as pit toilets with or without slabs. Despite its wide application, the septic tank has several drawbacks, including a low treatment efficiency [5]. As the septic tank works as a primary treatment unit only, its effluent still contains high concentration of the pollutants. The disposal of such partially treated wastewater in the surrounding environment poses a

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serious risk to the aquatic environment as well as the public health [6]. Another disadvantage of the septic tank is its incapability to handle hydraulic shock loads. The peak flow disturbs the settling zone and causes high suspended solids in the effluent. Hence, there is need for further improvement in the design of the existing onsite treatment systems to overcome the various drawbacks, including low treatment efficiency. Although, numerous alternatives to the conventional onsite wastewater treatment systems have been suggested [7–10], the biofilm-based treatment of the septic tank effluent using anaerobic filter is the most commonly recommended solution that can further reduce the biochemical oxygen demand (BOD) and faecal coliform (FC) in the septic tank effluent by an additional 30–80% and 43–95%, respectively [11]. However, all these alternates consist of large-sized reactors, which require a high-cost involvement in terms of land and construction.

Recently, there have been reports of increased application of the packaged pre-fabricated STPs for the treatment of single household domestic wastewater all over the world. These packaged systems can be easily installed with little construction work due to a more compact size than the other conventional treatment systems [12]. Therefore, an anaerobic packaged-type onsite wastewater treatment system consisting of two bioreactor chambers (a septic tank and an anaerobic filter) was developed to carry out the present study to utilize the combined process of sedimentation plus biofilm. The septic tank chamber was found to be adequately effective for the primary process of the system as it trapped the solids present in the wastewater significantly, which consequently reduced the organic load on the following anaerobic filter chamber while facilitating flow equalization. The biofilm process (anaerobic filter) was found to be ideal for the treatment of the household wastewater having large fluctuations in quantity and quality both. The removal of solids from the wastewater was further enhanced as the flow of wastewater converted from horizontal to upflow mode as it entered the filter chamber.

The performance of the present packaged system for onsite treatment of unaltered domestic wastewater has been discussed here. The two salient features of the present study were (1) characterization of the raw wastewater generated by a single household and (2) identification of the pollutant removal efficiency of the system using a combination of physicochemical and biological treatment processes. The performance evaluation included (a) long-term performance for the removal of organic matter, suspended solids, nutrients and faecal indicators (including pathogens) as well as desludging interval, (b) 24-h flow variation of the generated household wastewater and (c) hydrodynamic characteristics of the packaged system.

2. Materials and methods

2.1. Reactor design and operation

An actual demonstration-scale study was conducted in the backyard of a single household of five members (two adults and three children) residing in the campus of Indian Institute of Technology Roorkee, India. The flow scheme of the packaged system and the typical layout of the experimental set-up are illustrated in Fig. 1.

The packaged system was made by a low-density polyethylene material, suitable for underground installation of the septic tank, which was supplied by Sintex Industries Ltd. (PWTS AM 1200). The system was installed directly after excavating down to a depth of 2,000 mm from the ground level on a 10-cm-thick platform of Portland cement concrete at the base. All the wastewater generated due to the household activities flowed directly into the system. The packaged system consisted of two chambers, where the first one acted as a primary sedimentation tank and the following one as an upflow anaerobic filter. Most of the settleable and suspended solids were settled

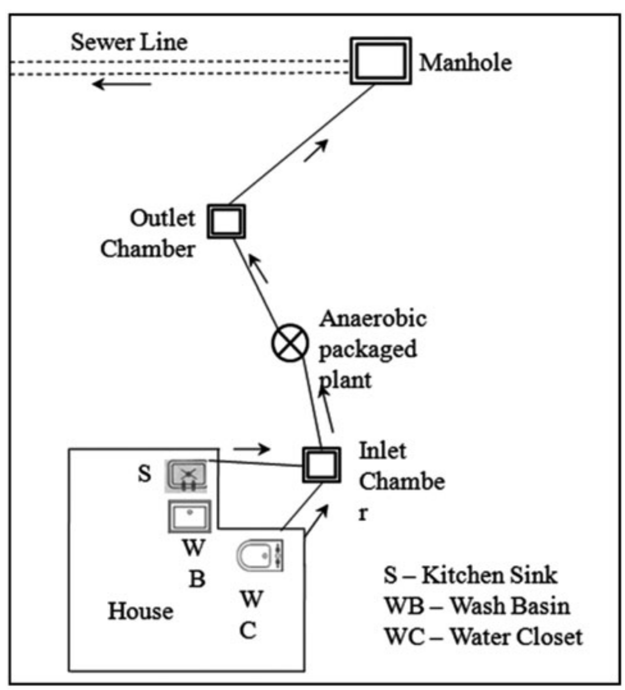

Fig. 1. Typical layout and flow scheme of the single household packaged system.

down in the primary chamber, which were further degraded anaerobically in the bottom zone of the tank. The second chamber was the core part of the system with the liquid flow in upward direction. The upper part of this chamber was packed with pall ring media (polypropylene) designed to offer a minimum specific surface area of 100 m^2/m^3. The presence of the media of a high specific surface area not only prevented clogging, but also provided intensive contact between the fixed-film anaerobic micro-organisms and the substrate present in the influent wastewater. The enhanced contact between the substrate and the micro-organisms substantially increased degradation of the organic matter. The total effective volume of the system was 1,200 L with the individual volumes of the septic tank chamber and the filter chamber being 950 and 380 L, respectively. The system was started in November 2012 without using inoculums with direct inflow of actual domestic wastewater without any change in its characteristics.

2.2. Raw wastewater characteristics

The actual wastewater generated in a single household, including toilet wastewater, was used to carry out the present study. The concentrations of chemical oxygen demand (COD), BOD and total suspended solids (TSS) in the domestic wastewater were observed to be of varying degree of characteristics. The average concentration of the various physicochemical and microbial constituents in the raw domestic wastewater is illustrated in Tables 1 and 2, respectively. According to the classification by Metcalf and Eddy [13], the characteristics of the raw domestic wastewater corresponded to a medium-to-high strength wastewater. The organic matter present in the domestic wastewater is a mixture of biodegradable and non-biodegradable constituents, which can be estimated by the COD-to-BOD ratio. The ratio variation from 1.5 to 2.0 indicates an organic matter that is readily biodegradable. The average COD-to-BOD ratio was observed to be 2.31 with a standard deviation of 0.55, which was a good indication that the domestic wastewater could be successfully treated by means of biological treatment [13]. The concentrations of nitrogen and phosphorous were found to vary in the range of 13.5–56.9 and 2.2–25.4 mg/L, respectively, with the average COD/N/P ratio being 100:5:1.2. The maximum COD/N/P ratio required for micro-organisms usually reported in the literature is 250/5/1 to 500/5/1 depending on the influent COD concentration or the extent of loading [14,15]. The present ratio suggested that a sufficient quantity of nutrients required for the micro-organisms was present in the domestic wastewater for anaerobic treatment.

2.3. Sampling and analysis

The wastewater samples were collected weekly, based on 24-h composite sampling, from the raw wastewater and the treated effluent over a period of one year. All the samples were analysed for physicochemical and microbiological parameters.

The physicochemical parameters, such as COD (5220D, close reflux method), BOD (5210B, 3-d BOD test at 27°C), TSS (2540D, oven dried at 103–105°C), ammoniacal nitrogen (NH_4-N, 4500G, automated ascorbic acid reduction method), total Kjeldahl nitrogen (TKN, 4500-N_{Org} D, macro-Kjeldahl method) and total phosphate (TP, 4500F, stannous chloride method), were measured according to Standard Methods [16], except volatile fatty acids (VFA) and alkalinity. The concentration of VFA and alkalinity was measured according to the method suggested by DiLallo and Albertson [17]. The measurements of pH and ORP of the samples were done onsite by HQ Series portable pH/ORP probes (Model 40 D Hach, USA). The measurement of total organic carbon present in the samples was done with the help of a TOC analyser (Model TOC-5000A, Shimadzu, Kyoto, Japan).

All the samples were assayed for faecal indicators: total coliform (TC), FC, faecal streptococci (FS), *Escherichia coli* (*E. coli*) and pathogenic microbes (*Salmonella* and *Shigella*). TC, FC and FS were measured by the multiple-tube fermentation technique according

Table 1
Approximate percentage of generated wastewater and COD load distribution in the domestic premises

Sampling point	Wastewater quantity (%)	COD load generation (%)
Laundry	21.6	26.7
Toilet	12.8	18.3
Bathing	18.2	16.8
Kitchen	42.1	37.2
Wash basin	5.3	1.0

Table 2
Concentration of various parameters of wastewater during the study (average value ± standard deviation)

Parameter	Units	Influent	Effluent	Removal (%)
pH	–	7.30 ± 0.49	7.26 ± 0.31	–
Alkalinity	mg/L as $CaCO_3$	342 ± 45	351 ± 38	–
Turbidity	NTU	119 ± 21	43.8 ± 13	63.2 ± 10.4
COD	mg/L	858 ± 254	208 ± 84	70.9 ± 11.8
BOD	mg/L	382 ± 80	123 ± 51	68.7 ± 8.5
TOC	mg/L	271 ± 55	98 ± 15	62.1 ± 5.9
TSS	mg/L	442 ± 119	85 ± 23	78.1 ± 4.7
VSS	mg/L	320 ± 84	79 ± 88	74.9 ± 15.3
VFA	mg/L	13.6 ± 8.2	39.6 ± 11.1	–
TKN	mg/L	40.1 ± 9.3	33.4 ± 7.8	15.9 ± 8.8
TN	mg/L	47.1 ± 12.8	37.5 ± 8.0	20.2 ± 8.4
TP	mg/L	10.1 ± 2.6	8.2 ± 2.3	13.8 ± 3.7

to the Standard Methods [16]. *E. coli* and *Shigella* were detected by serial dilution of samples on MacConkey agar medium and MacConkey agar with Xylose Lysine Deoxycholate (XLD) medium, respectively. The respective plates were incubated in an inverted position for 24–48 h at 37˚C for *E. coli* and 24 h at 37˚C for *Shigella* detection. For *Salmonella* pathogenic species, samples were cultured on the plates of modified semisolid Rappaport-Vassiliadis medium and incubated for 17 h at 42˚C. The suspected colonies were sub-cultured for confirmation on XLD agar with 21-h incubation at 35˚C [18].

2.4. Tracer study

The hydrodynamic characteristics of the system were examined on the basis of the residence time distribution (RTD) curves. The RTD curves were generated from tracer studies. Lithium chloride was used as a tracer due to a certain beneficial aspects [19]. The study was performed by adding pulse input of the tracer, at the rate of 12 mg Li^+/L of the reactor volume, to the influent wastewater. During the tracer study, tap water was continuously fed to the reactor at a constant rate of flow which maintained the 36-h HRT of the feed flow. The tracer study was performed after nine months of operation of the system. The samples were collected regularly from the outlet chamber for a duration that was at least twice the HRT or till the concentration of the tracer reached a steady state, whichever was earlier, after addition of pulse tracer in the influent stream. The concentration of tracer in the effluent was analysed for lithium concentration using a microprocessor-based flame photometer (model TMF 45, Toshniwal, India). The effluent tracer concentrations (C_i) and the sampling time (t) were normalized with the input tracer concentration (C_0) and the theoretical hydraulic retention time ($\mathrm{HRT_{ideal}}$), respectively. The normalized concentration ($C_{\theta i}$) and normalized time (θ) were determined using Eqs. (1) and (2), respectively.

$$C_i = \frac{C_i}{C_0} \tag{1}$$

$$= \frac{t}{\mathrm{HRT_{ideal}}} \tag{2}$$

The normalized tracer concentration in the effluent was plotted against the normalized time to generate the RTD curves. The RTD curves were subsequently analysed for actual or mean HRT (θ_m) and the variance (σ_θ) using Eqs. (3) and (4), respectively.

$$\theta_m = \theta_{mean} = \int \theta C d\theta \tag{3}$$

$$\sigma^2 = \frac{\int (\theta - \theta_m)^2 C d\theta}{\int C d\theta} \tag{4}$$

Mean HRT (θ_m) and σ_θ were used to calculate the dispersion number (D_d) using Eq. (5).

$$\sigma^2 = 2\left(\frac{D}{uL}\right) - 2\left(\frac{D}{uL}\right)^2\left(1 - e^{-\frac{uL}{D}}\right) \tag{5}$$

The dimensionless dispersion number measures the extent of axial dispersion in the treatment unit. A large dispersion number, $D_d = \infty$, implies a perfectly mixed system, whereas a small dispersion number, $D_d = 0$, relates to a plug flow system. Similarly, $D_d = 0.02$, is defined as intermediate and $D_d = 0.2$, as a large degree of dispersion [20,21].

Additionally, Morrill dispersion index (MDI) was also calculated for better interpretation of the hydrodynamic behaviour of the reactor [13]. The assessment of MDI was endorsed by Teixeira and Siqueira [22], which can be expressed by Eq. (6).

$$\mathrm{MDI} = \frac{t_{90}}{t_{10}} \tag{6}$$

where t_{10} and t_{90} represent the time at which 10 and 90% of the tracer had passed through the reactor, respectively. A theoretical ideal plug flow reactor would have the value of MDI as 1.0, and about 22 for a completely mix flow reactor. The MDI value of 2.0 or less is indicative of effective plug flow reactor.

The volume of dead spaces within the reactor was estimated on the basis of the ratio of mean and theoretical HRT, which can be expressed by Eq. (7).

$$V_d = \left(1 - \frac{\theta_m}{\mathrm{HRT}_{\mathrm{ideal}}}\right) \times 100\% \tag{7}$$

2.5. Flow characterization study

Information about the 24-h variation in the quantity of the generated domestic wastewater quantities in a typical single household in actual Indian conditions is relatively rare. For this purpose, the system was monitored for 24 h for quantitative study of the hourly flow variations in the influent wastewater generated due to the household activities on working days. For characterization study, spot sampling was carried out at various water-consuming points and allowed to collect within the tank. The tank had arrangements to measure the volume of wastewater generated over 24 h at each drain point within the household. Further, the collected wastewater samples were analysed for flow variation and mass loading rates.

3. Result and discussion

3.1. Wastewater generation and flow characterization

The average amount of domestic wastewater generation from the household activities, excluding the water used for gardening, over the six-month period of the summer was found to be 140 L/p/d. This corresponds to an average water consumption rate varying from 150 to 190 L/p/d for the households living in the apartments, which includes some quantity of water used for irrigation or landscaping [13]. Out of the total wastewater generated by different consuming points, the largest contribution was from the kitchen (about 44%) with about 37% COD loading on the system. However, the black water (wastewater generated by flushing of toilet) was found to be only about 18% of the total wastewater generated with a similar contribution in the COD loading. The distribution of the domestic wastewater generation and its relative COD loading by the different consuming points is illustrated in Table 1. The hourly flow variations of the wastewater generated in the single household during the study period are presented in Fig. 2.

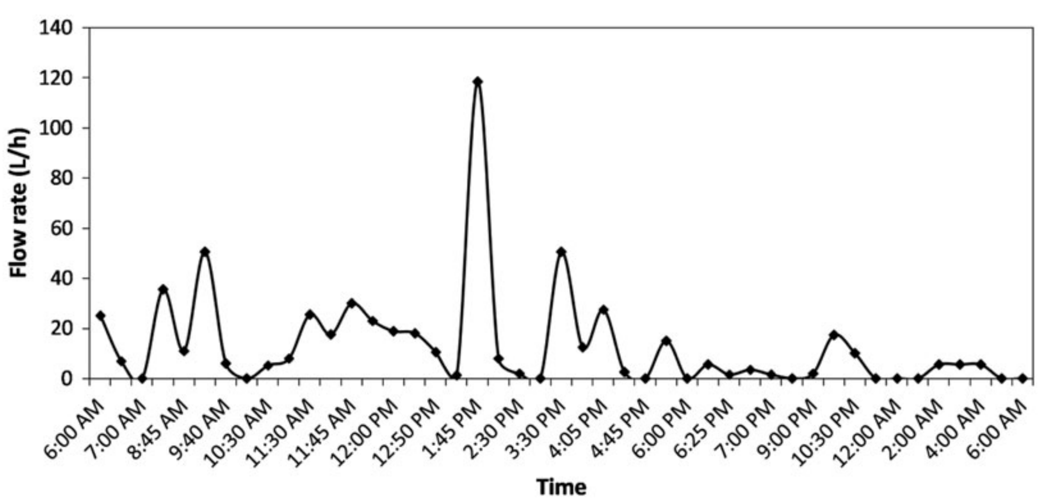

Fig. 2. Hourly fluctuations in the generated domestic wastewater.

Over a typical 24-h period, the hourly fluctuations in the quantity of the influent domestic wastewater indicated that the average hourly flow rate was about 13 L/h with the maximum rate of wastewater generation observed from 06:00 am in the morning till 02:30 pm in the afternoon. There was no flow during the night (11:00 pm–06:00 am) and a particular duration in the evening (07:00 pm–09:00 pm) representing a total of 9 h of no-flow condition. The maximum flow was observed to be 119 L/h, which indicated more than six turns of average flow. On the basis of 24-h flow variation, the daily flow variation in the domestic wastewater was noted to be around 587 L/d, which indicated that the anaerobic packaged system was operated at about 48-h HRT.

3.2. Removal of physicochemical parameters

Average characteristics of the raw sewage and the treated effluent with removal efficiency of each constituent are summarized in Table 2. During the study period, the values of ORP were found to be in the range of –198 to –236 mV, which indicated that the reactor worked under anaerobic conditions.

The pH, VFA concentration and alkalinity are closely related and very important factors for the suitable operation of anaerobic processes. The pH values of the effluent were found to be in the range of 7.02–8.10, indicating that no excessive acidification occurred within the reactor due to the accumulation of VFA. As the effluent pH never dropped below 6.8, it was an indication of the good buffering capacity of the anaerobic reactor [23]. In addition, the ratio of VFA and alkalinity was never observed to be lower than 0.4 throughout the study period, which avoided process instability. The maximum VFA concentration was found to be 78 mg/L, which was much below the inhibitory limit (150 mg/L) to permit the methanogenic process [23]. However, the alkalinity of the effluent was in the range of 296–416 mg/L as $CaCO_3$, which was 4.7–11.9% higher than the influent alkalinity. This increase in alkalinity might be due to formation of carbonates and bicarbonates in the system.

During the study period, organic loading rate (OLR) varied from 0.27 to 1.22 kg COD/m^3/d, which indicated large variations. These large variations in the OLR significantly affected the COD removal efficiency, but it still remained over 52.6% throughout and even up to 90.5% for some days. It was found that the COD removal efficiency increased with the increasing OLRs (Fig. 3).

As the actual domestic wastewater was used for the experiment, influent COD and TOC showed wide variation as was reflected in the standard deviation (Table 2). The corresponding effluent concentrations of COD and TOC were observed to vary in the range of 113–249 and 60–114 mg/L registering 70.9 and 62.1% average removal efficiency, respectively. It was clear from the data that the percentage removal of TOC was lower than COD, which might be due to the fact that COD analysis included the measurement of several compounds, such as metallic cations and inorganic compounds, which were not included in the TOC measurements. In addition, some of these compounds have the property to be absorbed by the biofilm, which results in an increased percentage removal and low effluent concentration of the COD [24]. The effluent BOD concentration varied in the range of

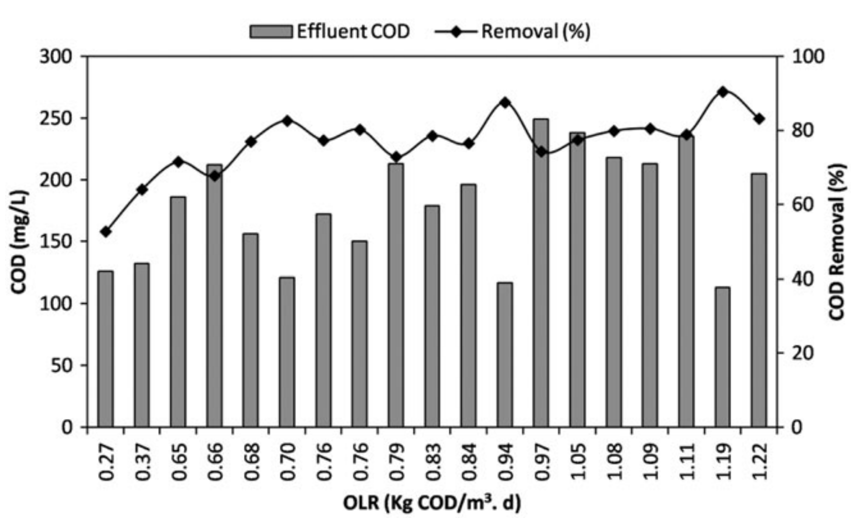

Fig. 3. Effects of OLR on COD removal.

34.5–175 mg/L as illustrated in Fig. 4(a) registering an average of 68.7% removal.

The concentration of SS in the effluent was observed to vary in a wide range of 46–125 mg/L as shown in Fig. 4(b). However, it was observed that the average removal of SS was found to be 78.1% and the effluent SS concentration was not affected by the large input-SS variation. A significant variable for wastewater quality is the concentration of volatile fraction of suspended solids (VSS). The VSS concentration of influent varied between 161 and 453 mg/L indicating a 72–81% fraction of SS during the study. The effluent concentration of VSS was observed to be in the range of 49–118 mg/L registering 74.9% removal efficiency. The removal of VSS was lower than the removal of TSS throughout the study period. In the anaerobic reactors, the removed VSS gets converted into different fractions, such as growth of biomass and production of useful biogas [23,25].

Since turbidity is considered to be a carrier for nutrients and pathogens, which can cause biological activity, it also becomes an important parameter for monitoring the performance of the system. It was observed that the average turbidity level of the treated effluent was 28–69 NTU. The trend of turbidity reduction was similar to the reduction in SS.

The removal of nutrients from the domestic wastewater is a challenge for protecting the water bodies from eutrophication. However, it can be expected that anaerobic treatment systems are not very effective in the removal of nutrients from the domestic wastewater [26]. During the investigation period, the present system displayed an average of 13.8% TP removal efficiency with effluent concentration in the range of 3.8–11.9 mg/L. The removal of phosphorous might be attributed to its utilization for biomass growth, precipitation and entrapment within the digested sludge.

The concentrations of NH_4^+-N in the treated effluent were observed to be higher than the influent concentration with an average increase of 30.1%. This might be due to the hydrolysis of domestic wastewater occurring in the anaerobic system. The average removal of TKN, which is the combination of ammonium nitrogen and organic nitrogen present in the wastewater sample, was 15.9%. The system could not efficiently reduce the TN from the domestic wastewater with only 20.2% average removal efficiency and the effluent concentration varying in the range of 24–47 mg/L. The results indicated that the system was not efficient in the removal of nitrogen, probably due to ammonia volatilization, while NH_4-N was released due to degradation of biodegradable nitrogen compounds, like proteins, under anaerobic conditions [27].

3.3. Removal of faecal indicators and pathogens

Table 3 illustrates the concentration level of faecal indicators and pathogenic microbes in the raw influent wastewater as well as in the treated effluent with the average (log_{10}) removal efficiency of the system. During the study period, the average effluent concentration of TC, FC and FS was observed as 7.8×10^5, 1.3×10^4 and 2.0×10^4 MPN/100 mL, respectively. In addition, average effluent concentration of *E. coli* was found to be 7.1×10^3 CFU/100 mL. For the

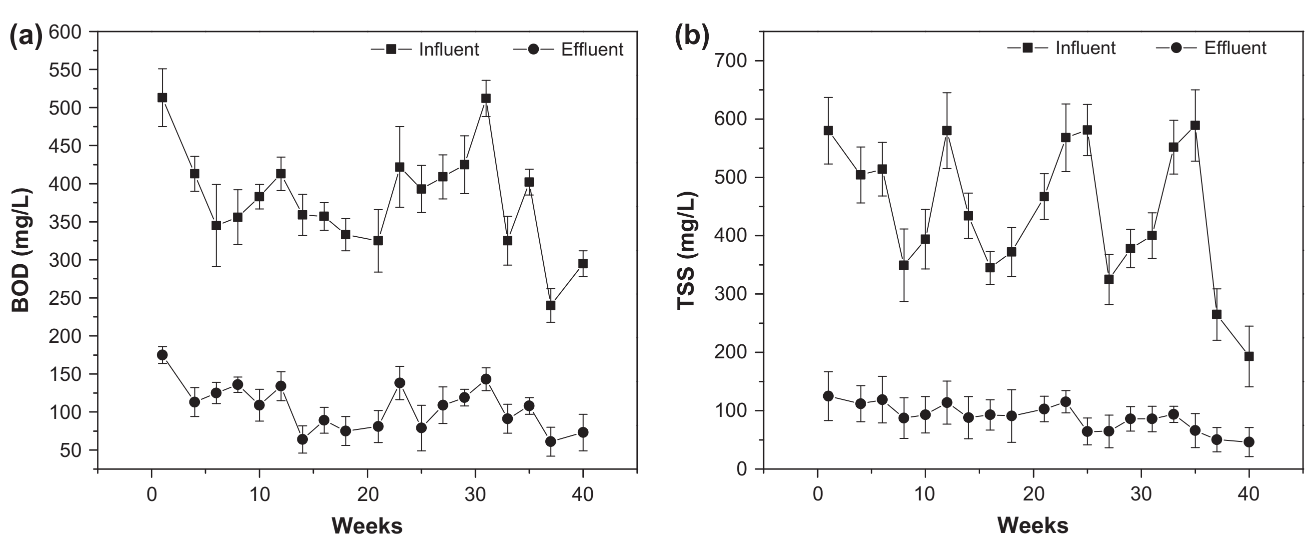

Fig. 4. Time series plot of concentration (a) BOD and (b) TSS.

Table 3
Concentrations of the microbial wastewater constituents during the study period

Constituents	Units	Influent[a]	Effluent[a]	Removal[b]
TC	MPN/(100 mL)	$1.5 \times 10^7 \pm 7.4 \times 10^6$	$7.8 \times 10^5 \pm 3.3 \times 10^5$	1.30 ± 0.74
FC	MPN/(100 mL)	$6.8 \times 10^5 \pm 2.6 \times 10^5$	$1.3 \times 10^4 \pm 9.4 \times 10^3$	1.10 ± 0.38
FS	MPN/(100 mL)	$1.3 \times 10^5 \pm 9.1 \times 10^4$	$2.0 \times 10^4 \pm 1.9 \times 10^4$	0.96 ± 0.26
E. Coli	CFU/(100 mL)	$9.4 \times 10^5 \pm 1.1 \times 10^5$	$7.1 \times 10^3 \pm 8.8 \times 10^3$	1.13 ± 0.08
Salmonella	MPN/(100 mL)	$2.9 \times 10^3 \pm 5.0 \times 10^2$	$1.3 \times 10^3 \pm 2.1 \times 10^2$	0.36 ± 0.01
Shigella	CFU/(100 mL)	$6.4 \times 10^3 \pm 2.4 \times 10^3$	$1.6 \times 10^3 \pm 4.1 \times 10^2$	0.61 ± 0.14

[a]Average value ± standard deviation.
[b]Efficiency on $\log_{10}$.

pathogens of *Salmonella* and *Shigella*, it was observed as 1.3×10^3 MPN/100 mL and 1.6×10^3 CFU/100 mL, respectively.

On an average, the $\log_{10}$ reductions of faecal indicators and pathogens by the anaerobic packaged system were 1.30 ± 0.14, 1.10 ± 0.11, 0.96 ± 0.16, 1.13 ± 0.14, 0.35 ± 0.02 and 0.61 ± 0.14 for TC, FC, FS, *E. coli*, *Salmonella* and *Shigella*, respectively. It was observed that the removal of the pathogens was not significant in comparison to the faecal indicators. This might be attributed to the fact that removal of pathogens is a result of physicochemical process coupled with natural die-off and presence of toxicity of the specific pathogens. Yang et al. [28] had also cited the same reason of natural die-off of microbes.

3.4. Hydrodynamic characteristics

The calculated results of the hydrodynamic characteristics of the system are summarized in Table 4. The normalized RTD curve generated through tracer study at 36-h HRT is illustrated in Fig. 5. The mean HRT of the system was observed to be 28.8 h, which indicated the actual exposure time and retention of substrate within the system. The presence of dead space plays an important role and significantly affects the mean

Table 4
Results of the hydrodynamic study

Parameters	Theoretical HRT (θ) (h)	Mean HRT (θ_m) (h)	Dead volume (V_d) (%)	Dispersion number (D_d)	Morrill dispersion index (MDI)
Value	36.0	28.8	19.8	0.087	3.86

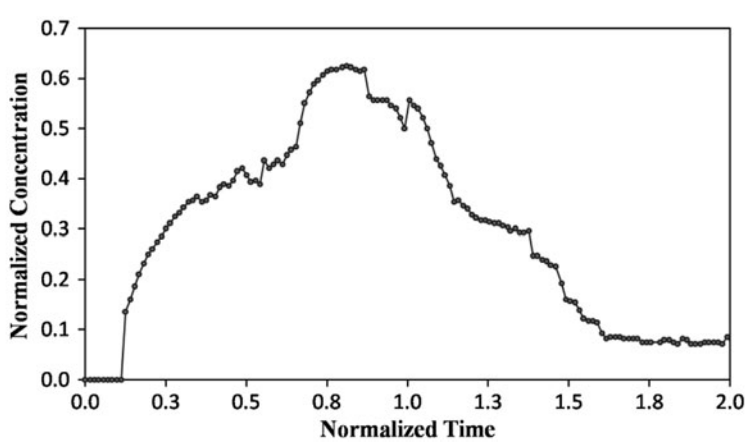

Fig. 5. Normalized RTD curves for the packaged system.

HRT and effective volume of the system. The total dead space present in the system was observed to be 19.8% only, indicating a satisfactory distribution of the substrate within the system. Moreover, the low percentage of the dead space significantly reduced the possibility of short-circuiting and helped in maintaining the desired HRT. Again, the low value of dispersion number, obtained as 0.087, suggested that the system could be considered to have a plug-flow regime based on the classification prescribed by Levenspiel [21]. Similarly, the calculated MDI value also showed the presence of low dispersion. However, the MDI of 3.86 was more than 2.0, which indicated that the system was outside the range of "effective plug flow regime" [13]. The tracer study provided significant evidence that a non-ideal flow regime occurred within the system, which partially explained the performance of the anaerobic packaged system.

4. Conclusion

Considering the need for the development of highly efficient onsite domestic wastewater treatment systems as feasible alternatives to the conventional septic tank, a differently configured demonstration-scale anaerobic packaged system was continuously operated for the treatment of actual domestic wastewater generated by a typical Indian middle-class family. The system produced lower pollutant concentrations in the effluent with the average values of main water-quality parameters of BOD, COD, TSS and FC observed to be 123, 208, 85 mg/L and 1.3×10^4 MPN/100 mL, respectively. Although, the system provided a better effluent than the septic tank, it still contained high pollutant concentrations that required additional post-treatment measures as well as disinfection for a safe disposal to the surrounding environment.

After one year of continuous operation, less than 50% volume of the system was filled with the biological sludge indicating that the system did not require frequent desludging. The system also showed only 19.8% dead volume, which indicated a uniform distribution of wastewater and an increased contact with the active biomass.

Based on the results of the actual onsite performance, the present packaged system with a simple design, low-cost involvement and electricity-free operability has a significant potential to be considered as an alternative to the conventional septic tank for the treatment of high-strength domestic wastewater in the unsewered rural and peri-urban areas of the developing countries like India.

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