INNOVATIVE SOLUTIONS FOR DECENTRALIZED WASTEWATER TREATMENT

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Chlorination and UV light are currently the most common methods used for disinfection of wastewater. While these processes are generally well-adapted to community or municipal installations, their operation and maintenance needs present some limitations to assure sustainable performance at the level of individual wastewater treatment systems. As reported in many papers (U.S. EPA, 1999), use of chlorine for wastewater disinfection presents environmental risks related to toxicity for aquatic life and trihalomethane (THM) compounds formation according to organic content of treated effluent. Also, to assure disinfection efficiency, chlorine must be added on a regular basis that is often neglected because few regulations include mandatory maintenance requirements.

Use of UV light for wastewater disinfection presents less risk than chlorination because no chemical reacts with organic matter. However, the reliability of UV disinfection performance is subjected to transmissivity of UV light in the wastewater to be treated that is influenced by many factors acting in different ways. The content in suspended solids (TSS) reduces UV light efficiency by masking UV rays for bacteria inactivation (NSFC, 1998). Presence of iron and manganese in more than 0.3 and 0.05 mg/L respectively, absorbs UV light and calcium (hardness) promotes, in combination with iron, fouling of quartz tube that it reduces transmission of UV light (Sehnaoui and al., 2001). Fouling of quartz tube is also increased by other factors like intermittent flow. Flow interruption (vacation, week-end, etc.) increases the wastewater temperature in UV unit promoting carbonates precipitation on quartz tube (Whitby, 2002). Also, the reject of backwash from drinking water treatment system (ex: softener) in septic system has a major impact on quartz tube fouling. Considering that these previous factors are dependant on the quality of drinking water, family life habits and wastewater treatment system used in front of UV unit, the performance of UV disinfection, as well as the time required for quartz tube fouling, will vary from site to site.

In such conditions, as previously discussed, it clearly appears that management of chlorination or UV disinfection systems on an individual basis is too costly (maintenance requirements varying from site to site) to allow a safe disinfection performance in all conditions in the field. In view of these limitations, a need remains for a low maintenance disinfection system suitable for an individual wastewater treatment system. This paper presents the solution developed by Premier Tech Environment (PTE) that meets this need.

System description

The passive disinfection system developed is essentially a horizontal sand filter (HSF), which is fed vertically by the advanced secondary effluent produced by the peat based Ecoflo® Biofilter.

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The biofilter effluent is uniformly applied on the first section of the horizontal sand filter with low pressure distribution system or by using an open bottom Ecoflo® module. This inlet zone consists of a 20 cm (8 inch) layer of gravel over a 30 cm (12 inch) layer of sand on a surface varying between 7 to 9 m² (75 to 100 ft²) according to design flow. As illustrated in Fig.1, the effluent is percolating vertically through the gravel and sand layers to flow horizontally near the bottom of the filter. In this manner, the feeding section is always maintained well drained.

The horizontal filter consists of a 30 cm (12 inch) layer of filtration sand (D_{10} = 0.2 to 0.4, C_u = 2.5 to 4) spanning on a length of 10 m (33 ft) with a slope of 4 to 5 %. The filter width varies from 4.5 to 7.5 m (15 to 25 ft), according to the different system sizes (design flow). The horizontal filter operates in aerobic conditions and air renewal is provided by interconnection of gravel layer over the sand with Ecoflo® Biofilter aeration means. At the downstream extremity of the horizontal filter, a collection and sampling device is provided. The treated effluent is collected by a perforated pipe located in a gravel trench surrounded by a geotextile followed by a sampling port and a diffusion pipe for final dispersion.

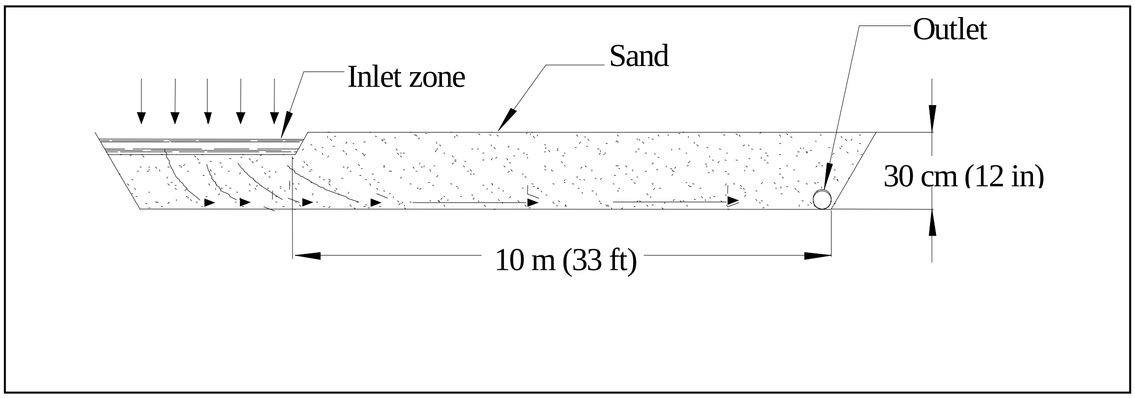

Fig. 1. The Cross Section of the Horizontal Sand Filter

Material and methods

The HSF system is tested at full scale in two different sites. The first system (Site 1) was installed in September 2003 at the Ontario Rural Wastewater Centre (ORWC) located at Alfred campus of the University of Guelph. The experimental system consists of a 3,600 L (950 gallon) septic tank with a Premier Tech Effluent Filter EFT-080 and an Ecoflo® Biofilter ST-500 (open bottom module). Fig. 2 and 3 present a plan and profile views of the system tested. The base of the biofilter consists of a 30 cm (12 inch) layer of 2-4 mm sand and a 15 cm (6 inch) layer of 6-10 mm gravel. The tipping bucket on top of the peat layer delivers effluent equally to the two halves of the biofilter. Effluent beneath the south half of the biofilter percolates through the sand and gravel base and directly into the ground. An impermeable liner was installed beneath the sand and gravel base of the north half of the biofilter and continues for 33 ft under the horizontal sand filter. Therefore, all effluent from the north half of the biofilter percolates through the peat layer, through the sand and gravel base, and onto the 6 mil PVC impermeable liner and then flows horizontally through the 2.4 wide x 10 m long (8 ft x 33 ft) horizontal filter. The liner is sloped at 4-5% to direct flow down the filter and is raised on three sides to contain the effluent. The effluent flows into the ground at the end of the horizontal filter. The system is fully raised to avoid any influence from groundwater. Three sampling wells are located in the horizontal filter as illustrated in Fig. 2. Well 1 is at the beginning of the mantle (next to the biofilter), Well 2 is located 5 m (16.5 ft) from the biofilter (mid span) and Well 3 is located 10 m (33 ft) from the biofilter (outlet). Each sampling well consists of a 50 mm (2 inch) perforated ABS pipe laid in a trough perpendicular to the length of the horizontal filter and sloped toward the sampling well. The trough was filled with gravel and covered with geotextile. Each PVC pipe was passed through the liner and into a sampling well. A valve was installed on each pipe for sample collection. Three pieziometers were installed in the sample well outlet pipes in order to monitor standing water levels in the mantle. The pieziometers are comprised of 12.5 mm (½ inch) outer diameter PVC standpipes.

The second full scale system (Site 2) is in operation since May 2005 at a single dwelling home located at Malartic (Abitibi) in the north part of the province of Quebec (Canada). The system consists of an 3,200 L (850 gallon) septic tank with a Premier Tech Effluent Filter EFT-080 and an Ecoflo® Biofilter ST-650 (open bottom module). The base of the biofilter consists of a 30 cm (12 inch) layer of 2-4 mm sand and a 15 cm (6 inch) layer of 6-10 mm gravel. An impermeable liner was installed beneath the sand and gravel base of the biofilter and continues for 10 m (33 ft) under the HSF. Therefore, all effluent of the biofilter percolates through the peat layer, through the sand and gravel base, and onto the impermeable liner and then flows horizontally through the 5.5 m wide x 10 m long (18 ft x 33 ft) horizontal filter. The liner is sloped at 4-5% to direct flow down the filter and is raised on three sides to contain the effluent. The effluent flows into the ditch at the end of the horizontal filter. The system is fully raised to avoid any influence from groundwater. Three sampling wells, similar to them described previously for Site 1, are located in the horizontal filter at 5, 7.5 and 10 m (16.5, 25 and 33 ft) from the biofilter.

Wastewater sources and dosing regime

At Site 1, the septic tank is dosed with wastewater from the Alfred municipal sewer line using a sewage pump. The system is dosed in a manner to represent typical residential usage and follows the dosing regime defined in the National Sanitation Foundation (NSF) Standard 40 Protocol:

- 35 % between 6:00-9:00
- 25 % between 11:00-14:00
- 40 % between 17:00-20:00

The flow rates were calibrated using measured tips from the Ecoflo® tipping bucket. The system was evaluated at both 900 and 1,200 L (240 and 320 gpd) dosing rates.

At Site 2, the system received the wastewater produced by the house for a mean actual flow rate of 750 L (200 gpd) evaluated with a flow meter installed on the drinking water supply line.

Results and discussion

The objective of the experiments done at the two sites is to evaluate pathogen attenuation within the horizontal sand filter system receiving advanced secondary treated effluent. The next paragraphs describe the effluent quality over 33 months of system operation at site 1 (ORWC University of Guelph in Ontario) and over 18 months at site 2 (Malartic, Quebec). Data collection included bacteria (fecal coliforms), organic matter ($CBOD_5$) and total suspended solids (TSS) at different sampling locations: influent (septic tank effluent) and sample wells located at different distances into the mantle.

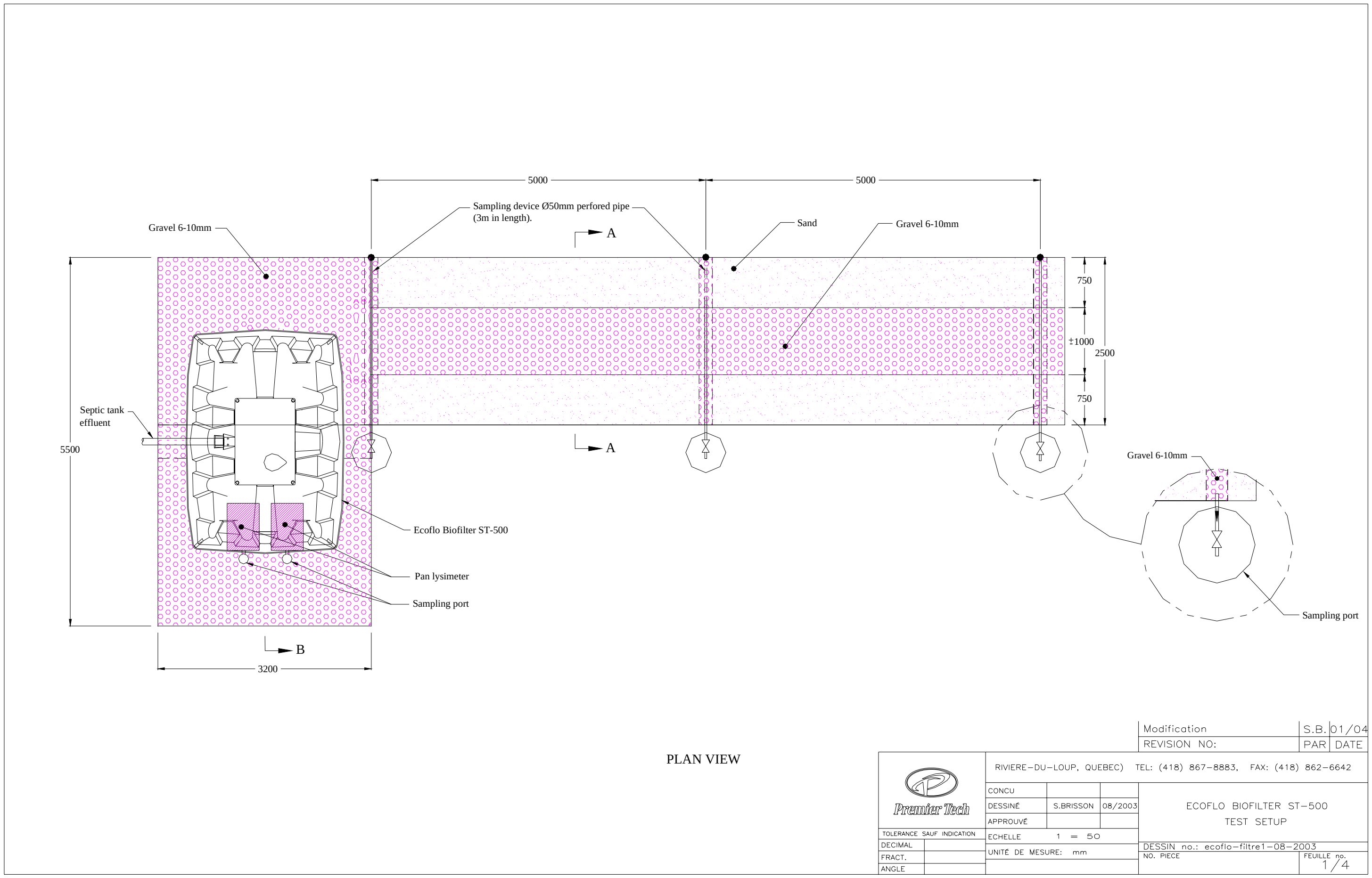

Fig. 2. Plan View of the Horizontal Sand Filter tested at ORWC (Site 1)

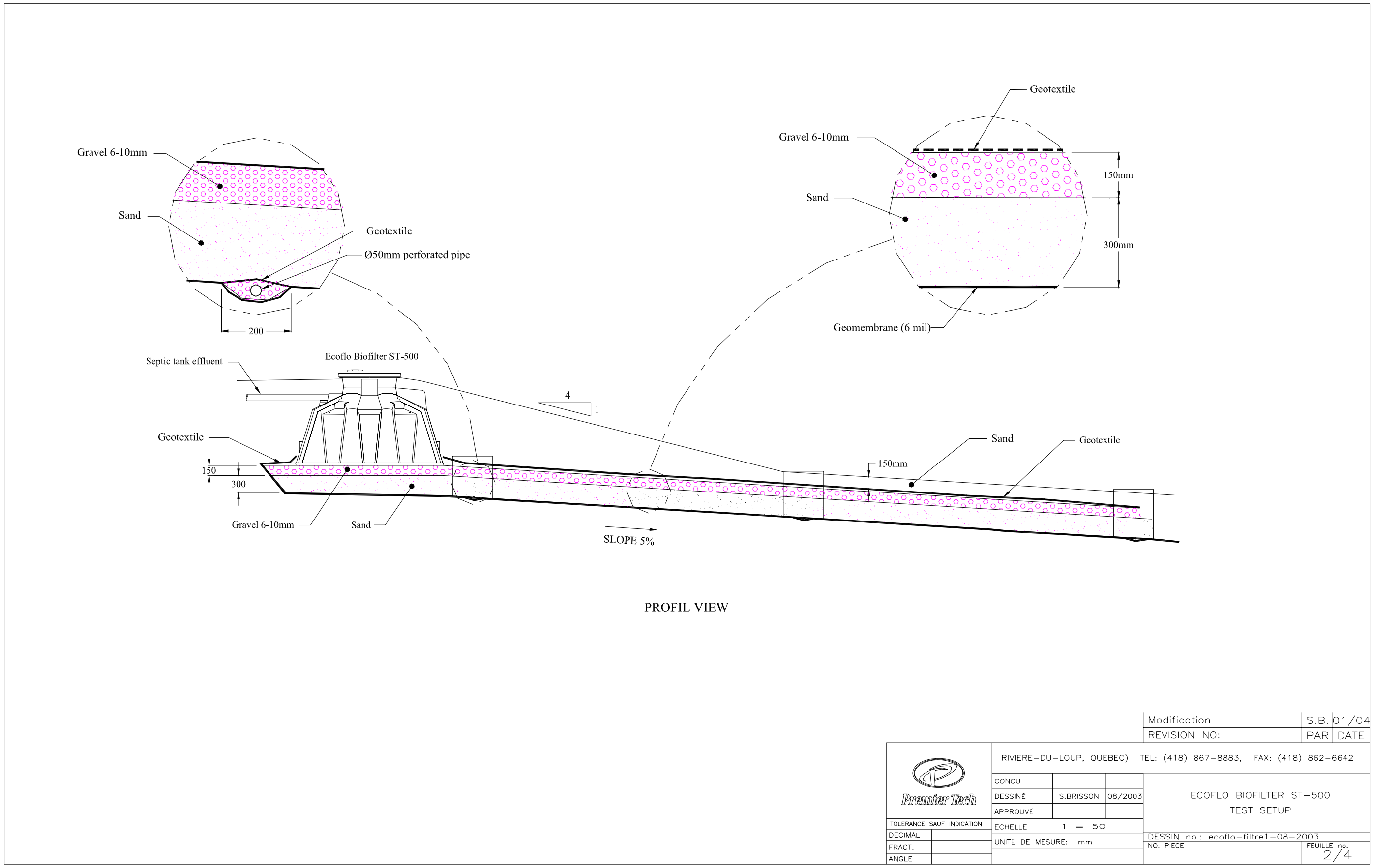

Fig. 3. Profile View of the Horizontal Sand Filter tested at ORWC (Site 1)

Results obtained at Site 1

The characteristics of the septic tank effluent at Site 1 are presented in Table 1. The wastewater composition at this site corresponds to typical domestic wastewater for single dwelling as reported by Rothe and al. (2006). It is important to note that the wastewater temperature at this site was particularly cold in winter with values at septic tank effluent ranging from 1.2 and 5.5 °C (34 to 42 °F) in January and February. Globally, the septic tank effluent temperature during the 33 months of testing varied between 1.2 to 22 ˚C (34 to 72 ˚F).

Table 1. Septic tank effluent characteristics at Site 1

Parameter	Units	Average	Median	Min.	Max.
$CBOD_5$	mg/L	167*	154	44	363
TSS	mg/L	59*	53	26	166
Fecal coliforms	counts/100 mL	1.3×10^6 **	1.4×10^6	4.7×10^4	9.9×10^6

* Average of 67 samples
** Geometric average of 117 samples

To evaluate the performance of the HSF, samples were collected at three locations (Wells 1, 2 and 3) corresponding to the inlet, mid span and outlet of the HSF. Tables 2, 3 and 4 present the results obtained respectively at these three sampling points.

The biofilter and the inlet zone of the HSF effectively reduced median $CBOD_5$ concentrations from 154 to 2 mg/L and mean $CBOD_5$ concentrations from 167 to 4 mg/L. $CBOD_5$ concentrations in the horizontal sand filter were reduced from a median of 2 mg/L and a mean of 4 at filter inlet (Well 1) to below the detection limit value of 1 mg/L at mid span and outlet of the filter (Wells 2 and 3). The biofilter and the inlet zone of the HSF also reduced median TSS concentrations from 53 to 7 mg/L and mean TSS concentrations from 59 to 12 mg/L. TSS results in the horizontal filter varied considerably, with median values of 7, 4 and 15 mg/L from inlet to outlet (Wells 1, 2 and 3, respectively) and corresponding mean values of 12, 8 and 23 mg/L. TSS results for the HSF are indicative of soil particles washing into the sampling ports and are not representative of organic matter migrating in the filter. These is particularly evident from the elevated Well 3 median TSS concentration of 15 mg/L and mean concentration of 23 mg/L, where $CBOD_5$ is consistently below the detection limit of 1 mg/L. It was often observed that soil particles were flushed into the sample bucket when the valve was first opened. Improvements to the sampling methodology could address the high TSS concentrations observed in the well samples. The biofilter and the inlet zone of the HSF performed very well at reducing fecal coliform counts. It removed 2.7 logs of fecal coliform, reducing counts from 1.3×10^6 to 2.7×10^3 counts/100mL. The first 5 m (16.5 ft) of the horizontal sand filter removed a further 1.7 logs of fecal coliforms, reducing counts to 56 counts/100mL (Well 2 at mid span of the filter) and the second 5 m (16.5 ft) of horizontal filter, between Wells 2 and 3, removed a final 0.5 log of fecal coliforms, reducing fecal coliforms from 56 to 18 counts/100mL. These results indicate that the combined biofilter and horizontal sand filter are achieving complete or near complete removal of fecal coliforms (4.9 logs reduction). Furthermore, we note that the performance is much less variable at the HSF outlet (fecal varying from 10 to 390 counts/100 mL) compared to results obtained at mid span of the horizontal filter (fecal between 10 and 43,000 counts/100 mL). It clearly appears that a 5 m (16.5 ft) long HSF is not sufficient to assure stable performance with 28 of the 108 results exceeding 200 counts/100 mL (usual criteria for surface discharge) compared to 6 of the 95 fecal results below 200 counts/100 mL at the HSF outlet (6.3% of the results).

Table 2. Effluent characteristics at the horizontal sand filter inlet (Well 1)

Parameter	Units	Average	Median	Min.	Max.
$CBOD_5$	mg/L	4*	2	< 1	23
TSS	mg/L	12*	7	< 2	35
Fecal coliforms	counts/100 mL	2,660 **	1,700	100	1.9×10^5

* Average of 61 samples
** Geometric average of 115 samples

Table 3. Effluent characteristics at mid span of the horizontal sand filter (Well 2)

Parameter	Units	Average	Median	Min.	Max.
$CBOD_5$	mg/L	1*	1	< 1	2
TSS	mg/L	8*	4	< 2	37
Fecal coliforms	counts/100 mL	56 **	12	< 10	4.3×10^4

* Average of 41 samples
** Geometric average of 108 samples

Table 4. Effluent characteristics at horizontal sand filter outlet (Well 3)

Parameter	Units	Average	Median	Min.	Max.
$CBOD_5$	mg/L	1*	1	< 1	1
TSS	mg/L	23*	15	< 2	35
Fecal coliforms	counts/100 mL	18 **	10	< 10	390

* Average of 41 samples
** Geometric average of 95 samples. Values that are less than detection limit were reported as the limit.

Table 5 compares the effect of dosing rate (900 versus 1,200 L/d or 240 versus 320 gpd) on fecal coliform numbers using a single factor ANOVA (P=0.05). There is no significant difference in geometric mean fecal coliform counts from increasing the dosing rate at STE. We note significant difference in fecal coliform counts at Well 3 (P=0.00), with increasing counts from 13 to 30 counts/100mL with increased dosing rates from 900 to 1,200 L/d. However, these values remain very low compared to usual surface discharge criteria of 200 counts/100 mL. It is also important to note that the results at Well 3 are strongly impacted by reporting of values below the detection limit of 10 counts/100mL as limit.

Table 5. Effect of dosing rate on fecal coliform results

Sample Point	Geometric Mean (counts/100mL)	P-value (P=0.05)
STE – 900 L/d	1.22×10^6	0.49
STE – 1,200 L/d	1.44×10^6	
Well 3 – 900 L/d	1.29×10^1	0.00
Well 3 -1,200 L/d	2.96×10^1	

Table 6 describes the effect of temperature (T =15±5°C versus T=4±2°C) on fecal coliform removal in the biofilter and the HSF using a single factor ANOVA (P=0.05). Dosing rate remained at 900 L/d (240 gpd) during this period.

Table 6. Effect of temperature on fecal coliform results (Q=900 L/d)

Sample Point	Geometric Mean (counts/100mL)	P-value (P=0.05)
STE (15±5°C)	1.09×10^6	0.14
STE (4±2°C)	1.67×10^6	
Well 3 (15±5°C)	1.42×10^1	0.60
Well 3 (4±2°C)	1.70×10^1	

No significant difference due to temperature was observed in STE fecal coliform results (P=0.14) and Well 3 values (P=0.6), with geometric mean fecal coliform numbers of 14 and 17 counts/100mL at high and low temperatures respectively. These results indicate that the biofilter and the HSF are effective at removing fecal coliforms to near detection limit values of 17 counts/100mL at extremely cold operating temperature of T=4±2°C.

Finally, examination of the horizontal filter after 30 months of testing revealed that the filtering sand was still in very good condition with no clogging mat formation. We also observed that 8 of the 12 inches of sand layer contributed to the filter effectiveness corresponding to the capillary fringe. Presence of microorganisms in the 8 inch wetted sand layer confirmed the biological activity. Based on these observations, we expect the horizontal sand filter to provide long-term performance with little maintenance.

Results obtained at Site 2

The characteristics of septic tank effluent at site 2 are presented in Table 7 and are representative of typical domestic wastewater for single dwelling reported by Rothe and al., (2006). The septic tank effluent temperature during the 18 months of testing varied between 1.5 to 16 ˚C (35 to 61 ˚F).

Table 7. Septic tank effluent characteristics at Site 2

Parameter	Units	Average	Median	Min.	Max.
$CBOD_5$	mg/L	223*	182	139	472
TSS	mg/L	69*	74	49	88
Fecal coliforms	counts/100 mL	4.6×10^6 **	4.8×10^6	3.3×10^4	7.3×10^6

* Average of 10 samples
** Geometric average of 6 samples

To evaluate the performance of the combination of Ecoflo® Biofilter and HSF, samples were mainly collected at the outlet of the HSF and only these results are presented in Table 8. The biofilter and the HSF effectively reduced median $CBOD_5$ concentrations from 182 to 1 mg/L and mean $CBOD_5$ concentrations from 223 to 2 mg/L. It also reduced TSS concentrations from 74 to 3 mg/L and mean TSS concentrations from 69 to 5 mg/L. The biofilter and the HSF performed very well at reducing fecal coliforms from 4.6×10^6 to 11 counts/100mL (5.6 logs reduction). All of the results obtained at Site 2 are comparable to values measured at Site 1 excepted for TSS. As discussed previously, the high TSS concentrations observed at Site 1 were related to the sampling method used causing soil particles washing in the sample by valve opening. At Site 2, sampling of HSF effluent was done at discharge pipe where effluent flows freely, confirming the TSS performance of the system with median and mean values of 3 and 5 mg/L respectively. Also, as observed at Site 1, the fecal coliform counts at the HSF effluent is very stable with only 3 of the 52 values exceeding 200 counts/100 mL (5.8% of the results).

Table 8. Effluent characteristics at the outlet (10 m) of the horizontal sand filter (Site 2)

Parameter	Units	Average	Median	Min.	Max.
$CBOD_5$	mg/L	2*	1	< 1	5
TSS	mg/L	5*	3	1	19
Fecal coliforms	counts/100 mL	11 **	12	< 1	500

* Average of 17 samples
** Geometric average of 52 samples

Conclusions

The combination of the Ecoflo® Biofilter and the HSF achieves complete or near complete removal of fecal coliforms in all conditions tested including very cold wastewater temperature. This performance is mainly related to the high quality effluent produced by the Ecoflo® Biofilter located in front of the horizontal sand filter and by the very good water and air circulation in the HSF. The physical barrier provided by the Ecoflo® filtering media results in stable performance even during peak flow conditions, that is avoiding application of peak load in TSS and $CBOD_5$ on the HSF which could reduce the life span of the horizontal filter. The use of this passive disinfection process with treatment systems not incorporating a physical barrier, such as fixed-film or other aerobic treatment units, is not recommended due to the effluent quality variations inherent to these systems during peak flow and in conditions of discontinued flow rate (ex: cottage).

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