

# Septage unit treatment by sludge treatment reed beds for easy management and reuse: performance and design considerations

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## ABSTRACT

Sustainable treatment and management of fecal sludge in rural areas require adapted solutions. Rustic and simple operating processes such as sludge treatment reed beds (STRB) have been increasingly considered for this purpose. The biggest full scale (2,600 m<sup>2</sup> of STRB) septage treatment unit in France had been built in Nègrepelisse with the final objectives of reusing treated sludge and leachates for agriculture spreading and tree irrigation, respectively. The aim of this investigation was to validate the treatment chain of this installation. The obtained field data showed firstly that the overall removal efficiencies of STRB were satisfactory and stable. Removal rates higher than 98% for chemical oxygen demand and suspended solids and a 95% for Kjeldahl nitrogen represented so far a beneficial septage treatment by STRB. The highlighted necessity of a suitable complementary leachate treatment (before tree irrigation) justified the presence of the second stage of vertical flow constructed wetland. The sludge deposit drying and mineralization efficiencies were on the right track. According to hydrotectural diagram analysis, surface deposit was however found to have high deformability probably due to the youth of the installation. An in-depth understanding of STRB system needs continuous long-term studies.

**Key words** | leachate treatment, performance, septage, sludge treatment reed beds

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## INTRODUCTION

Faced with the increase of septage flows in rural areas (Troesch *et al.* 2009), which have been induced by the action of public services for household wastewater treatment, sustainable treatment and management of fecal sludge has become important for small communities in France. This need is also true for developing countries where latrines are widely used (Kengne *et al.* 2009). If conventional treatment techniques rely on transporting septage to large wastewater treatment plants, they induce high costs and environmental impacts due to liquid sludge transportation. In this context, rustic and simple operating processes such as sludge treatment reed beds (STRB, or sludge drying reed bed) have been increasingly considered as adapted solutions (Paing & Voisin 2005; Kengne *et al.* 2009; Troesch *et al.* 2009; Uggetti *et al.* 2009; Vincent *et al.*

2011, 2012) to provide dedicated optimum septage treatment units near fecal sludge production areas.

Previously initiated for activated sludge volume reduction in Denmark since 1988 (Nielsen 1990), the STRB system has proved its efficiency (Obarska-Pempko-wiak *et al.* 2003; Nassar *et al.* 2006; Nielsen 2007; Troesch *et al.* 2009; Uggetti *et al.* 2009). In addition, this system allows long-term sludge reduction via dewatering and mineralization processes. Since the early 1990s in France (Liénard *et al.* 1995), the use of STRB has been progressively adapted for septage treatment (Troesch *et al.* 2009; Vincent *et al.* 2011, 2012). Several French research programs carried out during recent years (2007–2012) have proposed suitable design, operation and management rules for septage treatment by STRB (Molle *et al.* 2013). However, few full scale systems

have been monitored in France, and design and operating rules also needed to be validated.

A full scale STRB unit treating  $11,000 \text{ m}^3 \text{ y}^{-1}$  of septage has been built in Nègrepelisse (south of France) with the final objectives of reusing treated sludge and leachates for agricultural spreading and tree irrigation (the poplar and eucalyptus used for the municipal heating system), respectively. This septage treatment unit has been implemented on the basis of design rules established in pilot scale experiments (Troesch *et al.* 2009; Molle *et al.* 2013). This installation is the biggest trial in France, representing an ecological solution for satisfactory local treatment of fecal sludge and appropriate reuses of residual products. It therefore needed investigations to validate the treatment efficiencies and precise operation modes. For this purpose, this treatment plant has been monitored since its inception with a focus on: (i) fecal sludge characterization, (ii) performance assessment (septage by STRB and leachate by vertical flow constructed wetlands (VFCW)) and (iii) sludge deposit evolution (dewatering, mineralization and hydrotectural properties).

## MATERIALS AND METHODS

### Description of the treatment plant

#### Installation

The full scale STRB unit located in Nègrepelisse (Tarn-et-Garonne, France; Figure 1, Table 1) has been in operation since the end of 2013. It can receive 131 t of suspended solids (SS) per year. It corresponds to a design load of

$50 \text{ kg SS/m}^2/\text{y}$ . This load appears lower than the ones applied for activated sludge treatment in different climates (Stefanakis & Tsihrintzis 2012; Nielsen & Bruun 2015). Nevertheless, they are in accordance with design loads suggested by Vincent *et al.* (2011) for septage treatment in a temperate climate. This treatment capacity corresponds to 3,500 emptied septic tanks per year. The treatment line consists of: (i) a stone trap followed by automatic screening (10 mm mesh), (ii) an emptying tank ( $20 \text{ m}^3$ ), (iii) an aerated buffer tank (with a capacity of  $180 \text{ m}^3$ ), (iv) eight STRB planted with *Phragmites australis* ( $325 \text{ m}^2$  each), (v) two VFCW ( $50 \text{ m}^2$  each) for leachate treatment and (vi) a treated leachate storage basin for irrigation ( $140 \text{ m}^3$ ). In fact, the VFCW stage receives not only leachates but also a part of the outlet effluent of a nearby wastewater treatment plant in order to have enough water volume for irrigation. To prevent clogging of the installation, the filter layer of the VFCW was composed of a mixture of sand (0/4 mm) and gravel (2/6.3 mm), with a  $d_{50}$  of about 2 mm (Table 1).

#### On-site equipment

Inlet flow was determined by measuring the functioning time of the pump, whereas the outlet flows were measured by V channels equipped with pressure probes (STS) for STRB drainage and a flow insert equipped with a bubble flowmeter for VFCW drainage. The aerated buffer tank was equipped with pressure, SS and redox probes. Those continuous measurements allowed ensuring and controlling of the qualitative (maintaining aerobic conditions to avoid bad odours) and quantitative loads sent to the STRB (the mass of SS to be applied).



**Figure 1** | Schematic representation of the full scale STRB unit located in Nègrepelisse (Source: Epur Nature). (1) A septic tank emptying place, (2) a stone trap followed by automatic screening, (3) an aerated buffer tank, (4) eight STRB, (5) two VFCW, (6) a storage basin of treated leachate and (7) a filtration unit for irrigation.

**Table 1** | Particle size distribution of filter medium with depth in STRB and VFCW

	Layer	Depth (cm)	Materials
STRB	Filtration	10	0/5 mm sands
	Intermediate	10	2/6 mm gravels
	Drainage	40	15/25 mm gravels
VFCW	Filtration	40	0/5 mm sands + 2/6.3 mm gravels
	Drainage	20	15/25 to 20/40 mm gravels

## Functioning

For good acclimatization of reeds (October 2013), the whole installation was fed with low organic load (less than 20 kg SS  $m^{-2} y^{-1}$ ) during the first 6 months. After this period, a 1 year period was conducted from May 2014 with a sludge loading rate of 30 kg SS  $m^{-2} y^{-1}$ , 8-bed configuration and 1/7 days of feeding/resting cycles. Then, the load was progressively increased until it reached 40 kg SS  $m^{-2} y^{-1}$  with a six-bed configuration and 3/15 days of feeding/resting cycles (summarized in Table 2). Only during irrigation periods (from May to September), the leachate of the STRB was treated by one stage of VFCW and then sent via the irrigation network to a short rotation coppice (SRC, 3.2 ha of planted poplars and eucalyptus).

## Description of field monitoring campaigns

### Regular campaigns

From its inception, performance monitoring was conducted to evaluate the overall performance of each treatment stage; a total of 32 regular campaigns were conducted with 24 h time-proportional flow samplings. All water samples were analyzed at the departmental laboratory (Tarn-et-Garonne) for the following parameters: total suspended solids (TSS), total and dissolved chemical oxygen demand ( $COD_{tot}$  and  $COD_{diss}$ ), Kjeldahl nitrogen (KN) and ammonium nitrogen ( $NH_4-N$ ) according to standard

**Table 2** | Operation parameters, sludge loading rates and accumulation rate during the commissioning (May 2014–April 2015) and routine (May 2015–October 2015) periods

Period	Number of beds	Feeding/resting period (d/d)	Hydraulic load ( $cm d^{-1}$ )	Organic load ( $kg SS y^{-1}$ )
Commissioning	8	1/7	6	24
Routine	6	3/15	11	37

methods (APHA 2005). Moreover, quantitative and qualitative measurements of sludge deposits were performed biweekly. Core samplings were conducted at five different points of each bed at different distances from a feeding point. In addition to height measurements of accumulated deposits, the five core samples were homogeneously mixed to obtain a composite sludge sample before the determination of the dry matter (DM) and organic matter (OM) contents according to the standard method (APHA 2005).

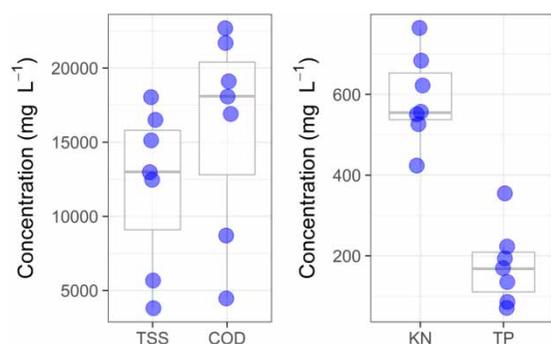
### Specific campaigns

Two specific campaigns were conducted in May and August 2015, in order to perform continuous measurements of nitrogen parameters in each processing step as well as follow the evolution of sludge deposits with resting time. Online monitoring of ammonium and nitrate nitrogen was carried out using ion specific probes (WTW VARION, with simultaneous compensation of potassium and chloride). In order to determine the mechanical and hydraulic properties of sludge deposits, hydrotextral diagram analysis was performed. This diagram links gravimetric water content ( $g_w/g_s$ ) to solid volume fraction ( $mL_s/mL_t$ ) to plot the course of the solid fraction against water content (Vincent *et al.* 2012). In order to know the exact sample volume, samplings were performed with Eijkelkamp stainless steel cylinders (100  $cm^3$ ). Solid densities of deposits have been measured with a helium pycnometer (Multivolume Pycnometer 1305, Micromeritics). Water and solid masses were determined by weighting samples before and after drying at 105 °C for 24 h. This analysis allows knowledge of the DM content from which the deposit behaves as a solid, i.e. when air enters into the matrix when drying.

## RESULTS AND DISCUSSION

### Influent fecal sludge characteristics

Physico-chemical characteristics of the incoming septage at Nègrelisse are illustrated in Figure 2. The incoming septage of the studied installation was found to be less concentrated than those from previous studies in France (Troesch *et al.* 2009; Vincent *et al.* 2011, 2012). Indeed, the quality of septage had been known to have extreme variability, depending on several parameters. Indeed, sludge quality depends on the practice of emptying (e.g. frequency), the use of housing (i.e. primary or secondary residence), the type of



**Figure 2** | Physico-chemical characteristics of the incoming septage at Nègrepelisse.

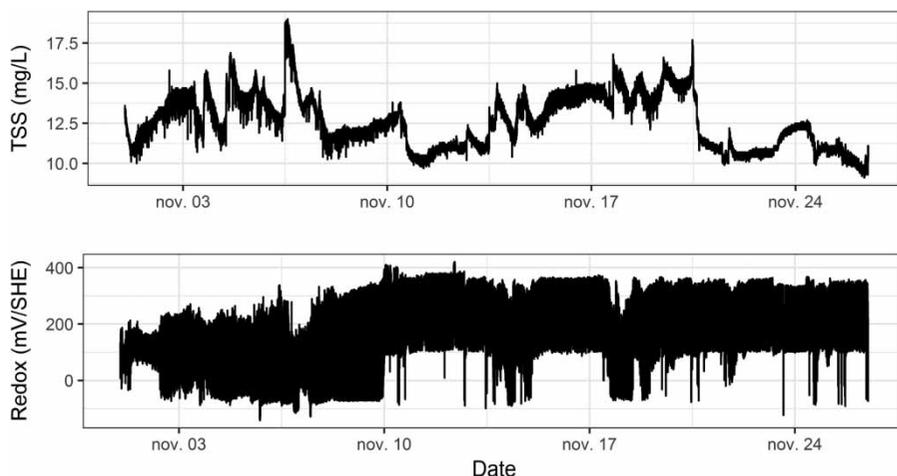
septic tank (i.e. for all house wastewaters, flush tank, water-tight tank, Imhoff, etc.).

Despite high variations in the concentration of the incoming septage (Figure 2), the online measurement of TSS within the aerated buffer tank (Figure 3) confirmed its buffering role for TSS concentration (ranged between 10 and 20 g L<sup>-1</sup>). The continuous redox potential measurement (Figure 3) confirmed that aeration allowed avoidance of the establishment of an anaerobic condition (Eh maintained above 0 mV SHE) within the buffer tank. Particle size distribution analyses (results not shown here) showed that there were no other effects (e.g. flocculation) of aeration on the physical quality of septage.

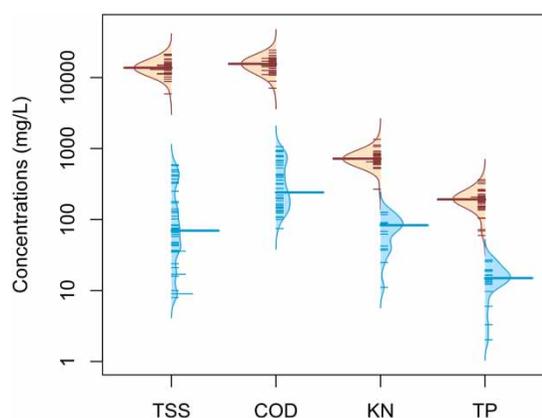
## Effluent treatment

### STRB performance

The data distribution curves of concentrations of different parameters at the inlet/outlet of the STRB are shown in Figure 4.



**Figure 3** | A monthly example (November 2014) of continuous monitoring of TSS concentration and redox potential within the aerated buffer tank.



**Figure 4** | Distribution curves of different parameters monitored at inlet (brown, left)/outlet (blue, right) of STRB. The small and large bars correspond to individual data and medians, respectively. The full colour version of this figure is available in the online version of this paper, at <http://dx.doi.org/10.2166/wst.2017.461>.

Non negligible variations of inlet/outlet concentrations were noted (log scale of Figure 3). The performance of STRB was found to be satisfactory from the monitored commissioning period (a load of 24 kg SS m<sup>-2</sup> y<sup>-1</sup>) to loads of 37 kg SS m<sup>-2</sup> y<sup>-1</sup>. The removal efficiency for TSS (99.5%) was excellent, as well as for COD<sub>tot</sub> (98.3%), KN (94.9%), and total phosphorus (TP) (94.8%).

Despite those good removal efficiencies, according to the characteristics of STRB leachate (Table 3), variations of STRB outlet concentrations were found to be important enough for COD<sub>tot</sub>, KN and TP parameters (753, 94 and 19 mg L<sup>-1</sup>, respectively; Table 3), in which dissolved fractions are not negligible. The necessity to have further leachate treatment was therefore confirmed before tree irrigation. This justified the additional treatment of this leachate by VFCW.

**Table 3** | Concentrations (mean  $\pm$  std.) of monitored parameters at inlet/outlet samples of STRB

Parameter	Inlet (mg L <sup>-1</sup> )	Outlet (mg L <sup>-1</sup> )	Removal efficiency (%)
TSS	14,320 $\pm$ 737	401 $\pm$ 41	99.5
COD <sub>tot</sub>	17,168 $\pm$ 457	753 $\pm$ 39	98.3
DCO <sub>diss</sub>	379 $\pm$ 24	283 $\pm$ 16	23.0
KN	742 $\pm$ 26	94 $\pm$ 8	94.9
NH <sub>4</sub> -N	66 $\pm$ 9	43 $\pm$ 7	-
NO <sub>3</sub> -N	0.4 $\pm$ 0.1	37 $\pm$ 12	-
TP	217 $\pm$ 21	19.2 $\pm$ 1.5	94.8
PO <sub>4</sub> -P	1.6 $\pm$ 0.7	5.9 $\pm$ 0.7	-
SO <sub>4</sub>	55 $\pm$ 4	89 $\pm$ 6	-
Cl	251 $\pm$ 27	218 $\pm$ 14	-

### Leachate treatment by VFCW

The mixture of leachates and treated wastewater is sent on to the VFCW stage with a mean hydraulic load of the order of 85 cm day<sup>-1</sup>. The effluent characteristics at the inlet/outlet of the VFCW (Table 4) underlined a dilution of leachates by treated wastewater. Additional leachate treatment efficiencies by VFCW were also highlighted.

At the outlet of the VFCW stage, the observed TSS concentrations remained, however, non negligible, with a modest filtration performance (50%). TSS particle sizes arriving at the VFCW stage are relatively small (80% of particles in a range of 5 to 80  $\mu$ m). Particle size of the VFCW filtration layer (d<sub>50</sub> of about 2 mm) is slightly rough to ensure efficient filtration of fine particles. The sand particle size could be optimized in the future. Moreover, to improve the nitrification, it would be interesting to investigate the optimization of filtration layer depth.

**Table 4** | Concentrations of monitored parameters at inlet/outlet of VFCW expressed as mean  $\pm$  SEM (number of campaigns)

Parameter	Inlet (mg L <sup>-1</sup> )	Outlet (mg L <sup>-1</sup> )
TSS	182 $\pm$ 22 (16)	90 $\pm$ 8 (16)
COD <sub>tot</sub>	378 $\pm$ 31 (17)	232 $\pm$ 14 (17)
COD <sub>diss</sub>	169 $\pm$ 12 (11)	127 $\pm$ 5 (11)
KN	46.9 $\pm$ 8.3 (10)	19.8 $\pm$ 3.2 (11)
NH <sub>4</sub> -N	21.0 $\pm$ 3.9 (17)	8.8 $\pm$ 1.8 (17)
NO <sub>3</sub> -N	55.6 $\pm$ 5.7 (17)	66.8 $\pm$ 5.0 (17)
TP	14.5 $\pm$ 1.0 (12)	13.6 $\pm$ 1.0 (14)

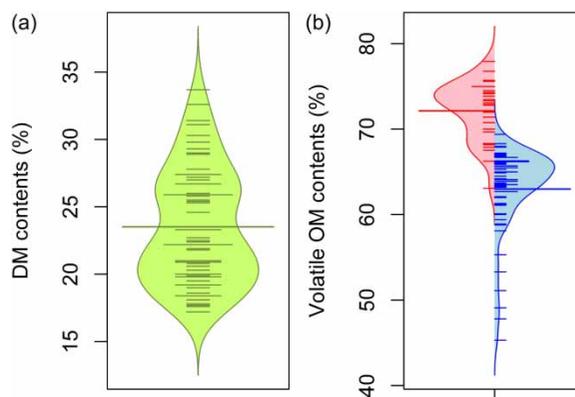
## Sludge treatment

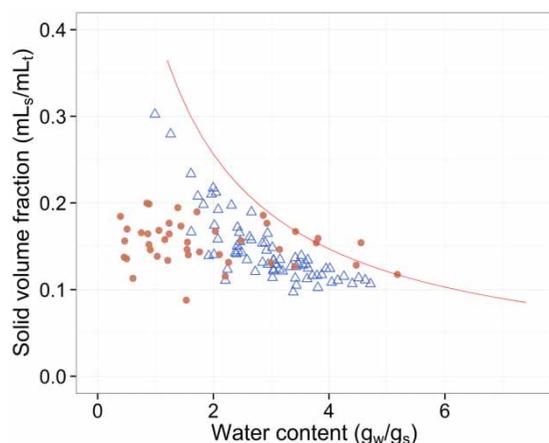
### Dewatering and deposit mineralization

Regarding the sludge accumulation, after the commissioning period, about 10 cm per year of deposit accumulation was noted. Regular monitoring (Figure 5(a)) also showed a good behavior of the STRB. The average dry matter (DM) content was around 24% ( $\pm$ 4.6%). Two different data distribution zones of DM contents, corresponding to seasonal variations, were noted. In summer, the DM contents at the end of the resting period were generally around 30%, but this could sometimes be impacted by heavy rains and decreased to about 20%. In winter, DM contents were stabilized around 20%. Despite the youth of the installation (2 years), significant reductions of volatile organic matters (OM) contents from the incoming septage (72  $\pm$  4% MES) to the deposit on STRB (64  $\pm$  5% MES) confirmed a good mineralization of the deposit (Figure 5(b)).

### Hydrotextural characteristics

As Vincent *et al.* (2012) highlighted that the hydrotextural properties of a deposit did not depend on applied loads; the hydrotextural diagram of the studied installation was compared to the results from this previous study (Figure 6). The important data dispersion and low sample water contents (<4 g/g, i.e. 20% DM) were in concordance with the referenced results (Vincent *et al.* 2012). The desaturation state, referred to as 'ideal shrinkage' (Ruiz *et al.* 2011), of the surface deposit studied here was however difficult to observe (Figure 6), suggesting that the studied samples

**Figure 5** | Data distribution curves: (a) dry matter (DM) contents of surface deposit of STRB, (b) organic matter (OM) contents relative to DM of incoming septage in aerated buffer tank (left) and surface deposit of STRB (right). Small and large bars correspond to individual data and medians, respectively.



**Figure 6** | Hydrotextural diagram (i.e. solid volume fraction versus water content) for surface deposits of STRB (triangle points) compared with the reference values (round points) from Vincent et al. (2012). The red line represents theoretical desaturation curve for plastic materials. The full colour version of this figure is available in the online version of this paper, at <http://dx.doi.org/10.2166/wst.2017.461>

presented higher deformability than the one observed by Vincent et al. (2012). This may be explained by: (i) the incoming septage characteristics (less concentrated) resulting in higher hydraulic load; (ii) the age of the installation at sampling moments (17 months' operation in this study compared to 50 months for the referred study); (iii) the depth of deposit samplings (first 5 cm in this study compared to 10 cm for referred study).

## CONCLUSION

The results shown in this study were obtained from field monitoring conducted during almost 2 years to evaluate the performance of STRB designed and operated for the treatment of the municipal septage collect of Nègrepelisse (France). The field data thus obtained showed firstly that the overall removal efficiencies of STRB were satisfactory and stable. Removal rates higher than 90% for COD and SS and a bit lower for KN represented so far a beneficial septage treatment by STRB, simple and easy to operate. The necessity of a suitable complementary leachate treatment was however highlighted (before tree irrigation), justifying the presence of the second stage of VFCW. The sludge deposit drying and mineralization efficiencies were on the right track. According to hydrotextural diagram analysis, the surface deposit was, however, found to have high deformability, probably due to the youth of the installation.

As with other constructed wetlands, an in-depth understanding of the STRB system needs continuous long-term

studies. Further investigations would therefore be worth while to evaluate the sustainability of the whole installation.

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