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Treatment of domestic wastewater using modified septic tank

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ABSTRACT

The treatment of domestic wastewater using conventional, single-baffle, two-baffle, and packed-type septic tanks was the main theme of the present study. The septic tanks were fed continuously with domestic wastewater at three hydraulic retention times (HRTs), ranging from 24 to 72 h. The average characteristics of raw domestic sewage investigated in this study in terms of chemical oxygen demand (COD), biochemical oxygen demand (BOD), and total suspended solids (TSS) were 960, 450, and 295 mg/l, respectively. The product quality of the treated domestic wastewater by the four types of septic tanks in terms of physicochemical and biological characteristics proved to be satisfactory. Comparison wise, better results were obtained using the packed-type septic tank for primary treatment. The average removal of pollutants for each type of septic tank in terms of COD, BOD, and TSS improved in direct proportion to HRT. The fecal coliform removal values were affected by the type of the septic tank and the HRT. The highest percentage removal reached only one log. The accumulated sludge volume and weight were found to be dependent on the septic tank type and HRT. The average percentage of sludge volatile organic matters was almost equal. At each HRT, the due time for tank desludging was observed to be in order of conventional > single-baffle > packed-type > two-baffle septic tank. Based on the achieved results, either the two-baffle or the packed-type septic tank is considered to be a viable solution for the on-site decentralized treatment of high-strength domestic wastewater, especially at rural communities.

Keywords: Domestic; Wastewater; Treatment; Conventional; Baffled; Packed; Septic tank; Desludging

1. Introduction

Domestic wastewater treatment in rural areas is important for preventing pollution of aquatic environments as well as sanitation. Because of the high cost of constructing sewage systems in rural areas and developing countries, on-site wastewater treatment systems are preferred in these situations [1–4]. Several treatment systems, such as trickling filter, activated sludge, septic tank, membrane bioreactor, constructed wetland, and ponds have been applied for on-site wastewater treatment [5–8]. Anaerobic technologies are the core of the sustainable decentralized wastewater treatment systems [9–12]. The interest in the anaerobic systems, had been traditionally perceived, is due to process simplicity, low operational costs, and the independency on electricity. The need for energy preservation and reduction potentials of CO_2 emission

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are prime driving forces for applying anaerobic technologies in recent environmental engineering trends [13]. Developing countries lack proper wastewater collection and treatment facilities, especially in rural areas. The centralized collection and treatment systems are apparently too costly and complex to solve their wastewater problems.

In the United States, about 60 million people use some form of on-site wastewater treatment systems of which about 20 million use the conventional septic tank system [14]. Australia is of no difference, where about 12% of the population uses septic tank systems to get rid of its wastewater [15]. In Canada, decentralized systems are employed in a number of locations. Around 14% of the population in Greece might be served by decentralized systems due to their location in rural areas [16]. Turkey tries to avoid centralized treatment due to the high cost of construction and operation. Of all the Turkish municipalities, up to 28% are served by septic systems. In other areas, the cluster systems and the package systems also exist [17]. In Tanzania, about 90% of the population is served by on-site sanitation systems: pit latrines (80%) and septic tanks (10%).

In Egypt, more than 95% of the Egyptian rural area is not provided with wastewater collection and treatment facilities. There are about 4,000 Egyptian rural areas with a population ranging from 1,000 to 20,000 capita. The wastewater produced from houses in these rural areas is mainly treated in septic tanks [18].

The septic tank has many advantages as this system is inexpensive, and simple to operate and maintain. In addition to primary treatment, the septic tank can reduce the sludge and scum volumes by as much as 40%. Septic tank is used in nearly all on-site systems regardless of daily wastewater flow-rate or strength. Hydraulic and organic shock loads have little effect on treatment efficiency; it has the ability to endure long pauses in feeding smaller land area. It does not need skilled labor to operate and has much less operation and maintenance requirement as well as involves less construction cost.

Septic tank systems can achieve a total suspended solids (TSS) removal of 50–70% [6]. Furthermore, it stabilizes the sludge by anaerobic digestion, reducing the amount of sludge generated. A septic tank removes many of the settleable solids, oils, greases, and floating debris in the raw wastewater, achieving 60–80% removal [19–21]. The solids removed are stored in sludge and scum layers. Septic tank effluent varies naturally in quality, depending on the characteristics of the wastewater and condition of the tank. Sabry [22] showed that the treatment system is slightly influenced by the drop in the temperature. The performance of the septic tanks is rather poor despite the long operated HRT due to their inherent design feature viz. the horizontal flow mode of the influent sewage [23,24]. A significant improvement of the septic tank was achieved by integrating in-tank baffles.

Many modified anaerobic septic tank systems were used and tested atin different countries, Panswad and Komolmethee [25] used full-scale septic tank/anaerobic filter unit with the tank's retention time varying from 22.5 to 90 h. They recommended a rather high retention period of not less than 48 h if the Thai effluent standards are to be met [18,25–27]. The baffled anaerobic septic tank with or without anaerobic filter (BASTAF or BAST) represents a valuable and promising alternative to the conventional septic tank. Results of laboratory- and pilot-scale research on BAST and BASTAF systems showed that at a hydraulic retention time (HRT) of 2 d, the BAST(AF) significantly increases the removal efficiencies in terms of biochemical oxygen demand (BOD), chemical oxygen demand (COD), and TSS compared to a conventional septic tank. The experimental results indicated that combining one sedimentation chamber and equalizing chamber followed by two up-flow chambers can efficiently treat domestic toilet wastewater. Average treatment efficiency in the range of 70–80% for BOD, COD, and TSS can be achieved [28]. There is no doubt that the number of baffles plays an important role in the treatment process, as recent publications demonstrate [29,30]. The higher the number of up-flow chambers, the higher the treatment performances in terms of BOD, TSS, and COD removal. An increase to more than four up-flow chambers at the optimal HRT (48 h) did not lead to any significant increase of removal efficiencies. Taking economical consideration into account, two to four chambers are recommended for baffled septic tank configuration [31]. There are still important gaps of knowledge such as the optimal number of baffles, the optimal HRT, and the potential benefit of an anaerobic filter at polishing stage [28].

The objective of this study was to compare the performance of the conventional septic tank for domestic wastewater treatment with the performance of modified septic tank and try to define their optimal operating conditions. This study focused on improving the performance of conventional septic tank and also investigating the effects of HRT and organic loading rate on the treatment efficiency.

2. Materials and methods

To accomplish the study objectives, four septic tanks were operated over a seven-month period at three HRTs: 24, 48, and 72 h, corresponding to organic

loading rates ranging from 0.885 to 0.321 kg COD/m^3d. The four laboratory-scale septic tank models used in this study—conventional, single_baffle, two-baffle and two-baffle with packing material type—were designed and manufactured. The treatment systems were operated outdoors at ambient climatic conditions in the experimental area of the Water Pollution Research Department at the National Research Centre in Cairo. The systems were fed continuously with domestic wastewater via connection to a neighboring building. Characteristics of raw wastewater investigated in this study are listed in Table 1. At the beginning, no sludge was added to accelerate the growth of the sludge in the models. Dosing pumps were used to feed the septic tanks. The four septic tanks are made of perspex material with the same volume of 93.4 l, 63 cm length, 38 cm width, and 39 cm depth. They have "T"-shaped inlet and outlet pipes. The tanks are covered with 0.6 cm thick polyvinylchloride (PVC) material (Fig. 1(a)–(d)). Each compartment of the septic tank has three ports for sludge sampling and one port on each side near the top of the tank for the influent feed and effluent discharge.

2.1. Sampling and analytical methods

Twenty four hours composite samples from the treated effluent at the outlet point of the septic tanks and the raw wastewater were collected and analyzed on weekly basis. The measurements covered pH, temperature, total BOD, total COD, total TSS, total solids (TS), alkalinity, ammonia, total kjeldahl nitrogen (TKN), total phosphorus (TP), and fecal coliform.

Periodic measurements of the sludge on monthly basis during the study period covered sludge volume, sludge weight, volatile suspended solids, and quantity of accumulated sludge in gram per day. The analysis was carried out according to the standard method for examination of water and wastewater [32].

Raw wastewater and treated effluent from the four septic tanks were subjected to microbiological investigation using fecal coliform as fecal pollution indicator. Raw wastewater and treated effluent samples were collected in sterile test tubes, covered, and sent to the laboratory within minutes. The fecal coliforms were calculated using multi-tube technique [32].

3. Results and discussion

3.1. Performance of the investigated septic tanks

Four types of septic tanks of the same volume were investigated in this study using three organic loading rates: 0.321, 0.436, and 0.885 kg COD/m^3/d corresponding to HRT of 72, 48, and 24 h, respectively. At each HRT, it was observed that the type of the tank affects the percentage removal of the pollutants such that the packed type returns best results and the conventional type is the least.

3.1.1. Performance at 24 h HRT

The performance of conventional, single-baffle, two-baffle and packed-type septic tank at 24 h HRT in terms of COD percentage removals were 53.4, 55.3, 57, and 59.4% and the corresponding residual values were 412, 396, 380, and 359 mg/l, respectively. The BOD percentage removals were 53.5, 56, 60, and 63.5% and the corresponding residual values were 180, 170, 156, and 141 mg/l, respectively. The TSS percentage removals were 55, 65, 68, and 71% and the corresponding residual values were 123, 96, 87, and 78 mg/l, respectively (Table 2), (Figs. 2–4).

Table 1
Characteristics of raw wastewater investigated in this study

		Domestic wastewater		
Parameters	Unit	Minimum	Maximum	Average
Temperature	℃	16	32	27
pH		5.5	7.7	6.6
TCOD	mg O_2/l	817	1,184	962
TBOD	mg O_2/l	381	510	450
TSS	mg/l	228	370	296
TS	mg/l	700	1,070	842
TP	mg P/l	3.2	6.2	4.44
TKN	mg N/l	56	89	71
Ammonia	mg N/l	20.1	31.9	26.2
Alkalinity	mg/l	200	340	250
FC	MPN/100 ml	9.30E + 07	5.20E + 09	2.7E + 09

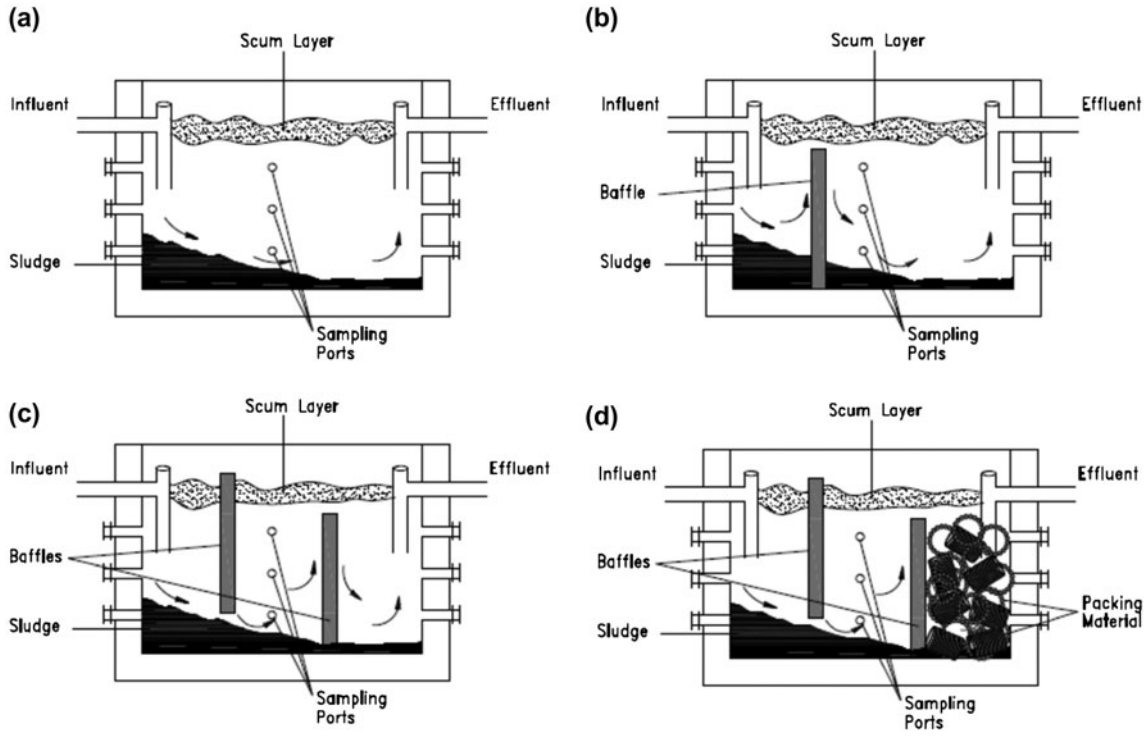

Fig. 1. Schematic diagram of (a) conventional septic tank, (b) single baffle septic tank, (c) two baffles septic tank and (d) packed septic tank.

The present study results are in line with those obtained by Nguyen et al. [28] who obtained average removal efficiencies from 48 to 65% and from 44 to 69% in terms of COD and TSS, respectively, depending on the HRT in the conventional septic tank. Also, the results agree with those obtained by Panswad and Komolmethee [25] who used full-scale conventional septic tank/anaerobic filter unit and achieved percentage removal of 52.1, 56, and 53.6% for the COD, BOD, and TSS, respectively, at an average retention time of 22.5 h. On the other hand, the results are higher than those obtained by Panswad and Komolmethe [25] who

Table 2
Summary of conventional, single baffle, two baffles and packed septic tank effluent and percentage removal

		HRT 72 h		HRT 48 h		HRT 24 h	
Parameters	Septic tank type	Average	%removal	Average	%removal	Average	%removal
TSS (mg/l)	Conventional septic tank	103 ± 16	65.3	115 ± 14	58.3	123 ± 13	55
COD (mg O_2/l)		334 ± 33	65.3	380 ± 43	56	412 ± 39	53.4
BOD (mg O_2/l)		142 ± 16	68.4	164 ± 20	57	180 ± 18	53.5
TSS (mg/l)	Single baffle septic tank	79 ± 14	73	85 ± 12	69	96 ± 10	65
COD (mg O_2/l)		266 ± 31	72.3	350 ± 36	60	396 ± 28	55.3
BOD (mg O_2/l)		115 ± 15	74.4	148 ± 14	62	170 ± 13	56
TSS (mg/l)	Two baffles septic tank	71 ± 17	76	77 ± 11	72	87 ± 12	68
COD (mg O_2/l)		248 ± 39	74	314 ± 46	64	380 ± 40	57
BOD (mg O_2/l)		106 ± 18	76.5	134 ± 20	65	156 ± 23	60
TSS (mg/l)	Packed septic tank	65 ± 10	78	69 ± 10	75	78 ± 8	71
COD (mg O_2/l)		221 ± 35	77	279 ± 38	68	359 ± 22	59.4
BOD (mg O_2/l)		94 ± 13	79	120 ± 11	69	141 ± 16	63.5

Values represent average ± standard deviation.

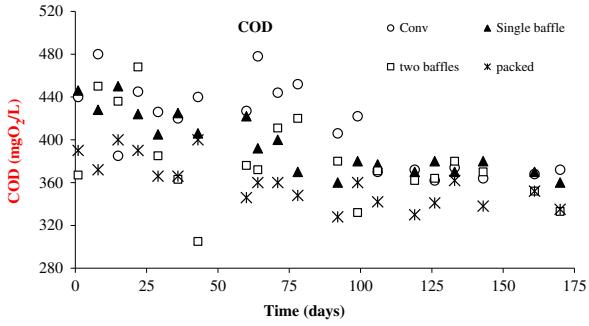

Fig. 2. Variation of COD in conventional, single baffle, two baffles and packed septic tank effluent at 24 h.

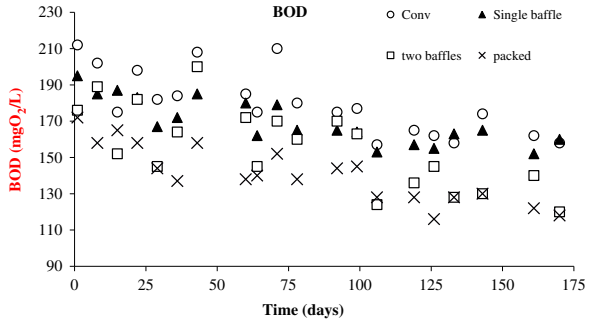

Fig. 3. Variation of BOD in conventional, single baffle, two baffles and packed septic tank effluent at 24 h.

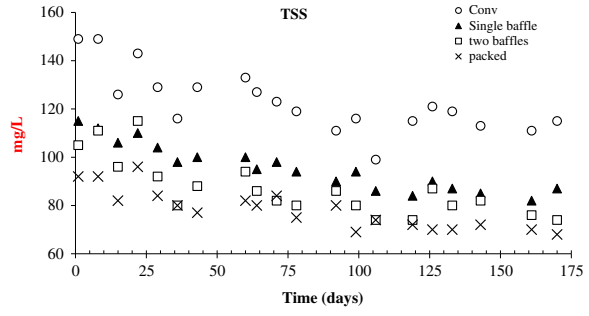

Fig. 4. Variation of TSS in conventional, single baffle, two baffles and packed septic tank effluent at 24 h.

obtained removal efficiencies of 52.1, 56, and 52.1% for COD, BOD, and TSS, respectively, operating conventional septic tank/anaerobic filter at an average retention time of 22.5 h. Equally, the results are higher than those obtained by Koottatep et al. [30] who obtained average removal efficiencies of 61 and 44% for TSS at HRT of 24 h when treating wastewater using anaerobic baffled reactor with anaerobic filter and anaerobic single-baffle septic tank, respectively. The results are lower than those obtained by Moussavi et al. [33] who studied the performance of a pilot-scale up-flow septic tank for on-site decentralized treatment of residential wastewater at 24 h HRT, and achieved removal efficiencies of 77, 85, and 86% for COD, BOD, and TSS at steady-state operation, respectively. Similarly, the results are lower than those obtained by Sabry [22] who obtained average removal efficiencies of 84, 81, and 89% for COD, BOD, and TSS, respectively, operating up-flow septic tank/baffled reactor at 20 h HRT treating domestic wastewater.

3.1.2. Performance at 48 h HRT

At 48 h HRT, the results obtained were: COD percentage removals of 56, 60, 64, and 68% and corresponding residual values were 380, 350, 314, and 279 mg/l respectively. The BOD percentage removals were 57, 62, 65, and 69%. Corresponding residual values were 164, 148, 134, and 120 mg/l, respectively. The TSS percentage removals were 58.3, 69, 72, and 75%, respectively. Corresponding residual values were 115, 85, 77, and 69 mg/l, respectively (Table 2, Figs. 5–7).

These results are in line with those obtained by Koottatep et al. [30] who obtained average removal efficiency of 76% for TSS when treating wastewater using anaerobic single-baffle septic tank at 48 h. The present study results are lower than the results obtained by Coelho et al. [34] who obtained removal efficiencies from 70–75% and from 65–70% for COD and TSS, respectively, treating domestic wastewater using conventional septic tank at 48 h HRT. Also, the results are lower than those obtained by Koottatep et al. [30] who obtained average removal efficiencies of 73 and 75% for COD and BOD, respectively, when treating wastewater using anaerobic single-baffle septic tank at 48 h. The results he obtained when treating wastewater using anaerobic baffled reactor with anaerobic filter at 48 h were 87, 86, and 87% for COD, BOD, and TSS, respectively. On the other hand, the present

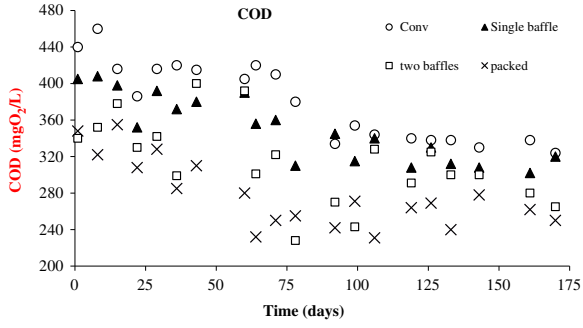

Fig. 5. Variation of COD in conventional, single baffle, two baffles and packed septic tank effluent at 48 h.

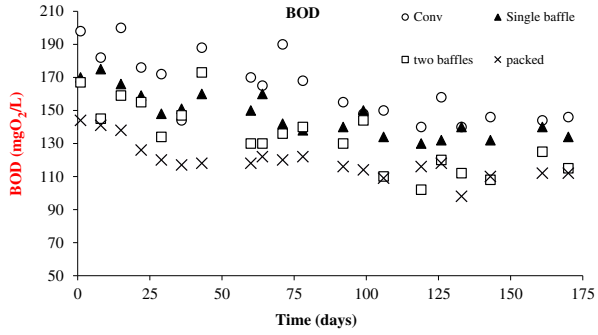

Fig. 6. Variation of BOD in conventional, single baffle, two baffles and packed septic tank effluent at 48 h.

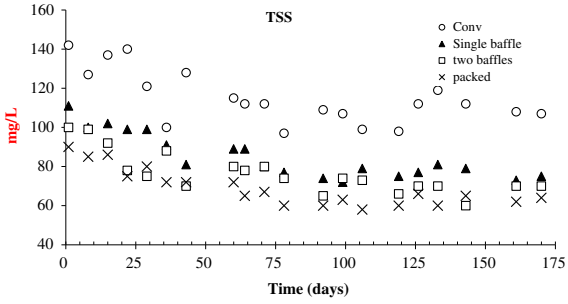

Fig. 7. Variation of TSS in conventional, single baffle, two baffles and packed septic tank effluent at 48 h.

study results are higher than those obtained by Burubai et al. [35] who obtained removal efficiencies of 53.1, 51.6, and 30.1% for COD, BOD, and TSS, respectively, at HRT of 48 h, treating toilet wastewater using single-compartment septic tank.

3.1.3. Performance at 72 h HRT

At 72 h HRT, the results obtained were: COD percentage removals of 65.3, 72.3, 74, and 77% and corresponding residual values were 334, 266, 248, and 221 mg/l, respectively. The BOD percentage removals were 68.4, 74.4, 76.5, and 79% and the corresponding residual values were 142, 115, 106, and 94 mg/l, respectively. The TSS percentage removals were 65.3, 73, 76, and 78% and the corresponding residual values were 103, 79, 71, and 65 mg/l, respectively. It can be observed that the percentage removal of pollutants for each type of septic tank improves in direct proportion to the HRT (Table 2; Figs. 8–10).

These results are in line with those obtained by Nguyen et al. [31] who obtained average removal efficiencies from 58 to 76% in terms of COD and from 61 to 78% in terms of TSS depending on the HRT in the baffled septic tank. In addition, the results agree with

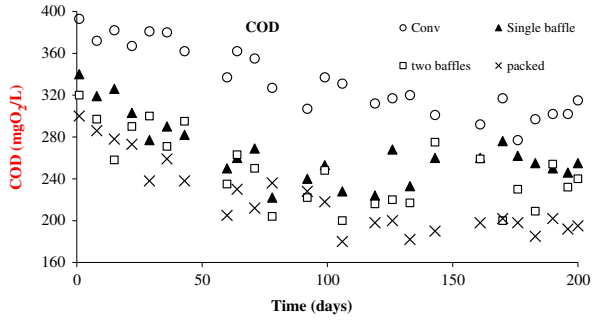

Fig. 8. Variation of COD in conventional, single baffle, two baffles and packed septic tank effluent at 72 h.

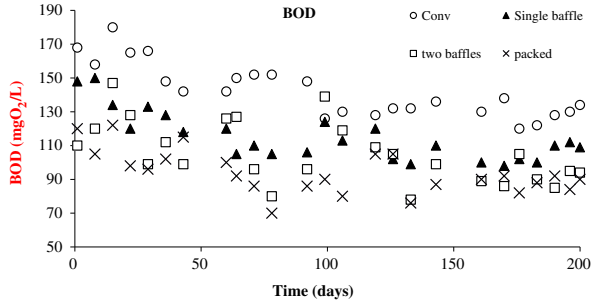

Fig. 9. Variation of BOD in conventional, single baffle, two baffles and packed septic tank effluent at 72 h.

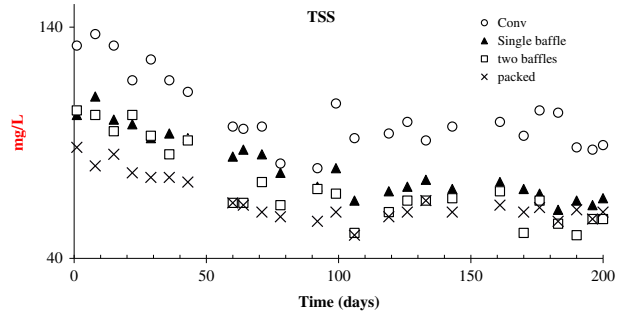

Fig. 10. Variation of TSS in conventional, single baffle, two baffles and packed septic tank effluent at 72 h.

those obtained by Kamel and Hegazy [36] who obtained more than 65% reductions of BOD operating the baffled septic tank at 60.5 h HRT and agree with those obtained by WSDH [37] who obtained residual value from 100 to 140 mg O_2/l for BOD when using septic tank with anaerobic filter for wastewater treatment. The results are higher than those obtained by Nguyen et al. [38] who obtained average removal efficiency of 64% with residual value of 180 mg /l for COD and 64% with residual value of 110 mg /l for

Table 3
Characteristics of sludge accumulated in conventional septic tank, single baffle septic tank, two baffles septic tank and packed septic tank

		HRT 72 h		HRT 48 h		HRT 24 h	
Time (d)	Septic tank type	Sludge accumulated (cm^3)	Sludge accumulated (g)	Sludge accumulated (cm^3)	Sludge accumulated (cm^3)	Sludge accumulated (g)	Sludge accumulated (cm^3)
30	Conventional	1,500	24	2,700	99	3,400	131
60	septic tank	2,700	57	4,200	201	5,400	368
90		3,200	88	6,100	364	7,200	611
120		5,500	195	7,200	481	8,600	910
150		7,000	299	8,500	689	10,000	1,201
180		7,850	350	9,600	900	11,300	1,600
210		8,500	560	10,500	1,150	12,500	1,850
30	Single baffle	1,600	25	2,900	110	3,580	144
60	septic tank	2,860	68	4,520	240	5,860	400
90		3,360	104	6,680	438	7,800	708
120		5,880	232	7,860	572	9,100	1,050
150		7,310	368	9,200	810	10,600	1,488
180		8,300	420	10,700	1,000	12,200	2,000
210		9,200	500	11,800	1,300	13,600	2,500
30	Two baffles	1,720	26	3,080	121	3,800	162
60	septic tank	3,200	81	4,800	276	6,100	466
90		3,580	119	7,000	512	8,020	859
120		6,440	262	8,240	761	9,450	1,230
150		8,140	448	9,800	1,046	11,000	1,995
180		9,200	600	11,300	1,250	12,400	2,650
210		10,100	850	12,600	1,600	13,600	3,400
30	Packed septic	1,650	24	2,920	113	3,680	150
60	tank	3,090	70	4,580	256	5,880	432
90		3,400	109	6,840	443	7,480	781
120		6,200	249	7,910	650	8,940	1,115
150		7,680	394	9,500	972	10,750	1,870
180		9,100	480	11,100	1,250	12,500	2,400
210		10,400	600	12,400	1,550	14,000	3,000

BOD when using the baffled anaerobic septic tank with anaerobic filter at 84 h. The results are in line with those obtained by Nguyen et al. [38] who obtained average removal efficiency of 75% with residual value of 87.5 mg /l for TSS when using the same design. Also, the results are higher than those obtained by Burubai et al. [35] who obtained removal efficiencies of 57.3, 57.4, and 40.6% for COD, BOD, and TSS, respectively, at HRT of 72 h, treating toilet wastewater using single-compartment septic tank.

3.1.4. Nitrogen, phosphorous, and fecal coliform removal

The nitrogen and phosphorous removal was found to be dependent on the type of the septic tank and the HRT. It ranged between a minimum and maximum value of 17.7 and 26.8% for nitrogen, 25.6 and 29.3% for phosphorous using conventional septic tank. Corresponding values for packed-type septic tank were 22.8 and 34% for nitrogen and 31.2 and 36% for phosphorous. These low removal values of nitrogen and phosphorous are due to the anaerobic digestion which takes place in the septic tank [39]. These results are in line with the results achieved by Nasr et al. [40] and Wanasen [41]. The results of this study are higher than those obtained by Mahmoud et al. [42] who attributed the lower phosphorus removal achieved to the relatively low biomass production in anaerobic systems. The ammonia concentrations at HRTs of 72, 48, and 24 h increased by 14.2, 10, and 7.2%, respectively. These results correspond favorably to those obtained by Nguyen et al. [28] who attributed the increase in ammonia concentration in the effluent compared to

the concentration of the influent due to the hydrolysis of wastewater occurring in the tank. High nitrogen–ammonia concentrations could be an important reason for not achieving high removal efficiency rates in the tank in some cases [28].

The fecal coliform removal values were observed to be affected by the same parameters: septic tank type and HRT; however, the highest percentage removal reached only one log with an average residual value in the final effluent of 5.6×10^7. These results agree with those obtained by El-Hamouri et al. [43] and Kamel and Hegazy [36].

3.1.5. Sludge and desludging

One of the mechanisms septic tanks use to remove solids is to make solids settle as sludge at the bottom of the tank [44]. Comparing the sludge characteristics produced by the investigated septic tanks, it was observed that the accumulated volume and weight depends on the septic tank type and HRT (Table 3). When comparing the sludge volatile organic matters of the septic tanks at each HRT, it was found that average values are almost equal. Assuming that sludge accumulation is proportional to time of operation and that desludging should occur at 60% of the septic tank volume, as recommended by the US Environmental Protection Agency [45], it was observed that the due time for desludging is directly proportional to the HRT. For example, the conventional-type septic tank requires to be desludged after 32, 38, and 47 months at HRT 24, 48, and 72 h, respectively. The due times for desludging of single-baffle septic tank were 29, 33, and 42.5 months at HRT 24, 48, and 72 h, respectively. Similarly, results obtained for two-baffle septic tank at the same HRT were 29, 31.5, and 39.5 months, respectively. The due times for the packed-type septic tank desludging at the same HRT were 28, 31.5, and 37.5 months, respectively.

4. Conclusion

The raw wastewater can be categorized of high strength as per world-recognized classification. Comparison wise, the packed-type returns best results and the conventional type is the least for primary treatment. Further processing by a post-treatment system, however, has to be applied to meet environmental standards. The average removal of pollutants for each type of septic tank in terms of COD, BOD, and TSS improves in direct proportion to HRT. The fecal coliform removal values were observed to be affected by type of the septic tank and the HRT; however, the highest percentage removal reached only one log. The accumulated sludge volume, weight, and due time for desludging are directly proportional to septic tank type and HRT. Based on achieved results, either the two-baffle or the packed-type septic tank is considered to be a viable solution for the on-site decentralized treatment of high-strength domestic wastewater especially at rural communities.

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