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Greywater treatment using different designs of sand filters

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ABSTRACT

Different designs of sand filter as a secondary treatment step for the treatment of the primary sedimented effluent were studied. Gravel filter down flow (GFDF), gravel filter up flow (GFUF), sand filter down flow (SFDF), gravel filter followed by sand filter (GFSF), and horizontal flow sand filter (HFSF) were used as a secondary treatment step. During the study period, GFDF, GFUF, and SFDF were operated with an influent flow rate of 173 $m^3/m^2/d$, while GFSF and HFSF were operated at flow rate of 86.5 $m^3/m^2/d$. The final effluent of GFSF and HFSF were found to be complying with the National Regulatory Standards for the treated effluent reuse in irrigation. The residual concentration of COD, BOD_5, and TSS for GFSF was 43, 16, and 7.5 while, the corresponding concentration for HFSF was 40, 17, and 9 mg/l, respectively.

Keywords: Greywater; Separation; Low cost; Simple technology; Sand filter; Reuse

1. Introduction

The increasing scarcity of water in the world along with rapid population increase in urban areas gives reason for concern and the need for appropriate water management practices. Because water is a limited resource, especially in countries with arid environments, water conservation has become of increased importance [1,2]. Separating wastewater flows (black and greywater, domestic and industrial, sewage and rainwater) and the development of technologies that aim to make these individual wastewater flows fit for reuse or recycling will, in the long run, contribute to water resources management. In addition, such approaches will reduce public health risks and environmental pollution, as well as the burden on the pollution carrying capacity of the environment [3]. The separation of the toilet stream from domestic wastewater generates effluents with reduced levels of nitrogen, solids, and organic matter (especially the hardly degradable fraction), but which often contain elevated levels of surfactants, oils, and salt [4]. In recent years, the recycling and reuse of ablution water has been adopted in some Middle Eastern countries. Some Arab countries, particularly the Arabic Gulf Cooperation Council States, have begun to treat and reuse greywater as a step in facing the water scarcity. In Yemen, this process began in 2006 in Aden city when the government, with the United Nations Development Programme, implemented a project involving the treatment of greywater from six mosques for reuse in middle kerb irrigation and afforestation purposes [2].

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Technology selection for waste management may have to take a broader perspective than purely meeting the present discharge standards formulated for the local situation. Anticipating the above trends might stimulate the use of an additional criterion in technology selection, i.e. sustainable use of scarce resources whether it be water, nutrients, energy, or space [5,6]. Sand filtration is one of the oldest wastewater treatment technologies known. If properly designed, constructed, operated, and maintained, a sand filter produces a very high-quality effluent. Slow sand filtration has been used successfully in Europe since the early 1900s and is still a popular method of treating municipal water supplies [7]. Sand filters are beds of granular material, or sand, drained from underneath so that pretreated wastewater can be treated, collected, and distributed to the land application system. Wastewater applied to the sand filter should be pretreated (sedimentation). The effluent from the primary sedimentation tank is then distributed uniformly on the sand surface [8].

A sand filter purifies the water in three ways:

- Filtration, in which particles are physically strained from the incoming wastewater;
- Chemical sorption, in which contaminants stick to the surface of the sand and to the biological growth on the sand surface; and
- Assimilation, in which aerobic microbes consume nutrients in the wastewater converting it (nitrification/denitrification) to volatile end product. The success of treating wastewater depends on these microbes. Dissolved oxygen must be available for these microbes to live [9,10]. Denitrification is an anaerobic process; it does not require dissolved oxygen.

Sand filter is known to be simple technique, low cost, efficient, and reliable for potable water treatment. These features make sand filter attractive for he treatment of wastewater [11]. Horizontal and vertical flow sand filters have been used to treat wastewater, especially in small communities. This is attributed to the simple maintenance of the filters and the high quality of effluents [8].

This study aims to achieve a low cost, low technology process for the treatment of greywater to close-loop usage of such water flows in small municipalities or settlements such as rural area not connected to a central wastewater treatment.

2. Materials and methods

2.1. Sampling sites

The study takes place in the National Research Center. The study period started for three months from July to August 2012. The gravel filter down flow, gravel filter up flow and sand filter down flow have the same dimensions (Table 1). The only difference between gravel filter down flow, and gravel filter up flow is the direction of the flow of wastewater. Table 1 shows the operating conditions of the under investigation systems, while Fig. 1 reveals the sequence of the treatment steps.

2.2. Sample collection and conservation

Greywater was collected from neighborhood house of twelve families. The systems were fed contentiously continuously with the effluent of primary sedimentation tank. Samples were taken once a week for six months. The HRT for sedimentation tank was fixed at 1 h. The sand used in this study with diameter of 1–2 mm, while the gravel fraction with diameter of 2–4 mm.

2.3. Analytical methods

Composite samples of raw sewage and effluents of the different treatment units were collected and analyzed for pH, COD, BOD_5, TKN, ammonia, nitrite,

Table 1
Operating conditions for different treatment system

System	SA* (m^2)	Depth (m)	Type and size (mm) of the used media	HRT** ($L/m^2/d$)	SLR*** ($g\,BOD/m^2/d$)
GFDF	1	1	Gravel of 2–4 mm	173	15.7
GFUF	1	1	Gravel of 2–4 mm	173	15.7
SFDF	1	1	Sand of 1–2 mm	173	15.7
GFSF	2	0.3	Sand of 1–2 mm and Gravel of 2–4 mm	86.5	7.83
HFSF	2	0.3	Gravel of 2–4 mm	86.5	7.83

*Surface area, **hydraulic loading rate, ***surface loading rate.

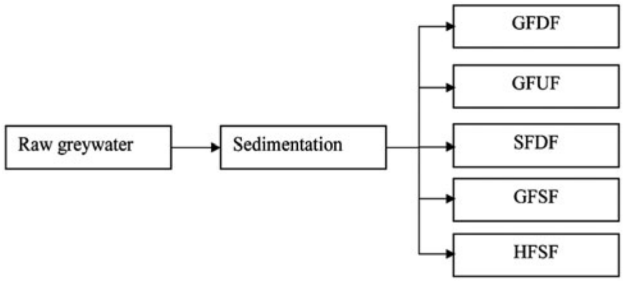

Fig. 1. Schematic diagram of the proposed treatment steps.

nitrate, phosphorus, oil, and grease, anionic surfactants by the methylene blue active substances method, and TSS. Analyses were carried out according to procedures described by Standard Methods Examination of Water and Wastewater (American Public Health Association, APHA) [12].

2.4. Statistical analysis

In order to reveal the trends of the results, statistical analysis of the data (including minimum, maximum, average, standard deviation, and XY error in the figures) was carried out using Microsoft Excel 2003.

3. Results and discussion

3.1. Raw greywater

Fig. 2 shows the greywater characteristics. However, the numbers are typical for a raw sewage, not greywater. The characteristics of household greywater can vary depending on the number of household occupants, their age, health status, lifestyle, tap water sources, water usage patterns, and household products used (such as soaps, shampoos, detergents, mouthwash, toothpaste, hair dyes, shaving cream, and body oils). The typical composition of greywater is shown in Table 1. Levels of COD, BOD_5, and TSS were varied greatly from 319.6 to 491, 120 to 307, and 26 to 201 mg/l, respectively. The biodegradability (BOD_5/COD, 0.54) was found to be slightly lower than domestic wastewater [13]. No, this is typical sewage. The characteristic of greywater was found similar with Jeppesen [14], Tandlich et al. [15], and Zuma et al. [16].

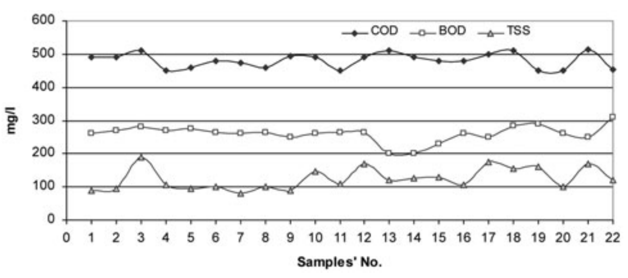

Fig. 2. Variation in COD, BOD_5 and TSS in raw greywater during the study period.

3.2. Performance primary sedimentation

COD, BOD_5, and TSS concentration ranged from 150 to 258, 75 to 140, and 33 to 112 mg/l, respectively, in the effluent of the primary sedimentation tank. The corresponding average residual concentration was 190.8, 90.5, and 41.4 mg/l, respectively. The performance of the sedimentation process was found to be limited and the effluent quality was not complying with the local regulatory standards for treated effluent reuse in irrigation (as shown in Table 2). However, the sedimentation tank cannot be considered as full treatment. Consequently, post-treatment was needed to valorize the treated effluent.

3.3. Performance of down flow gravel filter

Reduction of COD, BOD_5 and TSS in the down flow gravel filter (DFGF) effluent was ranged from 27 to 51, 28 to 55 and 36 to 69% with an average value of 41, 46 and 54%, respectively. The corresponding concentrations ranged from 90 to 171, 35 to 69, and 19 to 30 mg/l, respectively. The average percentage removal values are presented in Table 3 so they do not need to be included in the text.

3.4. Performance of up flow gravel filter

Table 4 shows the performance of up flow gravel filter (UFGF) for the treatment of primary treated greywater. The concentrations of COD, BOD_5, and TSS were ranged from 63 to 124, 28 to 55, and 10 to 18 mg/l. The ability of the system to remove these parameters was 57, 59, and 64%, respectively. The reduction of Oil and grease reached 41% with an average residual concentration of 41 mg/l.

3.5. Performance of down flow sand filter

Down flow sand filter (DFSF) shows 74, 76, and 82% reduction of COD, BOD_5, and TSS, respectively. On the other hand, the reduction of Oil and grease did not exceed 63% with an average of 36%. Table 5 shows the performance of DFSF.

Table 2
Performance of the sedimentation tank for the treatment of greywater (standard deviation in brackets)*

Parameter	Raw greywater	Sedimentation tank effluent	%R**
COD, mg O_2/l	481 (57)	190.8 (57)	60.3
BOD_5, mg O_2/l	260 (42)	90.5 (44)	65.2
TSS, mg/l	124 (30)	41.4 (18)	66.6
Oil and grease, mg/l	150.5 (31)	51 (15)	66.1
TKN, mg/l	19.8 (6)	16.7 (6)	15.7
Ammonia, mg/l	14.5 (6)	14.9 (6)	−2.8
Phosphate, mg/l	12 (4)	9 (3)	25.0
Detergent, mg/l	25 (7)	11 (3)	56.0

*Number of samples are 22, **%R: percentage removal.

Table 3
Performance of GFDF system*

Parameter	GFDF effluent	%R**
COD, mg O_2/l	112 (30)	41
BOD_5, mg O_2/l	51 (21)	46
TSS, mg/l	19 (7)	54
Oil and grease, mg/l	33.5 (12)	34.3
TKN, mg/l	13 (3)	22.2
Ammonia, mg/l	9 (2)	39.6
Phosphate, mg/l	5.5 (1)	38.9
Detergent, mg/l	7 (1)	36.4

*Number of samples are 22, **%R: percentage removal.

Table 4
Performance of GFUF system*

Parameter	Unit	GFUF effluent	%R**
COD	(mg O_2/l)	82 (20)	57
BOD_5	(mg O_2/l)	37 (11)	59
TSS	(mg/l)	15 (4)	64
Oil and grease	(mg/l)	30 (6)	41
TKN	(mg/l)	12 (3)	28
Ammonia	(mg/l)	8 (2)	46
Phosphate	(mg/l)	4.9 (1)	46
Detergent	(mg/l)	6 (1)	46

*Number of samples are 22, **%R: percentage removal.

3.6. Performance of gravel filter followed by sand filter down flow

In an attempt to enhance the quality of the effluent, combination between DFGF and DFSF was carried out. Table 6 shows the removal of COD, BOD_5, and TSS using gravel filter followed by sand filter (GFSF) reached 78, 82, and 82% with average residual concentration of 43, 16, and 7.5 mg/l, respectively.

3.7. Performance of horizontal flow sand filter

Table 7 shows the performance and average concentrations of the chemical characteristics. The level of organic load represented by COD and BOD_5 was reduced by 79 and 81.2%, with residual values of 40 and 17 mg/l, respectively. While the residual level of TKN and ammonia was 8 and 5 mg/l, respectively. The high efficiency of horizontal flow sand filter (HFSF) system may be attributed to the long horizontal distance that wastewater pass (2 m).

3.8. Comparison of the systems

Figs. 3 and 4 show the variations of different parameters in the final effluent of the treatment system. The level of COD in the effluent of GFSF and HFSF was found to be better than that of GFDF, GFUF, and SFDF systems. This may attributed to the lower HRT applied to GFSF and HFSF compared with that applied to the other systems (namely, GFDF, GFUF and SFDF). This implying that the greywater contains slowly/nonbiodegradable organic matter, especially in a dissolved form. This falls in line with findings of Eriksson et al. [17] and Friedler et al., [18]. The removal of BOD_5 by using GFSF and HFSF in this (82 and 81.2%, respectively) was found to be slightly lower than that obtained by Abudi [19].

The detergent level was reduced during the treatment process. HFSF was found to be efficiently removes detergent. Biodegradation processes and adsorption on slimy layers developed on the sand grains remove these chemicals from greywaters to a great existent. This result was found to be in a good

Table 5
Performance of SFDF system*

Parameter	SFDF effluent	%R**
COD, mg O_2/l	50 (13)	74
BOD_5, mg O_2/l	22 (4)	76
TSS, mg/l	7.5 (2)	82
Oil and grease, mg/l	25 (3)	51
TKN, mg/l	9.8 (2)	41
Ammonia, mg/l	6.7 (2)	55
Phosphate,mg/l	4.3 (1)	52
Detergent, mg/l	5.6 (1)	49

*Number of samples are 22, **%R: percentage removal.

Table 6
Performance of GFSF system*

COD, mg O_2/l	GFSF effluent	%R**
BOD_5, mg O_2/l	43 (11)	78
TSS, mg/l	16 (3)	82
Oil and grease, mg/l	7.5 (2)	82
TKN, mg/l	24 (4)	52.9
Ammonia, mg/l	7 (2)	58.1
Phosphate, mg/l	5.8 (2)	61.1
Detergent, mg/l	4.5 (1)	50.0
COD, mg O_2/l	5.7 (1)	48.2

*Number of samples are 22, **%R: percentage removal.

Table 7
Performance of HFSF system*

COD, mg O_2/l	HFSF effluent	%R**
BOD_5, mg O_2/l	40 (10)	79.0
TSS, mg/l	17 (3)	81.2
Oil and grease, mg/l	9 (2)	78.3
TKN, mg/l	20 (3)	60.8
Ammonia, mg/l	8 (2)	52.1
Phosphate, mg/l	5 (1)	66.4
Detergent, mg/l	4 (1)	55.6
COD, mg O_2/l	5 (1)	54.5

*Number of samples are 22, **%R: percentage removal.

agreement with Olusola and Benjamin [20] and Pangarkar et al. [4].

Sabbah et al. [8] examined sand filter for the treatment of facultative pond effluent. Sand filter influent was ranged from 110 to 200 l/m^2/d, while the organic loading rate was ranged from 20 to 40 g BOD_5/m^2/d. In our study, the hydraulic loading rate was adjusted to 86 l/m^2/d, while the organic loading rate

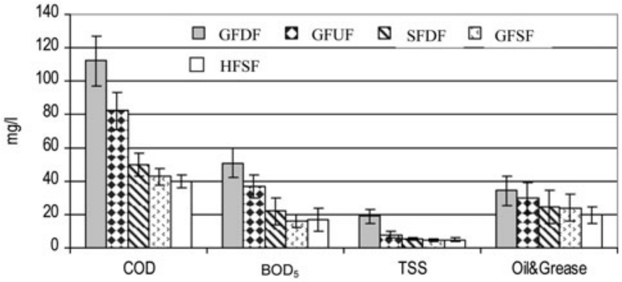

Fig. 3. The level of COD, BOD_5, TSS and oil and grease in the effluent of different treatment systems.

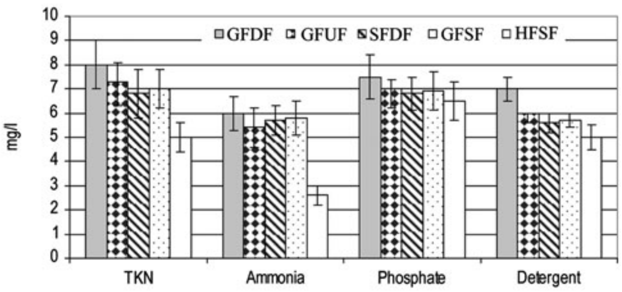

Fig. 4. The level of TKN, ammonia and phosphate in the final effluent of different treatment systems.

was 23.7 g BOD_5/m^2/d. EPA recommended that the organic loading rate not exceeding 24 g BOD_5/m^2/d. Sabbah et al. [8] found that COD and BOD_5 were removed by more than 90 and 95%, respectively.

Form the obtained results, it can be concluded that greywater has promising potential as a resource that can be used to supplement or replace potable water for the purpose of landscape irrigation.

4. Conclusions

Using of GFSF or HFSF for the treatment of greywater was found to be promising, simple and low-cost technique.

Sand filters can be used for a broad range of applications, including single-family residences, large commercial establishments, and small communities.

Separation of sewage water into greywater and blackwater reduces the area of the wastewater treatment plant consequently, reduces the cost.

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