A Comparison of the Design Criteria of 141On-Site Treatment Systems Available on the French Market

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Abstract
This article aims at summarizing the regulation elements available on interministeries website about on-site treatment. This paper only deals with two types of processes: the attached growth system on fine media and the activated sludge system (141 technical approvals; 36 manufacturers). We compare on-site design criteria with the collective treatment plant design criteria for each process.
Different materials for bacterial growth are used such as soil, sand or gravel, zeolite, coconut shavings or rock wool cubes. The variation range of effective areas is important: between 0.26 m^2 / PE and 5 m^2/ PE for one of the rock wool cubes filter and the vertical sand filter (traditional system), respectively. Some rock wool can receives an applied daily surface load of 160g BOD_5/m^2.
The activated sludge design parameters can range from: F/M ratio 0.025 to 0.34 kg of BOD_5/ kg of VSS / d, hydraulic retention time 0.28 à 3.7 d. For the clarifier design, the water up rise velocity can vary 0.15 to 1.47 m/h. In the sludge line, the sludge storage volume could be very small and ranges between 0.125 m^3 and 0.56 m^3/PE.

Keywords
Activated sludge; approved systems; attached growth of fine media; on-site system

INTRODUCTION

For several decades, new on-site treatment systems have been developed in Europe with the arrival of a new standard in construction products (EN NF 12566-3). Until September 2009, only the so-called traditional systems were allowed in France (4 types of technical). But now the regulation has changed and those new systems are available. There are currently more than 60 companies selling more than 600 different products. Consequently, for any consumer, it becomes difficult to choose. The various solutions offered to individual consumers generally fall into three families: attached growth systems on fine media (AGS), activated sludge systems (ASS) and biofilm systems. In this study, we mainly focus on the approved systems issued between 2009 and 2014, concerning two of those three groups: attached growth systems on fine media and activated sludge systems. The aim of this article is to present a technical comparison of all of these treatment systems. We therefore compare on-site design criteria with those of the collective treatment plant design criteria for each process.

MATERIALS AND METHODS

The French ministries in charge of environment and in charge of health maintains a website (MEDDE, 2014) with the updated list of technical approvals and their associated user manuals. In this study, only two categories were studied: the AGS and the ASS.
The synthesis on the attached growth systems concerns composed systems by:

- a septic tank (with the exception of a Reed Bed Filter named “Jardin d’assainissement” which receive raw water)

- a filter filled with fine materials. They operate by a mechanic filtration of the suspended solids and a degradation of the dissolved pollution by fixed bacteria. Oxygen is conveyed by molecular diffusion or/and by convection thanks to a ventilation device. This oxygen supply is not forced, thus those systems can operate without any power (electric power).

This study was structured according to the type of material used in the filter. There are mostly 5 types of material: i) soil, ii) sand and gravel, iii) zeolite, iv) coconut shavings, v) rock wool. Filters that include the french line of a Constructed Wetland (vertical flow red bed filter) were dealt with in a different chapter, although their filling material may be gravel or sand.

The analysis of activated sludge systems rests on the close reading of 97 approvals and concerns 25 companies developing 18 activated sludge and 7 Sequencing Batch Reactor (SBR).

Among those 18 devices using the principle of activated sludge, 7 have a similar synopsis named « general course » (figure 1).

Figure 1: General course of 7 activated sludge

The other 11 devices can be arranged differently: whether they resort to a tertiary treatment or not, whether they make use of the general course (absence of primary decanter, clarifier is replaced by another treatment step and the bioreactor is complemented by another biofilm device).

With regard to SBR, the 7 companies develop courses corresponding to the Figure 1.

In collective sanitation, sludge generated by the biological treatment are extracted, stored and treated separately in special sites dedicated to sludge treatment.

In on-site treatment, such dedicated sites do not exist: water and sludge treatments are undertaken in the same tank. That is the reason why the technical analysis of the whole processes is carried out according to both features of the water line and the sludge line.

We counted 44 AGS including the 4 traditional systems (sand filter and soil treatment) and 97 activated sludge systems. We have carried out intra group comparisons. For AGS, we compared size of preliminary treatment (septic tank in majority), effective area and daily applied organic load per area unit. For activated sludge, we compared Food to Mass ratio (F/M ratio), Hydraulic Retention Time (HRT), clarifier area and sludge storage volume.

The following results and graphs focus on the size of the most commercialized systems, in France, that is to say 4, 5 and 6 Person Equivalent (PE).

RESULTS AND DISCUSSION

Attached growth system on fine media

Water line

The useful surfaces of filters are variable. They can range from 0.26 to 12 m^2/PE. The most compact filters are those filled with rock wool, then come the filters comprising coconut shaves—the latter have an effective area of about 0.8 m^2/PE, finally one has the zeolite filters, that have an effective area of 1. Sand filled filters or those filled with planted gravel are more extensive. One type of sand filters remains very compact with its 1.68 m^2/PE effective area compared to the traditional sand filter with its 5 m^2/PE effective area.

As a reference value, one may remind that in collective sanitation, the AGS filled with sand have a size based on an effective area of 3 m²/PE. The operating conditions are different, with an imposed alternating feeding (Boutin C. *and all*, 2000).
This comparison of the daily applied surface loads aims at assessing the degree of solicitation of all the filters that rest on the principle of AGS.
This comparison has to be taken with a pinch of salt, as the settings used are extremely varied and their impact on the quality of the effluent, or the lifetime of the plants is not clearly known yet. But we may logically assume that the frailty of a system (and the clogging risk) is closely linked with the polluting load applied. From here is derived a degree of strength and a more or less high maintenance and exploitation level. Those elements make for a better understanding of the renewing frequencies of material supplied by the manufacturers.

Figure 2 shows the daily applied surface organic loads to filters. Calculations are based on the sole hypothesis of a 30% reduction of the BOD_5 in septic tank and a pollution daily residual of 42 g/PE on the filter. For the “Jardin d’assainissement”, the first stage receives used water corresponding to a 60 g daily pollution.

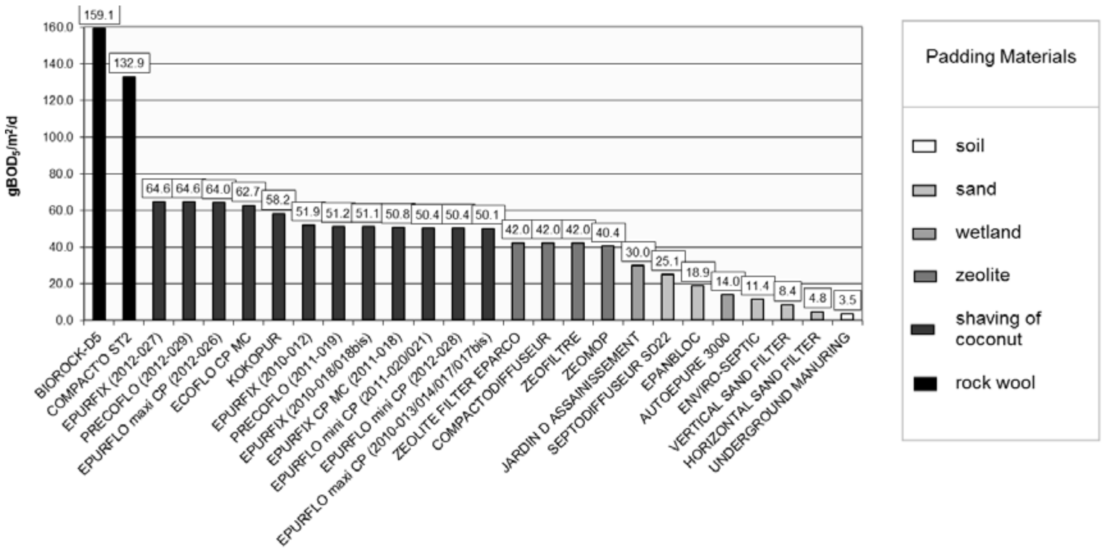

Figure 2. The daily applied surface organic loads on AGS and associated manufacturers

The degradation processes engaged in the system termed « earthed filters » used in collective sanitation lend themselves to the systems by AGS. It may be useful to underscore that the daily applied charges amount up to 12.5 BOD_5/m^2. This value is based on the overall effective area of 2 or 3 filters –for small size systems. We also have to remind that the operating conditions are different and that the alternated rhythm or the system requiring 7 days on/7 days off (in 2 filter-cases only) contributes to getting strict regulation of the clogging. The load imposed on the filter in operation therefore amounts to 25g BOD_5/m^2.
In on-site treatment, the systems akin to « earthed filters », and that are considered to be « extensive » will take daily applied charges inferior to the 12.5g BOD_5/m^2 threshold commonly accepted in collective sanitation. This concerns:
- underground manuring
- horizontal sand-filter (however, this system is the only one which is completely saturated. Any comparison should take this into consideration).
- vertical sand-filter with 8.4 g BOD_5/m^2.
- 2 types of vertical sand filter: “Enviro-septic” and “Epanbloc”

Beyond a daily applied surface organic load of 12.5g BOD_5/m^2, the systems belong in the family of compact filters. Notably:
- Vertical sand-filled “Septodiffuser”

- the 4 zeolite-filled systems
- coconut shavings systems
- the 2 rock wool-filled systems

Sludge line

The shape and material of septic tanks are extremely diverse.

- The most common shape is rectangular, two frequent models are cylindrical, and a single one is oval-shaped. Certain tanks have a rectangular base, and a cylinder on top of it.
- The materials used are, by order of prominence: HDPE, PE, glass fiber polyester and concrete. All the septic tanks are ribbed.

Septic tanks volumes all range from 3 to 5 m^3, since a 5 m^3 value is legally imposed to zeolite filled filters with a 5 PE capacity. Those volume differences, when combined with the three lowest capacities, boil down to unitary volumes ranging from 0.5 to 1 m^3 / PE. The amplitude is quite important and rises up to 200%. If we exclude zeolite based systems, this amplitude, in the interval 0.5 to 0.75, corresponds to a 150 % increasing factor.

This diversified situation undermines the assumption used throughout this report, presenting a unique yielding, independently from the hydraulic retention time, form and other non-synthesized elements such as deflectors (or other flow-breaking devices) or the number of compartments etc. The 30% reduction in the BOD_5 by this pretreatment, used by default, deserves to be supported by complementary measures in order to possibly differentiate the features of different geometries and "accessories".

Activated sludge system

Water line

Figure 2 below shows the F/M ratio values that different manufacturers use to size their ASS and SBR tanks. These values were calculated based on certain assumptions including an organic load of 60 g DBO_5 by PE, a VSS concentration of 3 g. L^{-1} in the bioreactor device and a 30% reduction of BOD_5 by primary settlement tank). The red horizontal line (figure 3) corresponds to a F/M ratio of 0.1 kg BOD_5/VSS kg/j being the commonly accepted value for ASS in collective sanitation (Canler JP., 2005). Most ASS have a design with a F/M ratio of less than 0.1, or even less than 0.05 for most of SBR systems. The aeration basin is oversized considering the pollution load. The main consequence is an important energy consumption. It may also lead to the development of nutritional deficiencies causing the development of filamentous bacteria (light brown foam), and a very bad settling of biological sludge, which can cause the beginning of simultaneous sludge along with the treated water.

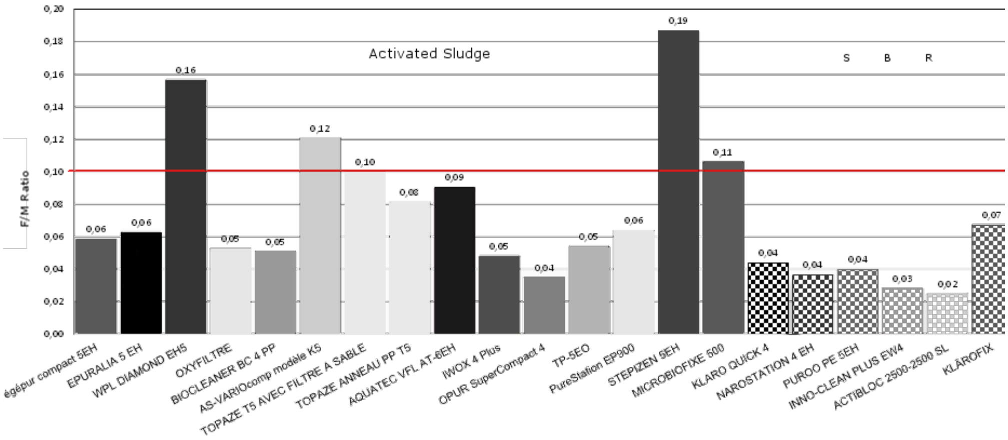

Figure 3. The F/M ratio in ASS and SBR and associated manufacturers (4, 5 and 6 PE sizes)

A single manufacturer widely exceeds the value of 0.1 for the F/M ratio applied in the aeration tank but its system is supplemented by a biofilm reactor. If we consider all manufacturers on the market, the F/M ratio, for sizes 4, 5 or 6 PE, ranges from 0.025 to 0.19.

Manufacturers commonly provide an average daily volume of 150L by PE. The hydraulic retention time is conversely proportional to the F/M ratio. The commonly accepted value in ASS and SBR for a low-load operation is 24 hours (or 1 day). For most manufacturers, the hydraulic retention time values are close or even exceed those traditionally met. Beyond 1.5 day, the aeration tank is oversized in view of the amount of pollution to treat. This concerns 49 systems out of 97 or 51% of all traded systems, 57% for common sizes (4, 5 and 6 PE).The main consequence is the same as the F/M ratio that are too low.

Values inferior to half a day corroborate the idea that the aeration tank is undersized, it is only the case of a single manufacturer and his system is complemented by an immersed fixed cultures process.

The surface of the clarifier is directly linked with the sedimentation processes in it. Indeed, this area influences the settling speed.

The larger the surface of the clarifier, the lower the up-rise velocity will be. Thus the settling velocity will be significantly greater than the up-rise velocity which allows good decantation. In collective network, the commonly accepted value for the rate of climb is 0.6 $m.h^{-1}$ at peak flow. This value is intended to limit sludge during water spurts. Conversely, an up-rise velocity higher than 0.6 m / h will lead to an increased risk of starting sludge by lack of settling capacity. We have calculated the hourly peak flow based on Annex 2 of the September 7, 2009 Decree, and notably for the time slot receiving the highest percentage of daily flow to which we have added 200 liters from a bath-tub drain, also provided for in Annex 2 of the decree.

Figure 4 mentions surfaces clarifiers (grey shade lines) and the corresponding rates of climb (black lines and checkered lines). only 50% of manufacturers meet the threshold value of 0.6 m / h and climbing speeds range from 0.18 to 1.47 m / h, that is to say an 8.2 ratio. This only applies to traditional activated sludge since the climb rate never exceeds 0.6 m / h for any SBR system manufacturer.

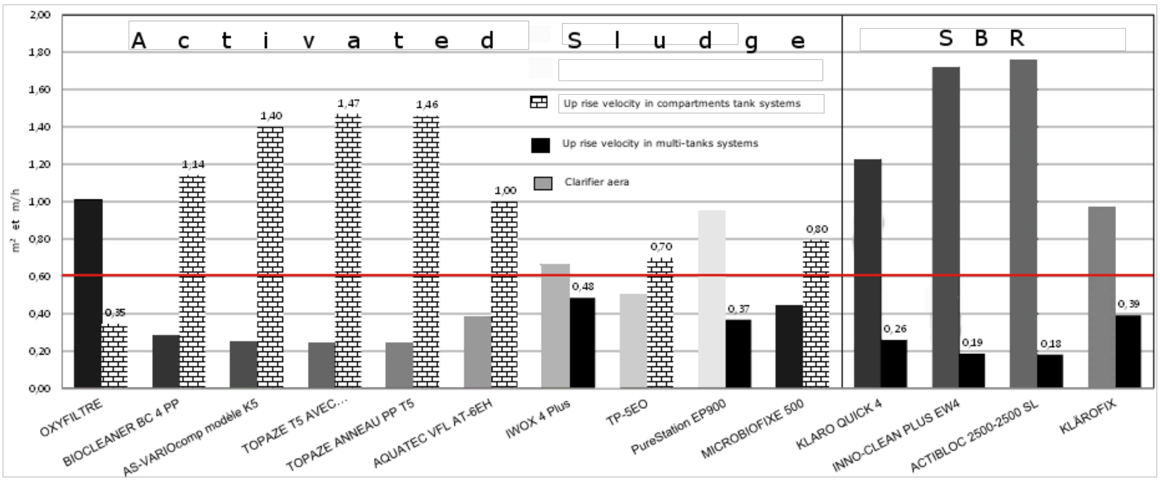

Figure 4. The clarification of surface and associated up rise velocity by manufacturers

Another highlight on the most traded systems is illustrated by Figure 4. It seems that most manufacturers who have chosen to market a single-compartmented tank exceed the safety value of 0.6 m / h. This analysis was limited to the most sold systems in order not to overload the graph where all installation sizes are represented. However it would be interesting to check this conclusion to know whether we find the same tendency for all sizes.

Sludge line

The comparison of the volume of sludge storage allows to highlight the maintenance cost of the device. Indeed, if this volume is large compared to the sludge production then the drain periodicity becomes large. Conversely, a low storage volume results in low drain intervals and increased maintenance costs.

The sludge, inevitable byproducts of sewage treatment, can be classified according to their origin. If we only include sludge encountered in on-site systems, we have:

- primary sludge, coming from the settling process of easily settleable fresh matter
- biological sludge, corresponding to excess bacterial growth, as a necessary consequence of the biological treatment of wastewater
- mixed sludge, consisting of a mixture of primary and biological sludge

Figure 4 makes the link between the sludge storage capacity and the different sludge types for the most common 4, 5 and 6 PE systems. Among all systems, a single one separately treats its primary sludge and excess biological sludge, namely, the “Vegepur” system. Primary sludge is stored in the primary clarifier akin to a septic tank, the drain of which is only required when storage reaches 50% of its useful volume. It is small compared to a proper septic tank, but it has a high capacity compared to other facilities. If emptying was imposed for a 30% filling volume, the calculated volume of 141L / PE would approach the high values that apply to the other systems.

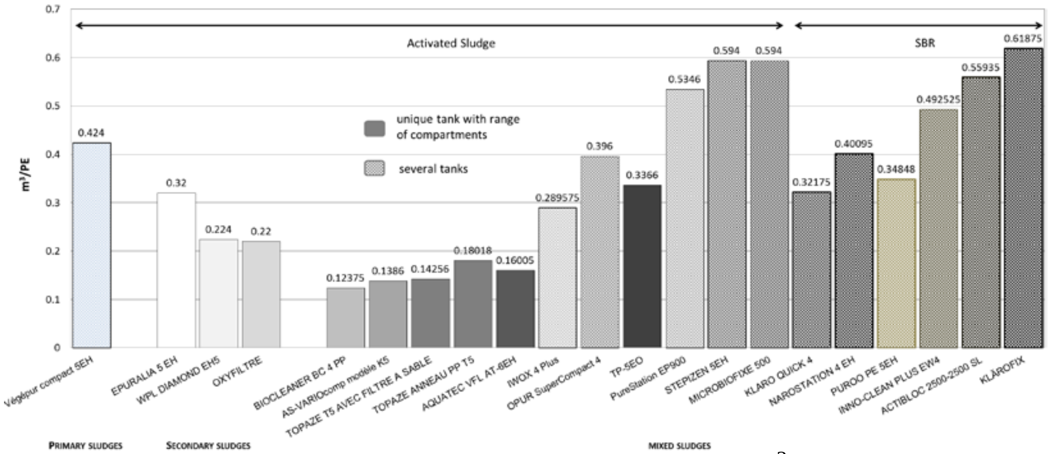

Figure 4. The storage capacity of sludge for ASS and SBR (m^3/PE) by manufacturers

Biological sludge is collected on a clarifying and drying bed, the size of which has not been analyzed in light of the criteria considered in public sanitation.

We observe a lack of control of the rate of biological sludge in the biological reactor: in the absence of recirculation pump, it is impossible to control either the concentration, or the age of the mud--essential factors for a quality biological treatment.

Three systems are designed in the absence of primary clarifier: the biological sludge are stored in the clarifier in the absence of pump providing recirculation and extraction. Storage volumes are approximately 100L / PE. These volumes might allow sludge extractions at higher frequencies than 6 months. However, the storing time of the sludge in the clarifier, several months, is particularly long and may cause a risk of anaerobic and denitrification in the clarifier. Yet these reactions, which necessarily come with sludge departures degrade the quality of the effluent. Only very frequent draining would partially mitigate these phenomena.

All other systems have both a primary settling tank and a clarifier. The assumption for calculating the volume of storage of mixed sludge concerns only the dedicated volume of the primary clarifier. In general, the nominal volume of storage of mixed sludge ranges from 0.15 to 1.125 m3, a ratio of 7.5 between the smallest and largest dimensions. Reduced to the population equivalent and for smaller sizes, the storage volumes go from 37 L to 187 L, that is a ratio of 5 between these two extremes. We should find the same variation factor for draining intervals. On the storage of mixed sludge, devices designed with several tanks have capacities greater than those of single-compartmented tanks.

CONCLUSION

Attached growth system on fine media

Reduction of areas leads to an intensive use of certain filters. Filters filled with zeolite, coconut shavings, then rock wool operate at applied loads, respectively 4 times, 5 to 6 times and then from 13 to 16 times greater than those applied to the vertical sand filter. The development of biomass requires more frequent renewal of the support material. Manufacturers actually recommend renewing coconut shavings on average every 10 years; for rockwool, the renewal frequency ranges from 4 to 8 years or even sometimes 10 years according to the major two manufacturers. For systems in which plants are fixed (the operation of which is similar to the reed bed filters with vertical flow), the daily surface load applied on the 1st floor ranges between 14 and 30 gDBO5 / m2, depending on whether the filter is preceded by a septic tank or not. In public sanitation, the corresponding daily load is 41 g BOD_5/m^2. Both systems “Autoepure” and “Jardin d’assainissement” operate on daily

surface applied loads below this standard value used in public sanitation. Again, the implementation (or not) of an alternation, on a limited number of panes (2 instead of 3) is an element which gives insight into the design adequate to the context of on-site wastewater treatment.
The government approved systems, less used in on-site conditions than collective sanitation are:
-“Enviro-septic”,
-“Autoépure”
- the “Jardin d’assainissement”.
All other approved systems support higher applied daily loads in on-site conditions than in public sanitation.
It is out of the question to reduce the dimensions of a system by fixed cultures on fine media to the only applied surface load which is presented here as a first indicator compared to known values in public sanitation. It is obvious that other factors such as the nature of the materials, the quality of the distribution, the design (air intake, for example), the septic tank, etc. should be taken into account to assess a system as a whole and identify priority constraints of maintenance and particularly replenishing material obligations.

Activated sludge system

On the “water line”, given the F/M ratio, it seems that almost all commercialised systems in activated sludge and SBR are oversized. The main consequences of this oversizing are high energy consumption, considering the amount of pollution to be treated and the risk of nutritional deficiencies that can cause the development of filamentous bacteria. Those are particularly unfit for the settling process. The negative impact on the performance of activated sludge systems are well known in public sanitation.
Regarding the clarifiers sizing, the advantage goes to SBR systems. Because of the solid / liquid separation in the biological reactor, they have climbing speeds lower than conventional activated sludge. However, SBR systems generally have a greater automation component than conventional activated sludge. In case of malfunction, this is very detrimental to their performance, for instance, draining treated water at the time of the aeration phase. It should also be noted that among the activated sludge devices, those composed of several tanks generally are better suited to the settling process, than those composed of a single-compartmented tank.
On the “Sludge line”, volumes dedicated to storage are highly variable from 37 to 280 L for 1 PE. Systems having low storage capacity will result in a higher cost in terms of operation including high frequency of draining of the sludge storage tank.
Generally, single-tank devices have lower storage capacities than multiple-tanks devices. Three main situations can be found:
• Separate storage of primary sludge and biological sludge
• Storage in the clarifier
• Simultaneous storage of mixed sludge in the primary clarifier
Storing biological sludge in the clarifier is rather unexpected. Long storage times necessarily imply anaerobic degradation or anoxia with denitrification in the clarifier. Yet these reactions are accompanied by sludge departures, very detrimental to the quality of the treated water.
Only frequent emptying would partly make up for these phenomena. In the absence of extraction pump within the clarifier, biological sludge is voluntarily stored in this item.
As a conclusion, although the design of the "water line" seems to approach the bases used in public sanitation, the integration of the "sludge line" within this system raises the issue of frequency of draining biological sludge necessarily produced by the basic principle of

purification by biological means. These frequencies have a direct impact on maintenance costs for the owner.

Next step is to carry out the same work on the biofilm reactor. It will allow us to undertake an inter-group comparison and to help citizen choose their system.

All this theoretical analysis highlights various design problems and requires an ever-increasing vigilance and maintenance by individuals. In addition to this literature review, we have started a follow-up study to take stocks of the possible malfunctionings that can take occur. This inspection involves in-situ measures in actual working conditions of the products in order to confirm our fears by testing the effluents quality from these on-site facilities.

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