

Manuscript #: 024135 – Technical paper

Published as: Rodgers, M., Healy, M.G., Prendergast, J. 2006. A novel hybrid filter for the treatment of septic tank effluent. ASCE Journal of Environmental Engineering 132(7): 764 – 768.

A NOVEL HYBRID FILTER FOR THE TREATMENT OF SEPTIC TANK EFFLUENT

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ABSTRACT

Intermittent sand filtration is a common and effective method for treating septic tank effluent. However, if the loading rate is too high, clogging and ponding of the sand filter surface layer can occur due to the accumulation of excessive biomass and the deposition of suspended solids. This ponding limits the practicality of sand filtration as it makes it necessary to take the filter out of service for maintenance. The objective of this study was to develop and test, on-site, a new hybrid filter system that would reduce the risk of clogging at an organic loading rate substantially greater than the maximum recommended loading rate for intermittent sand filters. The system comprised a 0.6 m deep horizontal flow biofilm reactor (HFBR) over a 0.85 m deep stratified sand filter. The HFBR consisted of a stack of 20 horizontal corrugated polyvinyl chloride (PVC) sheets, at 32 mm vertical spacings. The sheets were arranged so that the wastewater flowed over and back along alternate sheets down through the stack. The main biofilm growth formed on these sheets. The hybrid filter was loaded with septic tank effluent from an office/garage complex at the rate of 206 L/m²•d for a period of 400 days in 2 phases. During the first phase, the effluent volume of 600 L/d was applied in 24 doses/d for 10 minutes per dose, and during the second phase in 6

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doses/d for 40 minutes/dose. Biofilms in the HFBR substantially reduced the organic and suspended solids loads that reached the sand filter surface and allowed an average total biochemical demand (BOD_T) loading rate, based on HFBR plan area, of $37 \text{ g } BOD_T/m^2 \cdot d$ to be applied to the system without clogging. This rate was substantially greater than the maximum recommended loading rate of $24 \text{ g } BOD_T/m^2 \cdot d$ for intermittent sand filters (US EPA 1980). During both loading phases a BOD_T removal of 94% was achieved and nitrification was nearly complete. The average effluent BOD_T was $12 \pm 4 \text{ mg/L}$ during both phases. The hybrid filter system appeared to perform better in terms of suspended solids handling and nitrification during the more frequent dosing phase. The hybrid filtration system offers a more compact alternative to intermittent sand filtration on its own with little risk of clogging.

CE Database subject headings: Waste treatment, Wastewater disposal, waste disposal, waste management.

INTRODUCTION

Intermittent sand filtration has been used to treat septic tank effluent (Furman et al. 1955; Sauer et al. 1976; Piluk et al. 1989). The treatment methodology involves the intermittent dosing of wastewater, following settlement, onto the surface of a sand filter in timed incremental doses. Biological processes such as organic carbon removal and nitrification occur within the sand filter and phosphorus removal occurs through ion exchange and adsorption onto the sand grains.

The US EPA (1980) recommends sand filter depths of 0.6 to 0.9 m and a maximum hydraulic loading rate, based on filter surface area, of $40 \text{ L/m}^2 \cdot d$ applied to a covered filter with an effective grain size, d_{10} , between 0.35 and 1 mm and a uniformity coefficient, C_u , less than 3.5. Anderson et al. (1985) recommend that the maximum organic loading rate should not exceed $24 \text{ g } BOD_T /m^2 \cdot d$ and a minimum dosing frequency of two doses /d should be applied to single-pass sand filters.

An increase in dosing frequency may have a beneficial effect on the treatment performance of a sand filter (Anderson et al. 1985). In a study of 12 shallow sand filters (0.38 m deep), with an effective grain size (d_{10}) of 0.29 mm and an uniformity coefficient (C_u) of 4.5, Darby et al. (1996) found that increasing the hydraulic load application frequency from 4 to 24 times/d resulted in a slight but statistically significant increase in the removal of turbidity, chemical oxygen demand (COD) and organic-N. In a pilot and field scale experiment on single-layer sand filters ($C_u=4.4$), Boller et al. (1993) showed that small hydraulic flushes in short intervals (12 hydraulic flushes versus 3 hydraulic flushes both totaling 40 L/m²• d) enhanced the hydraulic storage capacity, increased the average water retention time by 2 to 3 hours, and prohibited breakthrough of organic matter in the filter.

Clogging of the upper layers of the filter surface and surface ponding may occur over time, due to excessive loading of organic matter and suspended solids. When this occurs, the operation of the sand filter must be temporarily suspended. The occurrence of surface ponding has been attributed to a number of causes, namely, biofilm and secretion build-up (Siegrist and Boyle 1987; Vandevivere and Baveye 1992; Schwager and Boller 1997; Bouwer et al. 2000; Rodgers et al. 2004) and deposition of organic and inorganic solids (Daniel and Bouma 1974; Platzer and Mauch 1997). In a study of a laboratory intermittently loaded stratified sand filter treating synthetic agricultural wastewater, Rodgers et al. (2004) investigated the characteristics of the clogging layer, following the occurrence of surface ponding. Measurements of field-saturated hydraulic conductivity within the upper layer of the sand filter indicated that the effects of the build-up of organic and inert matter may have extended to a depth of 0.165 m into the layer.

The main aim of this study was to develop and test, on-site, a new hybrid filter system, comprising a stack of 20 horizontal corrugated PVC sheets – spaced 32 mm vertically apart – over a stratified sand filter, for the treatment of septic tank effluent at a loading rate substantially greater than the maximum recommended rate for intermittent sand filters. It was expected that the 32 mm vertical spacing would provide sufficient volume for biofilms to grow without blocking the wastewater flow along the sheet channels. It was also considered that most of the substrates and solids would be removed in the biofilms on the sheets,

substantially reducing the loads applied to the sand filter underneath. A secondary aim was to establish if dosing the system every hour would give a better performance than dosing it every 4 hours with the same daily volume of septic tank effluent.

MATERIALS AND METHODS

A horizontal flow biofilm reactor (HFBR) and a stratified sand filter were used to form a 'hybrid filter' and were placed in a pre-cast steel-fibre reinforced concrete tank. The top of the tank had external plan dimensions of 2.8 m by 1.52 m, giving a top external plan area of 4.26 m², and had internal plan dimensions of 2.59 m by 1.35 m, giving a top internal plan area of 3.49 m². The height of the tank was 1.45 m and it tapered inwards towards the base.

The HFBR module in the hybrid filter had a plan area of 2.91 m² and was 0.6 m in depth. The module consisted of 20 corrugated PVC sheets that were levelled and placed over one another using vertical stainless steel threaded bars and nuts at 32 mm intervals along the height of the bars to space the PVC sheets. The 20 sheets that formed the module were enclosed within a metal frame made from galvanized angle iron, which facilitated the removal of the module from the tank in one piece.

Each sheet channel was blocked off at both ends using PVC trimming bolted onto the bottoms of the channels of the sheets; any remaining gaps around the trimming were sealed using silicone. The PVC trimmings used to seal the ends of the sheets were rested upon each other to give support to the individual sheets. There were 32 channels on each sheet, and a 20 mm diameter hole was drilled in each channel at alternate ends of the sequential sheets so that the wastewater flowed along the channels of each sheet from one side to the other and down through the module (Figure 1). The bottom sheet of the module was drilled in a pattern to provide an even distribution of the treated wastewater over a stratified sand filter (Figure 2). The diameters of the holes in this bottom sheet were 40 mm. There was an adequate gap at the side of the module parallel to the channels for air entry into the module.

The sand filter part of the hybrid filter was 0.85 m in depth with a plan surface area of 3.17 m² and consisted of three sand filter layers (Figure 3). A vertical section of the sand filter from top to bottom consisted of: a 0.05 m layer of distribution pea gravel (10-20 mm in size), a 0.2 m layer of coarse sand ($d_{10}=0.38$ mm; $C_u = 2.8$), a 0.05 m layer of pea gravel, a 0.2 m layer of fine sand ($d_{10}=0.16$ mm; $C_u=3.2$), a 0.05 m layer of pea gravel, another 0.2 m layer of fine sand, and a final 0.1 m layer of pea gravel. A 100 mm diameter WAVIN uPVC sewer pipe, with a series of 25 mm wide notches, was placed in the bottom 0.1 m pea gravel layer to collect the treated effluent.

A roof was constructed from 10 mm thick plywood and was bolted to the frame that surrounded the module. The roof prevented leaf litter and other organic debris from blocking the top of the module. The top of the roof was covered in impermeable PVC liner to prevent deterioration of the plywood. A length of PVC liner was hung from the front of the roof to allow easy access to the top of the module for inspection of the biofilm growth.

Septic tank effluent from an office/garage complex was applied to this hybrid filter at a rate of 600 L/d. The daily hydraulic loading rate did not change during the study, but 2 dosing regimes were used - Phase 1 and Phase 2. During Phase 1, which lasted 289 d, the wastewater was dosed 24 times/d for a 10-minute duration and during Phase 2, which lasted 111 d, the wastewater was dosed 6 times/d for a 40 minute duration. The septic tank effluent passed through a baffle filter (Zabel Environmental Technology, Crestwood, Ky., USA) into a feed pump sump. The operation of the feed pump was controlled by an electric timer and float switch that ensured the pump was not activated when the level of wastewater in the sump was very low. A valve was attached to the pump delivery hose so that the flow entering the hybrid filter could be regulated. The flow rate was measured by a flow meter.

The wastewater was delivered to the surface of the HFBR through a 42 mm DYKA pressure distribution pipe. Holes of 2 mm diameter were bored at the top of this distribution pipe at 75 mm intervals. A 250 mm diameter WAVIN pipe was cut in half and placed over the distribution pipe; this insured that the septic tank

effluent, on exiting from the distribution pipe, hit the WAVIN pipe, thereby slowing down the speed of the wastewater and spreading it evenly over the top of the HFBR module.

Grab samples of the influent wastewater from the sump (Influent in Tables 1 and 2) were taken by disconnecting the delivery hose from the DYKA pressure pipe and by then turning on the pump to fill a 500 ml container. Samplers, illustrated in Figure 4 and constructed from the stop ends of a 225 mm WAVIN pipe, were added to the ends of one of the channels on the 4th, 8th, and 16th sheet down the HFBR (Tables 1 and 2). Similar samplers also collected water samples in the gravel distribution layer at the top of the sand filter (1st gravel in Tables 1 and 2), the pea gravel layer between the coarse sand layer and the fine sand layer (2nd gravel in Tables 1 and 2), and the pea gravel layer between the 2 layers of fine sand (3rd gravel in Tables 1 and 2). Water samples were also taken at the outlet of the hybrid filter (Effluent in Tables 1 and 2). The locations of these sampling points are illustrated in Figure 3. Weekly grab samples were collected at all these locations. Following treatment by the hybrid filter, the final effluent was discharged to a percolation area. The results presented are for the period when steady state conditions (defined by near-constant effluent organic and nutrient concentrations) in the filter were achieved.

The water quality parameters measured included BOD (5-day BOD test), chemical oxygen demand (COD) (closed reflux, titrimetric method), ammonium-N (NH_4^+ -N) (ammonia-selective electrode method), NO_3^- -N (nitrate electrode method), ortho-phosphate P (PO_4^{+} -P) (ascorbic acid method) and suspended solids (SS) (total suspended solids dried at 103-105°C). All water quality parameters were tested in accordance with the Standard Methods for the Examination of Water and Wastewater (APHA-AWWA-WEF, 1995). The temperature of the influent and effluent wastewaters was also monitored throughout the study.

RESULTS AND DISCUSSION

The hybrid filter unit comprising the 0.6 m deep HFBR over the 0.85 m deep stratified sand filter was constructed above ground surface and the samplers were located in a south facing position. Both study phases took place under similar climatic conditions.

Carbonaceous oxidation

During Phase 1 of the study (Table 1), when the dosing of the septic tank effluent was hourly, the average HFBR influent total COD (COD_T) was 389 ± 75 mg/L and BOD_T was 179 ± 43 mg/L. The corresponding average HFBR organic loading rates were $80 \text{ g COD}_T / \text{m}^2 \cdot \text{d}$ and $37 \text{ g BOD}_T / \text{m}^2 \cdot \text{d}$, based on the HFBR plan area. The hydraulic loading rates were $206 \text{ L} / \text{m}^2 \cdot \text{d}$ on the HFBR and $189 \text{ L} / \text{m}^2 \cdot \text{d}$ on the stratified filter – the difference was due to the HFBR's smaller plan area. In the HFBR, the COD_T was reduced by 48 % and the BOD_T by 73 % leaving sand-filter loading rates of $38 \text{ g COD}_T / \text{m}^2 \cdot \text{d}$ and $9 \text{ g BOD}_T / \text{m}^2 \cdot \text{d}$, which is well below the US EPA (1980) maximum allowable filter loading rate of $24 \text{ g BOD}_T / \text{m}^2 \cdot \text{d}$. This low sand-filter loading rate reduced the risk of the sand filter clogging and no surface ponding occurred throughout the 400-day study duration. The final effluent from the stratified sand filter had average concentrations of 68 ± 17 mg COD_T / L and 12 ± 4 mg BOD_T / L corresponding to 82 % COD_T and 94 % BOD_T overall removals. These results compare favourably with results from Sauer et al. (1976) who measured a COD_T removal of 82 % in a 1.8 m deep, single-layer intermittent sand filter ($d_{10} = 0.45$ mm, $\text{Cu} = 3$) at a hydraulic loading rate of $203 \text{ L} / \text{m}^2 \cdot \text{d}$ and an organic loading rate of $58 \text{ g COD}_T / \text{m}^2 \cdot \text{d}$, and Effert et al. (1985) who measured a mean effluent BOD_T of 4 mg/L from a 0.76 m deep, sand filter ($d_{10} = 0.4$ mm, $\text{Cu} = 2.5$) at a hydraulic loading rate of $150 \text{ L} / \text{m}^2 \cdot \text{d}$ and an organic loading rate of $20 \text{ g BOD}_T / \text{m}^2 \cdot \text{d}$.

During Phase 2 (Table 2), when the dosing of the septic tank effluent was every 4 hours, the results for organic carbon removal were similar to those in Phase 1 for both the HFBR and the overall hybrid system e.g., the overall BOD_T removal in Phase 1 was 94 % for an influent BOD_T of 179 ± 43 mg/L compared to 93 % in Phase 2 for an influent BOD_T of 165 ± 30 mg/L.

It seemed that the organic carbon removal capability of the hybrid system for the 2 loading regimes - using the same total daily loading rate - were equally efficient.

Suspended solids removal

During Phase 1 (Table 1) there was a marked continuous reduction in the average SS concentrations down through the HFBR unit from 132 ± 95 mg/L in the influent to 58 ± 20 mg/L in the gravel underlying the HFBR – a decrease of 74 mg/L. This decrease brought about a low solids loading on the sand filter surface reducing the risk of clogging. During Phase 2 (Tables 2) the SS concentrations, while still showing a continuous reduction down through the HFBR, ranged from 89 ± 15 mg/L in the influent to 70 ± 15 mg/L in the gravel underlying the HFBR – a decrease of only 19 mg/L. Biofilm growth was most extensive on the uppermost sheets of the HFBR as a result of the greater organic loading on these sheets. There was also deposition of solids on these sheets from the influent wastewater. The greater the hydraulic dose applied to the HFBR the more likely it was that the biofilm and deposited solids would be suspended in the wastewater flow and transported from sheet to sheet to give a more even distribution of SS on the sheets and higher SS concentrations entering the sand filter, as happened in Phase 2 of the study, when the dose applied was about 3 L /channel – 4 times greater than in Phase 1. This increased transport of solids down through the hybrid system could lead to earlier clogging of the sand filter. This suggests that if the SS load on the sand filter is to be kept low, it is better to dose frequently e.g., hourly. This finding is in agreement with studies by Darby et al. (1996) who found that a 99 % SS reduction occurred in sand filters at hourly loadings and a 95 % SS reduction at loadings every 4 hours.

The overall solids removal was excellent in both phases and the final effluent had SS concentrations of 12 ± 4 mg/L in Phase 1 and 13 ± 6 mg/L in Phase 2. On analysing all the SS data down through the hybrid system, it seems likely that the sand filter could clog earlier under the Phase 2 loading than under the Phase 1 loading.

Nitrogen conversion

The concentrations of the influent NH_4^+ -N in both phases (Tables 1 and 2) were greater than normal domestic wastewater and were due to cleaning agents used in the office/garage complex. Despite these high concentrations, most of the NH_4^+ -N was eliminated in the hybrid filter in both phases.

In Phase 1, the $\text{NH}_4^+\text{-N}$ concentrations in the HFBR decreased from 120 ± 3 mg/L to 84 ± 26 mg/L – a reduction of 36 mg/L. The corresponding dissolved oxygen (DO) increase in the HFBR was from 1 ± 1 mg/L to 5 ± 1 mg/L (Table 1). The $\text{NH}_4^+\text{-N}$ reduction was substantially greater than that of 20 mg/L in Phase 2. The indication of less efficient nitrification in the HFBR in Phase 2 could, as a result of the high volume of wastewater applied in each dose in this phase, be attributed to the redistribution of solids from the uppermost sheets to the lower sheets and consequent adverse conditions for nitrifier growth throughout the HFBR.

For the overall hybrid system in Phase 1, there was an 88 % $\text{NH}_4^+\text{-N}$ reduction, producing a final effluent of 14 ± 10 mg $\text{NH}_4^+\text{-N/L}$, while in Phase 2 there was a 73 % $\text{NH}_4^+\text{-N}$ reduction producing a final effluent of 27 ± 17 mg $\text{NH}_4^+\text{-N/L}$.

The $\text{NH}_4^+\text{-N}$ data suggest that the hybrid system is well capable of reducing $\text{NH}_4^+\text{-N}$ concentrations in normal domestic wastewater to low values and that the hourly loading regime in Phase 1 is more efficient than the Phase 2 regime of loading every 4 hours.

Phosphorus removal

Phosphorus removal was similar in the HFBR and sand filters for both phases (Tables 1 and 2). In Phase 1, 10 mg $\text{PO}_4^+\text{-P}_T\text{/L}$ were removed in the HFBR and 3 mg $\text{PO}_4^+\text{-P}_T\text{/L}$ in the sand filter; in Phase 2, 12 mg $\text{PO}_4^+\text{-P}_T\text{/L}$ were removed in the HFBR and 2 mg $\text{PO}_4^+\text{-P}_T\text{/L}$ in the sand filter. The large removal of $\text{PO}_4^+\text{-P}_T\text{/L}$ in the HFBR could be attributed in part to the utilization of $\text{PO}_4^+\text{-P}_T\text{/L}$ in biofilm growth and in part to the presence of anaerobic and aerobic biofilm conditions on the PVC sheets that could encourage development of phosphorus accumulating organisms. This needs to be investigated further.

Bacteria removal

In Phase 1, the coliform content of the influent and effluent wastewater varied greatly. The average total coliform removal in the hybrid filter was 99.7% and the average fecal coliform removal in the hybrid filter was 99.5%.

CONCLUSIONS

The following can be concluded from the on-site testing of a new hybrid filter system comprising a 0.6 m deep horizontal flow biofilm reactor (HFBR) over a 0.85 m deep stratified sand filter:

1. At a hydraulic loading rate of $206 \text{ L/m}^2 \cdot \text{d}$ dosed hourly for 10 minutes and an average organic carbon loading rate of $37 \text{ g BOD}_T/\text{m}^2 \cdot \text{d}$, the system was capable of producing an effluent with a BOD_T of 12 mg/L and SS of 12 mg/l. These loading rates and dosing regime could be used in designs to give a substantially smaller treatment system plan area than an intermittent sand filter on its own.
2. No clogging was evident in the hybrid system as the main biofilm growth and suspended solids deposition formed in the HFBR where they could be readily accommodated. It appears from the SS data that dosing on an hourly basis would have less risk of clogging than dosing every 4 hours.
3. Nitrification of a high strength $\text{NH}_4^+ \text{-N}$ influent wastewater was 88 % complete in the hybrid system dosed on an hourly basis as against 73 % in the system dosed every 4 hours. This suggests that the more frequent dosing system is better for nitrification.

The system was easy and cheap to construct and run, and would be suitable as a wastewater treatment system for small applications including single houses.

ACKNOWLEDGEMENTS

The authors are grateful to Coffey Construction Ltd., Athenry, Co. Galway for support for the work. The authors acknowledge the technical help of M. Rathaille, M. O'Brien and G. Hynes (NUI, Galway).

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CAPTIONS FOR FIGURES

Figure 1. Vertical section of the side of the module.

Figure 2. Complete bottom PVC sheet of the module.

Figure 3. A section of the hybrid filtration system used in this study, including sampling locations.

Figure 4. Section of water sampler.

Table 1. Average nutrient values (\pm standard deviation) of the wastewater at the sampling points for Phase 1 of the study.

	COD _T	BOD _T	SS	NH ₄ ⁺ -N	PO ₄ -P _T	DO	T. coliform	F.coliform
	mg L ⁻¹						no./100 ml	
Influent	389 (75)	179 (43)	132 (95)	120 (3)	25 (4)	1 (1)	1.2 x 10 ⁷ (3.1 x 10 ⁷)	8.2 x 10 ⁶ (2.2 x 10 ⁷)
4 th Sheet	320 (53)	157 (37)	114 (62)	108 (21)	21 (4)	1 (1)		
8 th Sheet	294 (50)	102 (26)	87 (36)	102 (26)	19 (4)	1 (1)		
16 th Sheet	268 (46)	76 (19)	73 (29)	96 (26)	17 (3)	1 (1)		
1 st gravel	200 (41)	49 (19)	58 (20)	84 (26)	15 (3)	5 (1)		
% removal in horizontal flow filter ^a	48	73	56	30	40	-	-	-
2 nd gravel	156 (33)	39 (15)	45 (20)	38 (21)	14 (2)	6 (1)		
3 rd gravel	92 (20)	18 (6)	20 (5)	19 (10)	12 (2)	6 (1)		
Effluent	68 (17)	12 (4)	12 (4)	14 (10)	12 (2)	5 (1)	3.4 x 10 ⁴ (9.4 x 10 ⁴)	4.4 x 10 ⁴ (1.3 x 10 ⁵)
n ^b	24	24	24	24	24	24		
% removal in sand filter unit ^c	34	21	35	58	12	6	-	-
Overall % removal	82	94	91	88	52	-	99.7	99.5

^a % removal based on influent and 1st gravel concentrations.

^b n = number of steady-state data sets

^c % removal based on the sand filter removal as a percentage of the influent concentration.

Table 2. Average nutrient values (\pm standard deviation) of the wastewater at the sampling points for Phase 2 of the study.

	COD _T	BOD _T	SS	NH ₄ ⁺ -N	PO ₄ -P _T	DO
	mg L ⁻¹					
Influent	322 (70)	165 (30)	89 (15)	101 (29)	35 (16)	2 (1)
4 th Sheet	284 (59)	144 (27)	86 (32)	96 (27)	30 (17)	4 (1)
8 th Sheet	249 (61)	99 (19)	82 (20)	90 (26)	27 (15)	4 (1)
16 th Sheet	230 (58)	74 (11)	77 (17)	85 (26)	25 (14)	4 (1)
1 st gravel	198 (54)	43 (3)	70 (15)	81 (24)	23 (11)	5 (-)
% removal in horizontal flow filter ^a	39	74	21	20	34	-
2 nd gravel	149 (41)	34 (3)	52 (6)	51 (13)	22 (11)	5 (-)
3 rd gravel	93 (21)	18 (5)	29 (8)	40 (18)	22 (10)	6 (1)
Effluent	69 (21)	12 (7)	13 (6)	27 (17)	21 (10)	5 (1)
N ^b	10	10	10	10	10	10
% removal in sand filter unit ^c	40	19	64	53	6	-
Overall % removal	79	93	85	73	40	-

^a % removal based on influent and 1st gravel concentrations.

^b n = number of steady-state data sets

^c % removal based on the sand filter removal as a percentage of the influent concentration.

Figure 1. Rodgers et al. (2005). A novel hybrid filter for the treatment of septic tank effluent.

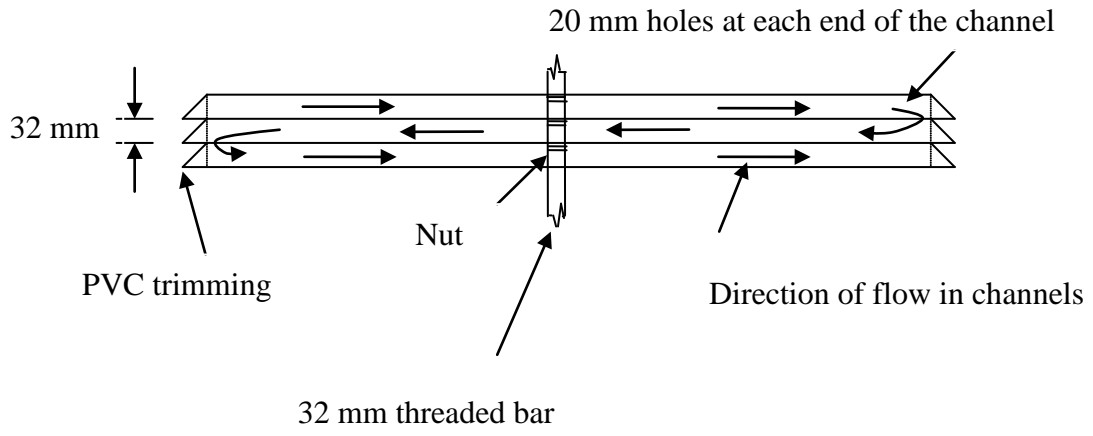


Figure 2. Rodgers et al. (2005). A novel hybrid filter for the treatment of septic tank effluent.

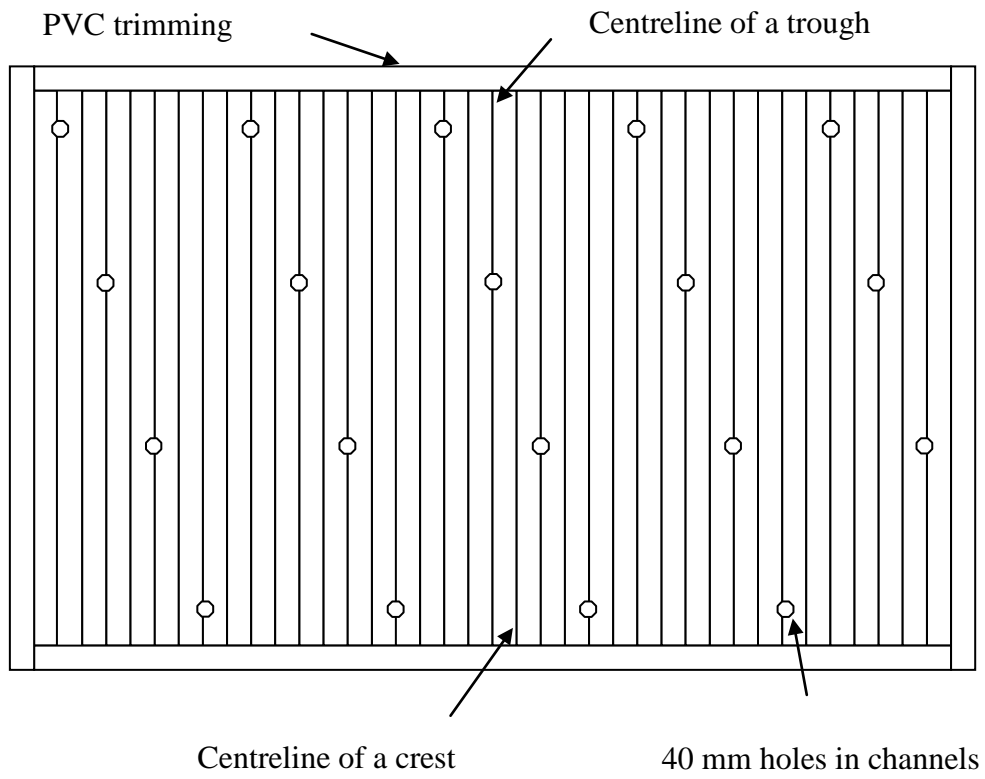


Figure 3. Rodgers et al. (2005). A novel hybrid filter for the treatment of septic tank effluent.

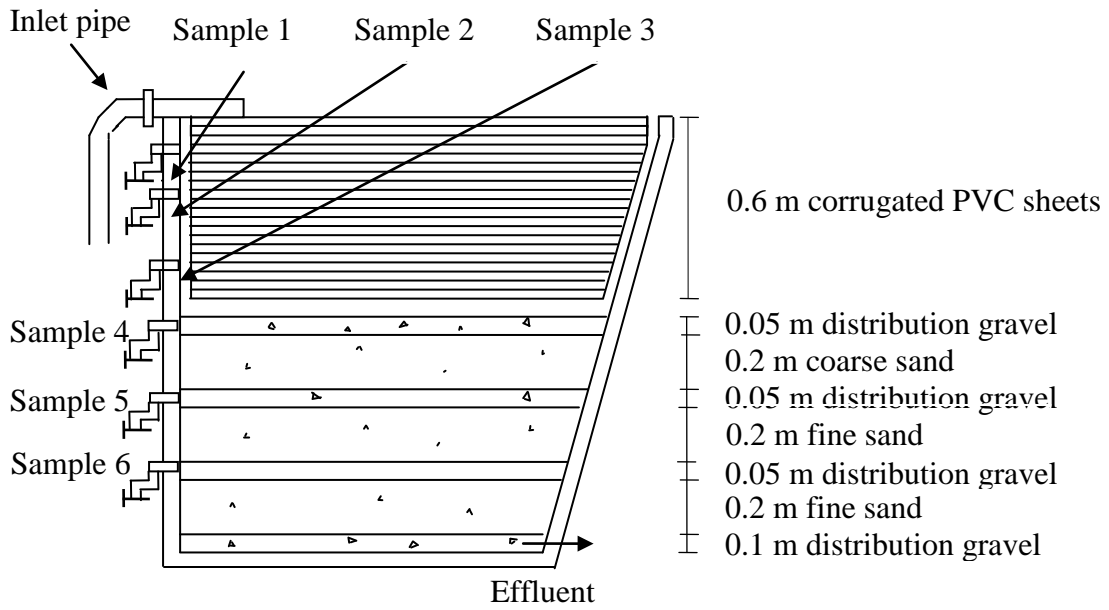


Figure 4. Rodgers et al. (2005). A novel hybrid filter for the treatment of septic tank effluent.

