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Wastewater treatment for small communities in tropical conditions: performances technologies comparison in real conditions.

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INTRODUCTION

Wastewater management in the French Overseas Territories (FOT) are lagging behind France mainland and both French and European regulations. Consequences lead to numerous issues regarding environment (the FOT represent 80% of the French national biodiversity), sanitary problems, and socio-economic activities. Municipalities are characterized by resources weakness in terms of self-financing capacities as well as skilled human resources for maintenance. Treatment technologies selection and choices made for systems designs are suffering from missing knowledges on their operation in tropical conditions. When applied by private developers the choices tend towards favoring compact systems, easy to install, more affordable and which are saving space for constructions. Nevertheless, tropical conditions (heat, humidity, salinity, extreme rain events and low redox conditions at the outlet of the sewer), poor maintenance and spares parts importations induce many systems dysfunctions.

Implementing a wastewater treatment plant (WWTP) in tropical conditions requires feedbacks on technologies behaviour under the tropics and knowledge of raw wastewater in order to adjust system design. Consequently a study has been conducted to compare treatments technologies performances, in real operating conditions, in order to optimize public investment by implementing suited systems to local constraints. The study has been focused on the five FOT (Martinique, Guadeloupe, Mayotte and La Réunion islands and French Guyana) and treatment plant capacities between 20 and 2 000 people equivalent (p.e.).

MATERIAL AND METHODS

A data-base of 24 h flow composite samples has been built with data gathered from 2 different sources:

- According to French regulation, WWTP self-monitoring has to be performed and sent to local water authorities. Those data are available from the FOT since 2012. The number of 24-hours flow-composites sample campaigns depends on plant size: 1 per 2 years from 200 to 500 p.e., 1 per year from 500 to 1 000 p.e. and 2 per year from 1 000 to 2 000 p.e. As there is no obligation for treatments systems below 200 p.e., such plants have been identified, but

few data are available. The following analyses are performing on the samples: COD, BOD₅, TSS, TKN, N-NH₄, N-NO₂, N-NO₃, P-PO₄, TP, pH, conductivity and flow measurements.

- Local water authorities had occasionally carried out studies on specific technologies, or local area, or precise capacity. When they are based on 24-hours flow-composites sample campaigns, results were added to the data-base.

The database achieved consists of 267 WWTP, and about 1 200 sampling campaigns. A validation step, through raw wastewater data was performed. It aimed at removed inconsistent data or outliers. Reliability has been evaluated statistically (PCA and Chauvenet's criterion tests) on both inlet pollutants concentrations and ratios between them, such as COD/BOD₅, TKN/COD, TSS/COD and NH₄N/TKN. With a small amount of data removed (from 0.59% for COD to 3.29% for NH₄), the database gained consistency (reduction of standard deviation: from 92.5% for COD to 13.9% for NH₄).

In order to improve WWTP design, raw wastewater in tropical area has been characterized and a definition of the tropical p.e. is given. Those results are compared to domestic wastewater values defined from a previous study about domestic wastewater characteristics in French rural areas (<2,000 p.e.) (Mercoiret *et al.* 2010).

The second part of the study focuses on treatments systems. The WWTP sample is described regarding the treatment technology, and their performances in terms of removal efficiency and outlet concentrations are compared.

RESULTS AND DISCUSSION

Characterization of tropical raw waste water

Regarding the range of variations for the concentrations of pollutants in raw wastewater (Table 1), the differences of mean values between FOT and France mainland are not significantly different, except for BOD₅ and NH₄. However, carbon and TSS upper bound values are higher in the FOT, showing that highly concentrate wastewater can reach the treatment systems.

Table 1. Means and range of variations for the main pollutants concentrations in raw wastewater of small communities (< 2 000 p.e.) in French Overseas Territories (FOT) and France Mainland (FM). Mainland values from Mercoiret *et al.* 2010. Bounds correspond to the 5th (lower) and 95th (upper) percentiles.

		BOD ₅ (mgO ₂ /L)		COD (mgO ₂ /L)		TSS (mg/L)		TKN (mgN/L)		NH ₄ (mgN/L)		TP (mgP/L)	
		FOT	FM	FOT	FM	FOT	FM	FOT	FM	FOT	FM	FOT	FM
Mean		339.6	265	652.6	645.7	300.5	288.1	64.9	67.3	48.7	54.9	8.8	9.4
Range of variations	Upper bound	800	570	1512.4	1341.3	824.7	696	128.6	123.1	97	98.3	18.6	18.4
	Lower bound	50	39	125.2	122	54.9	53	16.1	14.1	11.4	12	2.4	2
Number of values		1425	10491	1464	10491	1439	10470	713	9605	661	4381	798	9374

When flow measurements were available, pollutants fluxes per p.e. were calculated based on the definition of 60 gBOD₅/p.e./d. Daily p.e. production loads are presented in Table 2. All values are significantly different between tropical and French rural p.e. The main distinction

concerns COD production in the FOT (-16%), otherwise pollutants remain by between +/- 10%. Consumption behaviour with less chemicals could explain this smaller amount of COD. Based on these considerations, we proposed to use pollutant p.e. production of 60/130/60/15/2.5 g/d for small communities in FOT for BOD₅/COD/TSS/KN/TP respectively.

Table 2. Comparison of the French rural p.e. (Mercoiret et al. 2010) and the tropical p.e.

	BOD ₅ (gO ₂ /d)	COD (gO ₂ /d)	TSS (g/d)	TKN (gN/d)	N-NH ₄ (gN/d)	TP (gP/d)
p.e. in French rural areas	60	157	72	15.5	11.,5	2.1
Tropical p.e.	60	133	64	17.7	13	2.8

Small wastewater treatment systems in the FOT (20 to 2 000 p.e.)

About 900 WWTP under 2 000 p.e. have been identified in the FOT (Figure 1). Amongst them, a large part of the treatments systems remains unknown (42%) or belongs to on-site sanitation systems (22%). As no data were available for those categories (no obligation < 200 p.e.), they don't appears in the database. Activated sludge is the main technology implemented in the FOT.

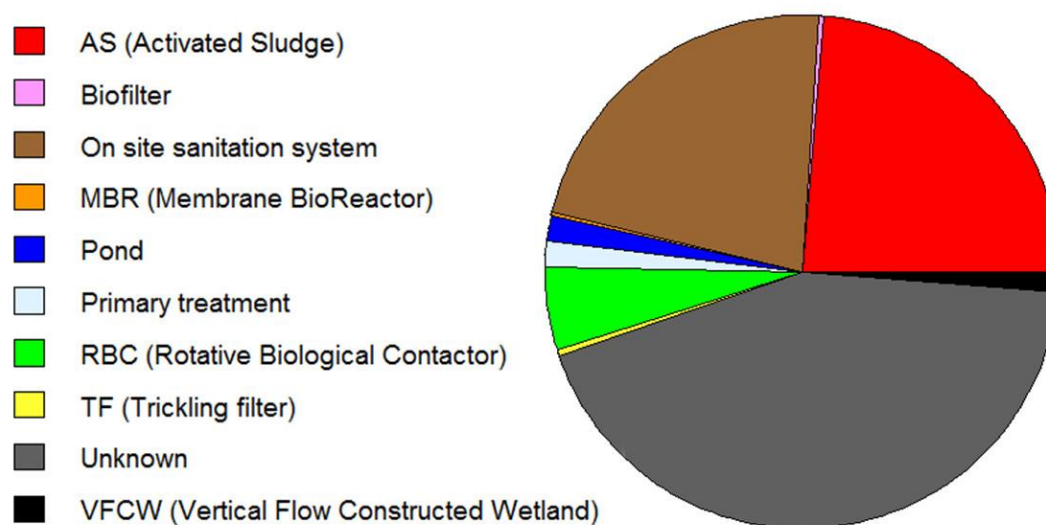


Figure 1. Repartition of the different treatment technology in the FOT (900 WWTP identified between 20 and 2 000 p.e.).

The database counts 267 WWTP. 4 treatments systems (biofilters, membrane bioreactors, primary treatment, trickling filters) were removed because the corresponding number of units was too low (<10). Due to contradiction or lack of information, uncertainties regarding the treatment types remain for about forty plants. They were also excluded for treatment technology evaluation. Finally, 4 technologies (activated sludge, pond, rotating biological contactor, single stage vertical flow constructed wetland), 213 plants and 962 sampling campaigns are usable for performances assessments (Figure 2).

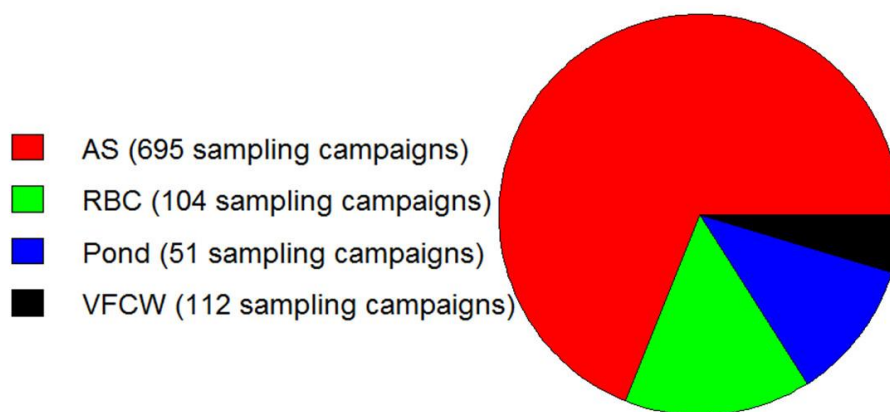


Figure 2. Proportion of the four technologies studied represented in the database (213 WWTP).

The number of 24-hours flow-composites sample campaigns per WWTP (figure 3) is homogeneous regarding capacities and is below 25. At technology level, average number of sampling campaigns per unit varies from 10 for the VFCW to 3.5 for RBC.

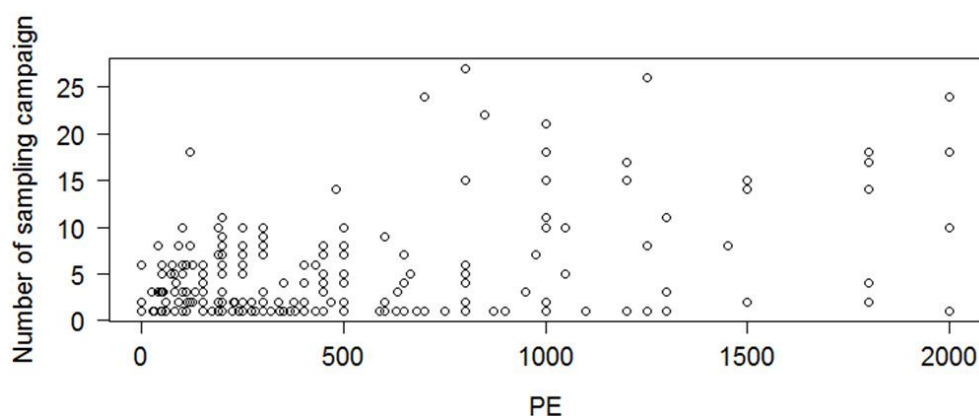


Figure 3. Number of sampling campaigns per treatment plant.

Performances of the different treatments technology are presented in terms of removal efficiency (Figure 4) and outlet concentrations (Figure 5). They are discussed regarding the French minimal regulation objectives (removal rates: 60/60/50% for BOD₅/COD/TSS or outlet concentrations below 35/200 mg/L for BOD₅/COD) and classical more ambitious ones (25/125 mg/L for BOD₅/COD and 70% removal rate for NTK). Values achieved are presented in Table 3.

Despite the fact that activated sludge is the most implemented technology, results show that it is the least reliable one. For over 17% of the campaigns, removal rates for TSS and COD are below the regulatory objectives and almost 30 % of the BOD₅ outlet concentrations are beyond the regulation. This is mainly due to sludge leakage or washout during the intense tropical rainy events. Null removal rates are observed for TSS. It shows that during about 10% of the sampling campaigns sludge were leaking out of the system. The absence of nitrification on about 12 % of the campaigns shows that maintenance of the systems can suffer from negligence.

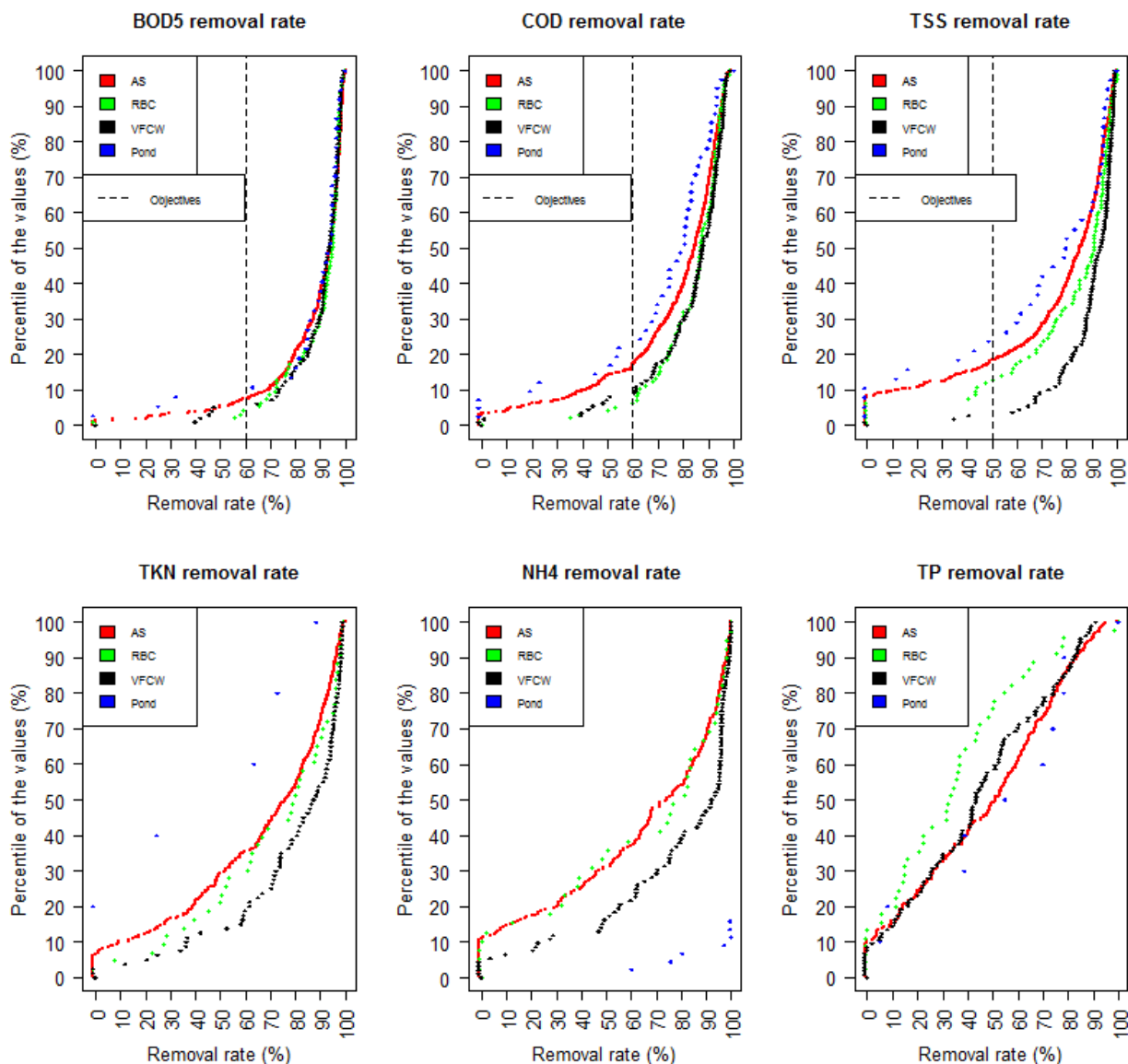


Figure 4. Removal efficiency of the treatments technologies for the main pollutants.

Ponds show the same type of pattern: weak removal rates, leakage of COD and TSS for about 10% of the campaigns. However outlet concentrations are better (93.2% COD are conform), suggesting that raw water are diluted. Effluent of ponds system usually has high concentrations of suspended solids, mainly due to the production of algae (Luduvicé et al., 2001); it reduces the efficiency when influents are diluted.

Rotatives biologicals contactors have the weakest COD outlet concentration conformity (82%). Their performances in terms of removal rates are much better (close to 95%) for carbon loads, but with 13% of samplings below the regulation objectives for TSS, sludge leakages may occur in the settling stage.

Vertical flow constructed wetland is the most reliable technology. It fulfills all the objectives at a frequency of 90 to 95%. The percentages of removal rates below minimal regulation for BOD₅/COD/TSS are respectively 5/9/3.1%. Regarding outlet concentrations over 90% of the samples achieve a higher standard for COD. Performance on NTK are also the best observed (75% over 70% removal), even if it is lower than the one usually mentioned on VFCW (Molle

et al., 2005). VFCW in the FOT has single stage, full nitrification is out of range in this configuration.

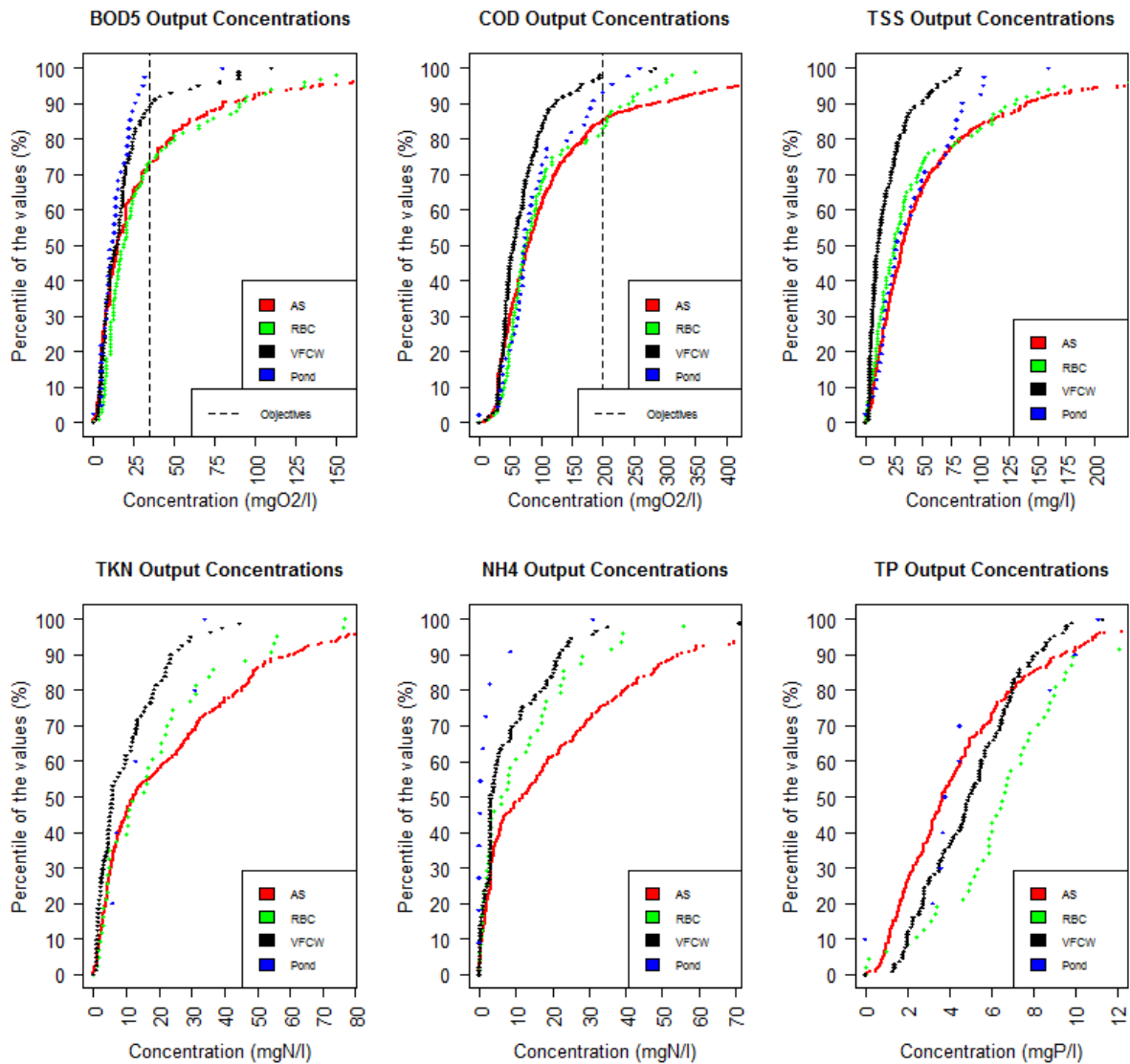


Figure 5. Outlet concentrations of the 4 treatments technologies.

Table 3. Values achieved by the studied treatment technologies regarding different level of performances. In grey, the French minimal regulation objectives.

	< 35 mgBOD5/L	< 25 mgBOD5/L	< 200 mgCOD/L	< 125 mg COD/L	BOD Removal > 60%	COD Removal > 60%	TSS Removal > 50%	NTK Removal > 70%
AS	71.6%	65.4%	85.2%	70.6%	7.5%	17.2%	18.5%	56.1%
Pond	96.5%	89%	93.2%	78.4%	10.5%	23.5%	24.2%	-
RBC	73.7%	63.7%	82%	75.3%	4.5%	6.3%	12.9%	57.8%
VFCW	89.1%	81.2%	98.5%	90.7%	5%	9%	3.1%	75.2%

CONCLUSIONS

Comparison of raw wastewater from small communities in the FOT and in French rural areas shows no major differences in terms of means concentrations. Upper bounds of the ranges of variations suggest that sometimes, highly concentrates influents reach the WWTP. The p.e. pollutants production has been evaluated at 60/130/60/15/2.5 g/d for small communities in FOT for BOD₅/COD/TSS/KN/TP respectively.

Performances comparison on the 4 treatments technologies gives important feedbacks :

- Activated sludge is the least reliable technology evaluated in the FOT. Sludge leakages are noticeable on 10% of the campaigns. Lack of nitrification observed suggests maintenances troubles.
- At low loads, algae prevent ponds from achieving French minimal regulation objectives for the removal rates.
- Settling troubles have been identified on RBC.
- With all the regulatory objectives fulfill with a 90-95% frequency, VFCW is the most reliable technology. It requires space and can't be implemented everywhere, even if tropical design has reduces the footprint (0.8 m²/p.e.). VFCW can reach high level performances (125 mgCOD/L), but shows also its limits (70% of NTK removal achieved by 75% of the sampling campaigns). Designs adjustments like unsaturated/saturated system or higher filtration layer enable adaptation to different objectives.

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