COUPLING LABORATORY EXPERIMENTS WITH IN-SITU INVESTIGATIONS FOR THE RECOGNITION OF A NEW ON-SITE SANITATION TECHNIQUE CASE OF THE OPTIMIZED VERTICAL SAND FILTER

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ABSTRACT

Traditional sand filtration systems are robust on-site sanitation technologies. Compared with prefabricated systems (small treatment plants or compact filters), they have the advantage of requiring limited maintenance. However, they also present the drawbacks of a large land footprint and a high demand for river sand.

A national research program was established (over a period of approximately four years) to enable the optimization of this type of technology. This program, supported and funded by the French public authorities, led to the definition of a new design approach, which was validated through two full-scale systems installed in a laboratory under controlled conditions. In parallel with this experimental work, around ten systems were implemented at private households in order to characterize the behavior of installers, operators, and property owners.

This scientific work resulted in the production of an operational installation guide describing system design, recommended materials, and implementation, operation, and maintenance procedures, as well as a proposal for inclusion in national regulations.

The objective of this paper is to share the scientific and technical approaches used, the results obtained, and the lessons learned with respect to the national recognition process of a new sanitation technique.

To highlight the research on the optimized sand filter, which is the focus of the present paper, it was considered useful to first present the performance achieved by conventional vertical sand filters, as observed in both full-scale experimental platforms and real-world installations.

INTRODUCTION

1) Laboratory-based research on vertical sand filter

In on-site wastewater treatment plants, domestic wastewater is pre-treated by septic tank and treated by soil infiltration or sand filtration systems, with unsaturated flow conditions. In France, 15 million people are concerned by this kind of plants. This process occurs in the presence of air and water and can remove carbon, nitrogen, and suspended solids efficiently (PELL and NYBERG, 1989 a). The purification of septic wastewater involves physical, chemical and biological mechanisms. Research on unsaturated flow in sand filters had

permitted the development of one hydrodynamic model including plug flow axial dispersion with "initial and final states of a closed system (LAKEL and al, 1998; MAMAN MOUSBAHOU and al., 2006). Other works have focused on influence of the physical and mechanical characteristics of sands on the hydraulic and biological behaviors of sand filters (ROLLAND L and al, 2009). Moreover, some studies have focused on the transport and fate of bacteria in porous media (GERBA and BITTON, 1984; CHABAUD and al, 2006; CHABAUD 2008) and disinfection capability (SELAS et al, 2003).

Furthermore, the use of crushed quarry sand as an alternative to river sand, within a sustainable development perspective, was already considered promising by several researchers in the early 2000s [LIÉNARD et al., 2000]. Subsequent studies made it possible to identify the effects of crushed sands on the treatment biofilm developing within vertical sand filters [WANG and al., 2015; WANG and al., 2019]. A major scientific contribution of Chen WANG's research was the demonstration that filters media selection directly impacts biofilm architecture, biomass accumulation, and EPS production, thereby governing treatment efficiency, especially regarding nitrogen removal. The observed differences between filter materials were found to be primarily related to their influence on biological microenvironments rather than to their intrinsic physical properties alone.

2) Full-scale experimental platform under controlled real-world conditions

CSTB conducted a 38-month full-scale investigation on behalf of VEOLIA to evaluate the performance of eight onsite wastewater treatment systems, including a vertical sand filter. The latter consisted of a 25 m² filtration area containing a 70 cm-deep silica sand bed. Primary treatment was achieved through a 3 m³ septic tank designed for five population equivalents (PE). A hydraulic loading rate of 150 $L \cdot PE^{-1} \cdot d^{-1}$ was applied throughout the study. The loading protocol included 27 operating phases encompassing underloading, nominal loading, and overload conditions, with hydraulic and organic loads reaching up to 200% of the design value

The sand filter system was fed continuously for 38 months with the raw wastewater. Table 1 gives the average concentrations for raw wastewater throughout the study.

Table1: Characteristics of raw wastewater issued from the public sewerage system and supplying the CSTB platform (analysis performed on samples average 24 h) throughout the program.

	TSS (mg /L)	Cod (mg O_2/L)	BOD_5 (mgO_2/L)	NTK (mg N/L)
Average	337	670	289	68
Standard deviation	300	435	200	17

The mean concentrations of microbial germs are listed in thetables 2 and 3. These microbiological characteristics are conventionally encountered in domestic wastewater.

Table 2: Microbiological parameters in raw wasterwater

	Escherichia Coli	Intestinal enterococci	Coliform Bactéria
	UFC.100m/L	UFC.100m/L	UFC.m/L
Average	8,7E+06	4,3E+06	1,9E+07
Standard deviation	9,0E+06	4,2E+06	2,0E+07

Table 3: Microbiological parameters in raw wasterwater

	Presumed Enterococci	Enterovirus	Salmonella	Helminthes eggs
	UFC100m/L	UFP.10/L	UFC.100m/L	n.1 /L
Average	3,3E+06	2,2E+05	2,3E+02	1,6E+02
Standard deviation	3,2E+06	6,7E+05	1,6E+02	1,8E+02

At the system discharge point, the main characteristics of the chemical pollutants for all programm are given in Table 4.

Table 4: Average characteristics of effluent.

	TSS (mg/L)	COD (mg O_2/L)	BOD_5 (mgO_2/L)	NTK (mg N/L)	$N\text{-}NH_4^+$ (mg N/L)	$N\text{-}NO_3^-$ (mg N/L)	$N\text{-}NO_2^-$ (mg N/L)	N-NO3- + N-NO2- (mg N/L)	P-total (mg P/L)
Average	6	43	4	10	12	38	1	39	4
Standard déviation	6	22	2	9	10	15	2	15	2

Throughout the program, the average concentration for COD, BOD_5 and TSS total are equal to 43 mg O_2.L-1: 4 mg O_2.L-1 and 6 mg/L. For nitrogen, we obtain the following average values:

- 12 mg-N/L for the ammonium ion,
- 38 mgN/L for NO_X ions (nitrite and nitrate ions).

COD/DBO_5 ratio is around 10. This ratio indicates that the residual material in the form of MES is very little or biodegradable mineral.

Mean microbiological characteristics of the effluent are given by tables 6 and 7.

Table 5: Average microbiological characteristics of sand filter effluent.

	Escherichia Coli (UFC.100m/L)	Intestinal Entérococci intestinaux (UFC.100m/L)	Coliform Bacteria (UFC.100m/L)
Average	7,1E+04	1,7E+04	3,9E+05
Standard deviation	1,2E+05	1,7E+04	9,6E+05

Table 6: Average microbiological characteristics of sand filter effluent.

	Thermotolerant coliform suspected (UFC.100m/L)	Enterovirus (UFP.10/L)	Salmonella	Helminthe eggs (n.1/L)
Average	1,7E+04	0,0E+00	3,8E+01	0
Standard deviation	2,1E+04	0,0E+00	6,1E+01	0

In summary, the sand filter showed very good performance. This work was conducted to determine the performance of one treatment system (septic tank combined with a vertical sand filter) over a period of 38 months and with the continuous feed. The studied installation was sized to treat 5 people. It is found that this system has a very high strength as shown by the analysis of the impact of variations in hydraulic and organic loads applied. This efficiency is about the parameters of carbon and nitrogen pollution but also on microbial parameters.

3) Field monitoring of the systems

The French authorities initiated a nationwide assessment of onsite wastewater treatment systems. Field monitoring carried out from 2011 to 2016 by the National Public Group [OLIVIER et al., 2019] provided the following average effluent characteristics:

- BOD_5 : 6 mgO_2/L
- COD : 48 mg O_2/L
- TSS :13 mg/L
- TKN : 31 N-mg/L
- Ammonium nitrogen : 27 N-mg/L
- Nitrate nitrogen : 51 N-mg/L
- Total phosphorus : 6.5 mgP/L
- Microbiological (indicator microorganisms): 2 to 3 log unit reductions

Previously, VIGNOLES C, 2015 conducted a separate evaluation programme between 2008 and 2014 on the performance of available onsite treatment technologies. The results showed that :

- 69% of TSS values were below 30 mg/L (french regulatory limit)
- 96% of BOD_5 values were below 35 mg/L ((french regulatory limit)
- 80% of COD values were below 125 mg/L (European regulatory limit for COD)

These findings provided the scientific basis and served as a precursor to the work presented in this paper.

MATERIALS AND METHODS

1) General Principle of the Study

Following the very positive performance results observed for vertical sand filters designed on the basis of 3 m² per inhabitant and a 70 cm filter bed depth, as well as the potential use of crushed sand demonstrated through R&D studies, it was decided, in agreement with the French ministries responsible for onsite (decentralized) wastewater treatment, to carry out experimental validation programs, provided that:

- the ANSES protocol (French Agency for Food, Environmental and Occupational Health & Safety) is applied for platform testing (see website; WESTERBERG E., 2009),
- in situ monitoring is conducted on full-scale installations implemented after the platform tests and in accordance with installation specifications developed collaboratively by all stakeholders.

At the conclusion of the experimental phase, and depending on the results obtained, the following actions are envisaged:

- incorporation of this treatment technology into the French regulatory framework;
- preparation of professional guide governing the installation, operation, and maintenance of the system by construction and maintenance companies. The establishment of this professional guide will enable installation contractors to obtain insurance coverage for the implementation of this type of system.

2) Description of the systems studied

On the CSTB test platform, there are several septic tanks (with different capacities) installed in parallel to produce septic effluent (corresponding to a 5-day hydraulic retention time, which generally reflects the retention time of septic tanks used in residential homes). This septic effluent is then conveyed by a pumping system to two filtration systems installed in parallel.

Each filtration system is equipped with a dosing device (intermittent distribution system). Each filter (figure 1) has a surface area of 15 m², corresponding to the treatment requirements of a five-person household. The filter media depth is 50 cm.

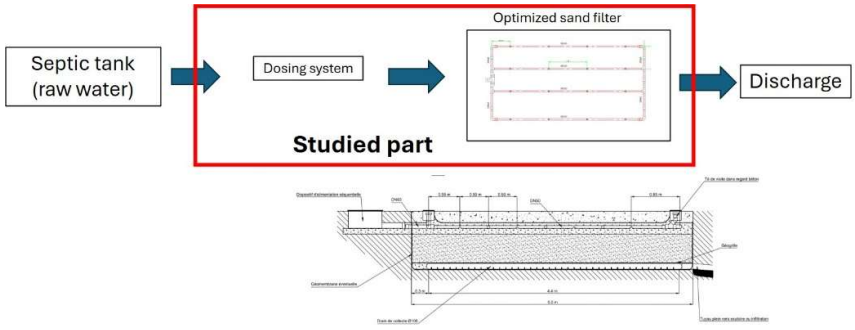


Figure 1: Presentation of the two filtration systems under study.

The two vertical sand filters consist of the following layers (from top to bottom):

- a 20 cm layer of topsoil,
- a geotextile sheet with characteristics identical to those used in conventional sand filter systems,
- a distribution network with perforations oriented downwards, embedded in a gravel layer. The design was adapted to improve the distribution of septic effluent;
- a 50 cm sand layer *,
- a geogrid with characteristics identical to those used in conventional sand filter systems;
- a collection network (DN 100 mm), surrounded by a gravel layer in accordance with the French construction standards for onsite wastewater treatment systems (DTU 64.1 standard, *"Onsite Wastewater Treatment Systems"*),
- a sealing system consisting of a geomembrane and a wall penetration collar (pipe boot) to ensure watertightness at the connection with the discharge pipe.

* The first filter is composed of siliceous sand with a D10 of 0.3 mm and a D60 of 1.3 mm. The second filter is composed of crushed sand with a D10 of 0.65 mm and a D60 of 2.9 mm. The percentage of fines (particle size < 63 µm) is less than 3% for both sands. Note that the sand is sourced from a non-calcareous rock quarry.

Each filter is supplied by a commercially available dosing device (industrial product). The distribution network is designed to be completely filled during each hydraulic dosing event. It should be noted that these products are not subject to any certification process, which has raised questions regarding the reliability and robustness of the manufacturers' performance claims.

3) Full-scale platform experimentation under "controlled real conditions"

This experimental study was conducted at CSTB over a period of 48 weeks of operation between 2020 and 2021. It was subsequently extended until 2024, representing an additional 1,000 days of operation.

The septic tank was fed with raw wastewater collected from a public sewer network, under the operating conditions described below.

Feeding conditions

- Daily hydraulic profile:

The plant is fed with domestic wastewater according to the following daily hydraulic profile described in table 7:

Table 7: Daily hydraulic profile used for the tests plateform.

Period		Percentage of the total daily volume
1	3 hours	30 %
2	3 hours	15 %
3	6 hours	0
4	2 hours	40 %
5	3 hours	15 %
6	7 hours	0
TOTAL	24 hours	100%

- Peak feeding:

To simulate hydraulic overloads, in addition to the daily flow during the nominal load sequences, a peak feeding corresponding to a volume of effluent will be injected over 3 minutes, at the start of period 4 (40 % of the daily flow). The number of peak feedings applied to the plant during the test will be 2x 200 litres.

b) Effluent characteristics

For information, the plant will be fed with the wastewater of the CSTB Nantes test platform. The average characteristics of this domestic wastewater are indicated in the table 8:

Table 8 : Characteristics of the wastewater used for the tests.

	Inlet	
	min	max
COD (mgO2/L)	600	1000
BOD5 (mgO2/L)	300	500
TSS (mg/L)	300	700
TKN (mg-N/L)	50	100
NH4+ (mg-N/L)	40	80
Total phosphorus (mg-P/L)	8	20

c) Sequence programme

The hydraulic loads are applied to the plant according to the following programme (table 9).

Table 10: Sequence programme

Sequence	Feeding conditions	Daily hydraulic load applied (percentage of the nominal load)	Duration (weeks)	Number of "inlet and outlet" pollution assessments
1	BIOMASS ESTABLISHMENT	100 %	4	-
2	NOMINAL LOAD	100 %	6	6
3	UNDER-LOAD	50 %	2	2
4	NOMINAL LOAD - POWER FAILURE (2)	100 %	6	6
5	LOW-OCCUPANCY CONSTRAINT - EFFLUENT FEED STOPPAGE	0 % (no feeding)	2	2
6	NOMINAL LOAD	100 %	6	6
7	OVERLOAD (1)	150 %	2	2
8	NOMINAL LOAD - POWER FAILURE (2)	100 %	6	6
9	UNDER-LOAD	50 %	2	2
10	NOMINAL LOAD	100 %	6	6
11	OVERLOAD 200%	200%	4	4
12	NON-OCCUPANCY STRESS	0 from day 1 to day 5 100 % on days 6 and 7	2	2
TOTAL			48	44

The installation is fed continuously without any interruption other than those indicated in Table (sequences 5 and 12).

d) Analyses

The analyses are carried out on samples representative of an average 24 h flow* at CSTB or in a subcontracted laboratory. A single measurement point is specific. Each sample will be the subject of a particular analytical monitoring.

Table 10: Parameters to be analysed on the samples * Analyses carried out by accredited laboratory (ISO 17065 standard).

Parameters	Raw water sample	Septic effluent samples	Outlet sand filters
Minimum number of samples	44	44	44

4) In-Situ Monitoring of the Installations

Following the installation of 12 systems, in-situ monitoring was conducted from 11 January 2022 to 8 April 2024. Two sites were excluded from the study due to poor filter watertightness, which resulted in either no effluent discharge or groundwater infiltration into the drainage system. Of the remaining 10 sites, two additional sites were excluded because of inappropriate sand selection by the installation contractor, specifically due to unsuitable particle size distributions (*sand not compliant with established construction standards*). A total of 92 analyses of filter effluents were carried out by ISO/IEC 17025 COFRAC-accredited laboratories. The field monitoring program was conducted across three French departments: Loire-Atlantique, Dordogne, and Charentes.

Table 11: Characteristics of the Sites Studied.

Country	Sites analyzed	Rounded sand (sillicious)*	Crushed sand	Hydraulic dosing system
Loire Atlantique	4	2	2	4 flush dosing systems
Dordogne	2	2	0	2 pumps
Charentes	2	2	0	1 pump, 1 flush dosing system

* : From river

RESULTS

Following approval of the installation specifications proposed by CSTB by the study's Technical Committee, the two filtration systems were installed on the CSTB test platform.

The systems were fed with wastewater throughout the 48-week testing period defined in the ANSES protocol. The monitoring results are presented in tables 12 and 13, including data collected during the additional 1,000 days of operation.

Table 12: Characteristics of the Raw Wastewate used for plate-form tests.

		Carbon pollutants		Nitrogen pollutants		Phosphorus
Parameter	TSS (mg/L)	COD ($mg/O_2/L$)	BOD_5 ($mg/O_2/L$)	KN (N-mg/L)	MH4+ (N-mg/L)	Pt (P-mg/L)
Mean	399	814	303	83	58	10
Standard déviation	115	203	79	18	15	2
Number of samples 84						

Table 13: Characteristics of the Treated Wastewater at the Outlet of the Two Filters. *Summary of the Performance Achieved on the Test Platform (52 Twenty-Four-Hour Composite Samples) Between 9 October 2020 and 2 July 2024, Including the Additional 1,000-Day Monitoring Period.*

		TSS (mg/L)	COD ($mg/O_2/L$)	BOD_5 ($mg/O_2/L$)	NTK (N-mg/L)	MH4+ (N-mg/L)
Filter 1	Mean (mg/L)	6	47	4,5	19	16
	Standard deviation	3,2	10,3	1,9	10,3	8,8
Filter 2	Mean (mg/L)	5,5	47	3	18,5	16
	Standard deviation	2,6	11,5	2,3	10,6	9,1
		Number of samples : 84				

Note : Some operational issues were observed on the test platform with the dosing device used. However, complete system failures were not encountered, unlike the situations observed later in field installations when flow rates were very low. It should be noted that gravity-fed wastewater loading was simulated by introducing 25 litres intermittent dosing batches upstream of the septic tank.

1) Installation of the systems at Private residences and in-situ monitoring

Observation of the construction work carried out on the CSTB test platform by the contractor made it possible to refine the initial installation specifications before implementation at private residences. These works were reviewed and approved by the study's Technical Committee. The first field installations also provided valuable feedback, allowing the specifications to be further adjusted before subsequent installations. In areas where the inspection authorities provided appropriate guidance and training, the systems were installed correctly. Construction was carried out using standard products and materials readily available from local suppliers.

Through the implementation of this new construction approach, the following observations were made in the field :

- Installation is faster than for a conventional vertical sand filter due to the smaller excavation required and the elimination of two sand transport trips.
- Construction of the raw wastewater collection system is similar to that of a conventional vertical sand filter, but without the recirculation inspection chamber.
- Fabricating the distribution manifold in a workshop prior to installation helps ensure its final levelness and alignment.
- The lack of prefabricated sampling chambers specifically designed for this type of vertical filter creates difficulties, resulting in chambers that are too narrow and have an insufficient drop height.
- The use of prefabricated kits could simplify on-site installation.
- Some poorly designed septic tanks may allow grease and floating materials to enter the dosing device.
- Operational issues were observed with the hydraulic dosing device, particularly a failure to trigger when wastewater flows from the house are very low.
- Adjusting the storage volume (operating water level fluctuation) within the pumping chamber can be somewhat challenging.
- Building material suppliers generally have limited knowledge of the specific requirements and characteristics of these systems.

5) Results of the in-situ monitoring of the installations

Malfunctions of the hydraulic dosing devices were observed on certain installations, resulting in performance levels that did not meet the expected criteria. Replacement of the defective dosing devices restored the systems' performance to the expected levels (Figure 2).

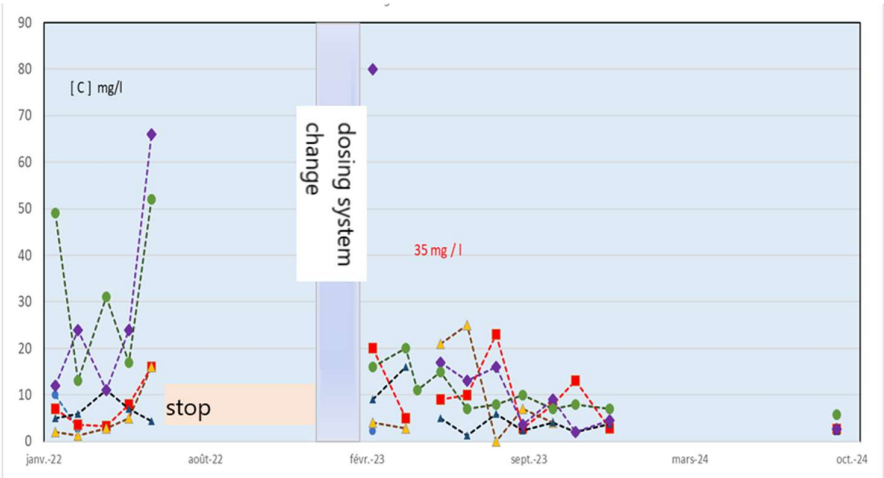


Figure 2: Example of performance improvement following the replacement of a defective hydraulic dosing device.

During investigations of the filters, it was observed that, despite the detailed installation specifications, certain construction defects were present, including excessive burial depths of the filters (up to 50 cm) and folding of the geotextile along the edges (double layers extending

up to 1 m from the perimeter). Both of these defects can restrict oxygen transfer within the filter medium and may therefore contribute to reduced treatment performance (see tables 14 and 15) of the filtration systems.

Tables 14 and 15 present :

- the average values obtained from both 24-hours composite samples and grab samples,
- the upper confidence limits of the confidence intervals established at the 90% confidence level, based on the Student's t-distribution, for both 24-hour composite samples and grab samples.

It can be observed that, despite certain construction defects, performance is excellent *(Sites 4 and 10 are excluded from the study because their sand media do not comply with good engineering practice requirements, being outside the specified particle size distribution ranges)*:

- 100% of BOD_5 values are below the regulatory limit of 35 mg/L
- 100% of TSS values are below the regulatory limit of 30 mg/L

The dissolved oxygen and redox measurements taken upstream and downstream of the filters also confirm these results. The bacteriological analyses carried out indicate a reduction in microbial populations comparable to that achieved by traditionnal vertical sand filters.

Field monitoring of these installations shows that, when the filters are installed in accordance with the specifications, their performance meets expectations (Sites 1, 2, 6, and 7).

However, the malfunction of the hydraulic flushing device, observed almost systematically on all affected sites, disrupted system operation. In response to this recurrent defect of the commercial product, six hydraulic flushing devices were replaced by modifying the number of holes in the distribution manifolds. In addition, for a series of filters, a contractor installed the filters at a depth that did not comply with the specifications (50 cm instead of 20 cm). The contractor also folded the geotextile over the filter for a length of at least 1 m on each side, covering at least half of the filter surface.

These latter two issues, combined with a severe malfunction of the tipping-bucket flushing system, explain the poor performance observed on some filters. The results are consistent between the measurements carried out on the test platform and those obtained from the full-scale installations.

Despite the excessive installation depth of the sand filters (50 to 60 cm instead of 20 cm), BOD_5 and TSS removal performance was maintained, with values remaining below regulatory thresholds. However, as is also observed with traditionnal vertical-flow sand filters, a reduction in nitrification performance was noted, as the autotrophic bacteria responsible for nitrification are more sensitive than the heterotrophic bacteria involved in organic carbon degradation.

The main difficulty encountered during this program was the malfunction of the hydraulic flushing device, which was related to the commercial product itself. This resulted in a significant deterioration of performance, with effluent quality exceeding regulatory limits.

However, performance was restored following replacement of the hydraulic flushing device. It is therefore essential to carefully define the selection criteria for products used in sequential feeding systems. This will require the development of more robust technical guides and standards for product selection.

Table 14 : Performance Observed at Five Sites (Outlet Concentrations in mg/L). *UCL: Upper confidence limit of the 90% confidence interval, calculated using Student's t-distribution*.

		TSS	COD	BOD	KN	NH4+	Comments
Site 1	Average of 24-hour samples	2,2	37,7	1,9	1,4	0,9	Feed by pompe
	Average of grab samples	2,5	47,0	1,8	2,9	1,9	Layer of topsoil : 20 cm
	Standard deviation of 24-hour samples	0,4	5,7	0,7	1,3	1,6	
	Standard deviation of grab samples	0,9	14,9	1,3	1,9	1,7	
	Upper confidence limit of the mean for 24-hour samples (90%)	3	49	3	4	4	
	Upper confidence limit of the mean for grab samples (90%)	4	75	4	6	5	Conclusion : very good running
Site 2	Average of 24-hour samples	3,5	44,6	2,9	8,2	7,7	
	Average of grab samples	2,8	54,0	3,8	7,3	6,5	Layer of topsoil : 20 cm
	Standard deviation of 24-hour samples	1,1	8,9	1,2	4,7	5,1	
	Standard deviation of grab samples	1,4	8,9	1,3	4,9	4,5	
	Upper confidence limit of the mean for 24-hour samples (90%)	6	61	5	17	17	
	Upper confidence limit of the mean for grab samples (90%)	5	71	6	17	15	Conclusion : very good performance
Site 3	Average of 24-hour samples	21,8	158,0	29,8	89,8	82,8	Faulty hydraulic flushing system not replaced
	Average of grab samples	105,7	383,7	166,7	106,7	99,3	Layer of topsoil : 10 cm
	Standard deviation of 24-hour samples	10,7	38,9	22,8	25,4	23,4	
	Standard deviation of grab samples	12,5	74,9	30,6	5,8	11,0	
	Upper confidence limit of the mean for 24-hour samples (90%)	42	232	73	138	127	
	Upper confidence limit of the mean for grab samples (90%)	129	525	224	118	120	Conclusion : Intermediate performance
Site 4	Average of 24-hour samples	31,8	156,3	32,3	83,8	77,0	Faulty hydraulic flushing system not replaced
	Average of grab samples	60,3	285,7	115,3	93,3	88,0	Layer of topsoil : 50 cm (risk of limitation of air transfert)
	Standard deviation of 24-hour samples	18,0	59,8	18,9	33,4	31,7	
	Standard deviation of grab samples	43,1	135,5	64,7	28,9	29,9	
	Upper confidence limit of the mean for 24-hour samples (90%)	66	269	68	147	137	Filter excluded from the study due to non-compliant sand grading Conclusion : bad performance
	Upper confidence limit of the mean for grab samples (90%)	142	542	238	148	144	
Site 5	Average of 24-hour samples	16,1	64,7	6,3	51,3	50,3	
	Average of grab samples	8,7	59,0	4,4	39,1	38,7	Layer of topsoil : 50 cm (risk of limitation of air transfert)
	Standard deviation of 24-hour samples	24,1	17,4	2,9	43,5	43,7	
	Standard deviation of grab samples	7,6	14,5	2,1	35,5	35,7	
	Upper confidence limit of the mean for 24-hour samples (90%)	62	98	12	134	133	
	Upper confidence limit of the mean for grab samples (90%)	23	86	8	106	106	Conclusion : good good performance

Table 15 : Performances observées sur autres 5 sites (outlet concentrations in mg/L). *UCL: Upper confidence limit of the 90% confidence interval, calculated using Student's t-distribution*.

		TSS	COD	BOD	KN	$NH4^+$	Comments
Site 6	Average of 24-hour samples	6,1	54,0	4,5	17,0	16,0	Feed by pompe
	Average of grab samples	4,2	43,8	5,4	14,6	14,4	Layer of topsoil : 20 cm (good)
	Standard deviation of 24-hour samples	3,3	9,0	1,4	24,0	24,0	
	Standard deviation of grab samples	1,8	15,8	6,0	28,7	29,2	
	Upper confidence limit of the mean for 24-hour samples (90%)	12	71	7	62	61	Geotextile partially double-layered (risk of limitation of air transfert)
	Upper confidence limit of the mean for grab samples (90%)	8	74	17	69	70	Conclusion : very good performance
Site 7	Average of 24-hour samples	12,60	70,29	9,89	47,29	44,71	Faulty flushing device – replaced during the project
	Average of grab samples	12,10	66,17	7,07	51,83	47,33	
	Standard deviation of 24-hour samples	12,60	70,29	9,89	47,29	44,71	Layer of topsoil : 60 cm (risk of limitation of air transfert)
	Standard deviation of grab samples	12,10	66,17	7,07	51,83	47,33	
	Upper confidence limit of the mean for 24-hour samples (90%)	36	203	29	137	129	Geotextile partially double-layered (risk of limitation of air transfert)
	Upper confidence limit of the mean for grab samples (90%)	35	191	20	150	137	Conclusion : Intermediate performance
Site 8	Average of 24-hour samples	25,4	126,0	18,0	84,2	78,6	Faulty flushing device – replaced during the project
	Average of grab samples	39,0	122,3	24,0	74,2	67,3	
	Standard deviation of 24-hour samples	37,1	71,1	30,7	52,2	46,0	Layer of topsoil : 50 cm (risk of limitation of air transfert)
	Standard deviation of grab samples	23,2	48,3	23,8	46,1	42,6	
	Upper confidence limit of the mean for 24-hour samples (90%)	95	260	76	183	166	G Geotextile partially double-layered (risk of limitation of air transfert)
	Upper confidence limit of the mean for grab samples (90%)	83	214	69	161	148	Conclusion : Intermediate performance
Site 9	Average of 24-hour samples	19,3	68,7	5,3	32,2	33,3	Faulty flushing device – replaced during the project
	Average of grab samples	9,6	73,3	6,3	38,1	35,6	
	Standard deviation of 24-hour samples	7,9	18,2	1,3	21,0	21,2	Layer of topsoil : 50 cm (risk of limitation of air transfert)
	Standard deviation of grab samples	7,7	21,5	5,9	23,2	22,1	
	Upper confidence limit of the mean for 24-hour samples (90%)	34	103	8	72	73	Geotextile partially double-layered (risk of limitation of air transfert)
	Upper confidence limit of the mean for grab samples (90%)	24	114	18	82	77	Conclusion : very good performance
Site 10	Average of 24-hour samples	23,0	67,7	11,8	41,5	36,7	Layer of topsoil : 50 cm (risk of limitation of air transfert)
	Average of grab samples	36,1	81,4	24,1	39,9	37,9	
	Standard deviation of 24-hour samples	16,6	10,3	4,2	19,3	15,4	*Filter excluded from the study due to non-compliant sand grading*
	Standard deviation of grab samples	39,0	33,1	19,9	21,2	19,4	
	Upper confidence limit of the mean for 24-hour samples (90%)	54	87	20	78	66	Geotextile partially double-layered (risk of limitation of air transfert)
	Upper confidence limit of the mean for grab samples (90%)	110	144	62	80	75	Conclusion : bad performance

LESSONS LEARNED FROM THE OVERALL APPROACH

The platform tests and in situ monitoring are complementary and inseparable. As it is unrealistic to move directly from laboratory-scale testing to full-scale implementation at individual household installations, platform testing is valuable for assessing treatment performance, provided that the ANSES testing protocol is correctly applied. However, such testing cannot claim to identify all potential technological issues that may arise under real operating conditions. Even after a robust experimental program on a test platform, it remains essential to monitor a number of field installations for a period of at least six months in order to identify technological shortcomings and/or poor construction practices.

For example, sequential dosing is a prerequisite for the proper operation of the filter, as demonstrated from the outset of the study, and must be triggered regardless of the flow rate, including under very low-flow conditions. In addition, misunderstandings or poor practices by contractors, such as excessive filter bed depth, improper use of geotextiles, and similar installation errors, must be thoroughly identified and addressed before wider deployment. Field monitoring also makes it possible to refine and validate the maintenance and servicing requirements initially defined in the technical specifications.

Nevertheless, this work has made it possible to establish the technical basis (generic system description) required for regulatory approval and authorization of use. In this context, the study steering committee submitted a draft regulatory text to the relevant ministries, and discussions have subsequently been initiated with the ministries responsible for on-site wastewater treatment.

With regard to construction professionals, the technical specifications, which have been progressively refined throughout the project, will be submitted to the relevant building sector organizations (Construction Quality Agency, insurers, building industry federations, etc.) with the objective of incorporating these systems into the family of recognized robust construction techniques. This process will lead to the publication of a public technical reference document describing the intended scope of application, detailed installation requirements, procedures for selecting materials and equipment, and maintenance, servicing, and repair requirements.

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