Waste stabilisation ponds in France: state of the art and recent trends

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Abstract Waste stabilisation ponds represent 20% of the total number of wastewater treatment plants in France. Practical expertise acquired during these last 20 years has led to modification in the design of the first facultative basin of WSP systems. Its active surface area is now dimensioned at 6 m$^2$(p.e.)$^{-1}$ in order to limit the risk of malfunctioning. The cumulated surface of the 2nd and 3rd basin is maintained at 5 m$^2$(p.e.)$^{-1}$.

Another practical point is also that WSPs must receive mainly diluted influents. Globally, the plants are on average far from their nominal loadings, which explains why the first sludge removals took place on average 13 years after being put in operation. Based on a representative sample of plants, i.e. 15% of the French WSPs, it has been possible to estimate the time, material means and cost needed for sludge removal as well as the amount of sludge accumulated. The sludge removed at the 1st yields on average 110 L (p.e.)$^{-1}$ which represents 12 kg DM (p.e.)$^{-1}$. The current trend of increasing the quality levels necessary for discharge into sensitive receiving bodies has led to adaptive solutions of polishing treatments by intermittent sand filter systems with or without the plantation of reeds.

Keywords Design; domestic wastewater; effluent quality; pond malfunction; sludge production; waste stabilisation pond

Introduction

The use of Waste Stabilisation Ponds (WSP) to treat wastewater has increased greatly in France since the end of the 1970s and is frequently chosen by small rural communities. There are now some 2,500–3,000 WSP installations each for on average 600 person equivalent (p.e.) representing 20% of sewage treatment plants. Some coastal plants are much bigger because of increased loading from tourists in summer. These 25 years of experience in the use of WSPs under French conditions has allowed us to study their functioning and better define the optimal conditions for their use. This article presents a summary of the results gathered either by Cemagref or local surveillance organisations (SATESE) together with the consequences resulting from design or operation of the plants.

Materials and methods

Different data sources were used:

- results gathered by SATESE whilst studying the quality of treated wastewater (Racault et al., 1995), improvements in quality (Boutin et al., 2003) and more recently sludge treatment;
- a summary of the results from monitoring carried out on 102 WSP over 3 years in the Ille-et-Vilaine area (department) of France (Delouveé, 2002);
- results from studies on several annual cycles of operation initially carried out to analyse the causes of malfunction of WSPs (Racault, 1993).
Results and discussion

Characteristics of WSP plants and feeding

During the last 20 years WSPs have assumed an important role in the treatment of domestic wastewater in France, especially in rural areas. Even though in total they handle only 1–2% of wastewater to be treated, they represent 20% of treatment sites in France, and up to or even more than 50% in certain rural areas.

A national survey (Boutin and Racault, 1986) was able to establish the exact number of WSPs in the different French departments 10 years after their introduction. Their rapid development was obvious. Their simplicity had answered the needs of many small communities where traditional methods had resulted in unreliable or unsatisfactory outcomes.

During the last 10 years the increase in installations has declined rapidly for several reasons: the very small size of communities still to be served; certain increased quality standards for treated wastewater which cannot be attained by WSPs (level D4 in Table 1); and finally the loss of interest by certain consultants.

Nevertheless, in certain departments where the technique has been used successfully; construction has continued steadily. The average size of WSP plants in France is still about 600 p.e. The average loading cannot be calculated accurately because measurements in such small plants where there is usually no electricity are limited.

A survey carried out by Cemagref in 1992 (Racault et al., 1995), found the average organic loading for all ponds to be 25 kg BOD₅·ha⁻¹·d⁻¹ the majority of which did not exceed 50% of the expected loading. A recent study in the Ille-et-Vilaine department (Delouveé, 2002) showed a similar average BOD loading of: 27 kg BOD₅·ha⁻¹·d⁻¹. The majority of WSPs in France are therefore under-loaded in comparison to their original design. The quantity of waste water treated is very variable. WSPs are often chosen for non-separated systems which accept water infiltration. Hydraulic loads can be high especially in winter (Racault et al., 1995).

Performance of existing plants

A survey of plants for which results were available in 1992 gave overall values for the quality of effluent for separated and combined networks as well as overall averages. These results showed large variations in all parameters which were indicative of variability of influent and seasonal differences with more or less dilution depending on the plant. Racault et al. (1995) showed that it can be difficult to obtain values in line with European standards (Table 1) if the networks are too separated.

Recent measurements (Delouveé, 2002) confirm the averages found in 1992. For these plants located in Brittany the BOD loading was between 16 and 48 kg BOD₅·ha⁻¹·d⁻¹ and the average age was 11.6 years. Table 2 shows a series of 317 measurements of which 30% were taken in summer (June to September). The figures are close to those obtained previously from non-separated networks (Racault et al., 1995). This can be explained by the frequent influx of rain and drainage water into WSPs in Brittany.

Whatever the cause, the results must be seen in relation to the organic loading which is, on average, well below the nominal loading. Due to long retention times there are

Table 1 European and/or French standards

<table>
<thead>
<tr>
<th>Load (kg BOD₅·d⁻¹)</th>
<th>COD₅'** = 120 mg·L⁻¹</th>
<th>SS = 150 mg·L⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>European/French Standard*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>For load &gt; 120 kg BOD₅·d⁻¹</td>
<td>COD₅'** = 120 mg·L⁻¹</td>
<td>SS = 150 mg·L⁻¹</td>
</tr>
<tr>
<td>For load &lt; 120 kg BOD₅·d⁻¹</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D3 level''</td>
<td>Yields: 60% for COD and N-NK</td>
<td></td>
</tr>
<tr>
<td>D4 level''</td>
<td>BOD₅ = 25 mg·L⁻¹</td>
<td>COD = 125 mg·L⁻¹</td>
</tr>
</tbody>
</table>

*values for WSPs
**COD₅': filtered COD
disparities in flow between influent and effluent. And thus, the removal must be calculated on loads. This method of calculation is more favourable to WSPs, especially in summer, and more representative of the actual effect on the receiving body. It has been used in France since 1997 when the D3 level was made compulsory by legislation (Ministère de l’Equipement, 1997).

Performance is obviously very dependent on/linked to seasonal variations. Additionally, the summer season favours WSPs processes as regards certain parameters measured on filtered samples at the same time as the receiving bodies become more sensitive. The age of the plant, as long as there is no excess sludge, seems to have little effect on carbon or nitrogen levels.

**Main causes of malfunction**

A certain amount of malfunction has appeared in WSP plants over the years. The main signs are a disappearance of algae, absence of oxygenation and olfactory nuisance. The phenomenon of “red water” can result if the number of phototrophic sulphur bacteria increases. These effects are most noticeable in autumn when decrease in day length and temperature can lead to a more or less sudden disappearance of the algae biomass (Racault, 1993). There are several causes for this but the most common factors, either singly or together, are as follow.

- Concentrated domestic wastewater (annual average $\text{BOD}_5 > 300 \text{ mg.L}^{-1}$) and presence of industrial wastewater are both risk factors.
- Organic overloading of the first pond even if only seasonal.
- Septic influents, which affect the stability of the pond’s ecosystem.
- Too deep a first pond. The thermic stratification formed in spring and summer in small ponds protected from the wind is destroyed in autumn and the layers are mixed. The consequences are related to the amount of water in an anaerobic condition.
- The shape of the pond. An elongated form leads to plug flow and consequent organic overloading of the first part of the pond.
- Accumulation of sludge in the sedimentation cone or over the whole first pond can lead to local anaerobia and the beginning of malfunction.

These phenomena can be the result of operational faults/poor maintenance which can be rectified or design faults. The observation of these problems in existing WSPs led to the modification of the French design adopted between 1975 and 1995.

**Design in France**

As a result of experience several changes have been made to the design recommendations established in the 1980s (Figure 1).

To ensure adequate functioning 3 ponds in series are necessary. The third pond even if it improves the performance little ensures good quality treatment during sludge removal of the first pond. Some departments recommend 4 ponds to increase holding capacity and improve disinfection.

### Table 2: Average quality of outflow from Brittany WSPs in mg.L$^{-1}$ (Delouveé, 2002)

<table>
<thead>
<tr>
<th>Period</th>
<th>$\text{COD}_f$</th>
<th>TSS</th>
<th>N-NK</th>
<th>N-$\text{NH}_4^+$</th>
<th>TP</th>
</tr>
</thead>
<tbody>
<tr>
<td>June–September</td>
<td>average std-dev</td>
<td>95</td>
<td>38</td>
<td>74</td>
<td>68</td>
</tr>
<tr>
<td>October – May</td>
<td>average std-dev</td>
<td>71</td>
<td>29</td>
<td>50</td>
<td>45</td>
</tr>
<tr>
<td>Total year</td>
<td>average std-dev</td>
<td>78</td>
<td>34</td>
<td>57</td>
<td>54</td>
</tr>
</tbody>
</table>

$\text{COD}_f$: filtered $\text{COD}$
The first pond. The main change in the first facultative pond is in regard to its dimensions. The behaviour of the first pond is essential to the performance of WSP systems. It was noticeable that there was a decrease in performance and increased risk of malfunction in the first pond when the loading was approaching the previous French recommendations. Consequently the recommended size for the first pond is now 6 $m^2$ (p.e.)$^{-1}$ (Table 3).

Taking the actual average load produced per person in rural areas to be 35–40 $g$ BOD$_5$ d$^{-1}$ (Pujol and Liénard, 1990), the actual maximum surface load in the first pond rises to 58–67 $kg$ BOD$_5$ ha$^{-1}$ d$^{-1}$.

When there is a large volume of rain or drainage water and ensuring watertight conditions is not too expensive, the size can be increased to 7 $m^2$ (p.e.)$^{-1}$ to maintain good levels. For plants serving a variable population during hot weather the loads can temporarily exceed the nominal value for several days as long as it is not doubled.

The recommended depth for the first pond in the literature is 1.5–1.75 m (Mara and Pearson, 1998). However, to ensure reliability it is important to limit the effects of a sudden demand for oxygen. For example, following a thermal de-stratification at the end of summer, the mixing of the amount of anaerobic water may induce a dramatic increase of oxygen demand. In order to maintain a sufficient quantity of aerobic water the recommended depth is therefore 1 m with a maximum of 1.2 m.

Increasing the depth beneath the pond inlet is recommended to facilitate removal of accumulated sludge. An extra depth of 1 m is recommended. This area should be limited to a few square metres to allow for easy sludge removal with vacuum liquid manure tanker. In some departments the first pond is always preceded by a small settlement tank which is emptied several times a year.

The shape of the first pond must not lead to plug flow in order to prevent organic overloading near the inlet. An ovoid shape is therefore recommended with a ratio of length to width of $\approx 3$. Baffles in the first pond generally serve no purpose and can even lead to dead zones (Racault and Boutin, 1984).

The third pond. During the 1980s, at the beginning of WSP development in France, putting shallow-rooted plants in the 3rd pond was advised. The presence of vegetation can

### Table 3 Differences in nominal and maximal loadings in the first facultative pond

<table>
<thead>
<tr>
<th>Surface of 1st pond</th>
<th>Theoretic p.e.</th>
<th>Actual loading per person (p)</th>
<th>Nominal (kg BOD$_5$ha$^{-1}$d$^{-1}$)</th>
<th>Actual maximum (kg BOD$_5$ha$^{-1}$d$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before 1997</td>
<td>5 $m^2$ (p.e.)$^{-1}$</td>
<td>50</td>
<td>100</td>
<td>35–40</td>
</tr>
<tr>
<td>After 1997</td>
<td>6 $m^2$ (p.e.)$^{-1}$</td>
<td>50</td>
<td>83</td>
<td>58–67</td>
</tr>
</tbody>
</table>

$p$: person connected to the sewerage system
improve quality both by providing shade which minimises algal development and by taking nutrients out of the pond. Statistical comparison of planted and unplanted ponds could neither prove nor quantify this benefit (Cemagref, 1997).

To attain the desired effect the vegetation must be cut back and removed in autumn to prevent the build up of a layer of anaerobic decomposing organic matter. Such harvesting should be performed by someone standing in the water to use special cutting tools after which the vegetation must be removed. This operation is rarely carried out correctly, so in reality the third pond is no longer planted and is the same depth as the other two.

Putting an “island” in the third pond encourages the presence of ducks which, if introduced in the spring, stay and keep the pond clear of duckweed.

Sludge removal

It is essential to remove anaerobic sludge from the bottom of the ponds. A survey was carried out to define optimal conditions for this difficult operation in 5 French departments (A, B, C, D and E). This sample represents about 15% of the French WSP plants (Table 4). Very variable experiences were reported. The number of removal sites was between 6 and 26 representing 8–50% of the total number of plants per department. Analysis of the results for all parameters both globally and by department confirms the variability of local practice.

The ponds cleared were on average 590 p.e., in line with the average French size. They were generally cleared for the first time after about 13 years of operation whereas between 7 and 10 years was usually recommended. There were some late sludge removals (26 years) because of low organic loading. The 3 early clearances are harder to explain.

An estimation of the actual load is rarely available. The loading is calculated from the number of people actually using the system (easily available figures) in relation to the nominal capacity multiplied by a coefficient of 0.8 to take the difference between the actual number and theoretical p.e. into account (Table 3). The average organic loading at desludging was 90%, far above the usual figure of 50%, which shows that clearance is most necessary in plants operating close to their nominal loading.

The main reasons for desludging were the age of the installation plus additional signs, visual, such as sporadic surfacing of sludge or milky colour of the first pond or occasional olfactory nuisance. For small plants, physico-chemical measurements are not taken often enough to show deterioration as a result of excessive sludge.

Usually the first step in sludge management is to take bathymetric measurements of the sludge depth to identify areas of accumulation. This is carried out over all the ponds. These measurements are taken from a boat, usually guided by a kind of grid on the surface, every 25–100 m² depending on the size of the pond. The successive steps are: estimation of the depth of sludge using an SS meter or ultrasonic probe; estimation of the depth of the pond using a rigid measure; and calculation of the difference between the two to obtain the actual depth of sludge.

This initial evaluation seems simple but requires a lot of organisation. For a medium-sized plant at least three people are needed for a whole day. Larger plants take longer but not in direct relation to the area to be measured. A technician is also needed for a day as his experience in overseeing and interpreting the findings is essential. Those who make these bathymetric measurements, usually SATESE operators, consider them to be the basis for good future operation. Contacts between municipal authorities and sludge clearance companies are now in fact based on them.

If the depth of sludge is more than 25 cm desludging is necessary. For water depths of between 1 and 1.2 m this amount of sludge represents 20–25% of usable volume. The
Table 4 Summary of results from sludge removal

<table>
<thead>
<tr>
<th>Département</th>
<th>Number of ponds in department</th>
<th>Number of ponds cleared</th>
<th>Year put in service</th>
<th>Size</th>
<th>Age</th>
<th>Organic loading at desludging</th>
<th>Amount of sludge from the first pond</th>
<th>Cost of the operation (exclusive of VAT)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>p.e.</td>
<td>year</td>
<td>%</td>
<td>cm</td>
<td>cm.y⁻¹</td>
</tr>
<tr>
<td>A</td>
<td>?</td>
<td>6</td>
<td>1985</td>
<td>850</td>
<td>19.0</td>
<td>46</td>
<td>31.5</td>
<td>1.7</td>
</tr>
<tr>
<td>B</td>
<td>114</td>
<td>26</td>
<td>1987</td>
<td>605</td>
<td>11.9</td>
<td>?</td>
<td>21</td>
<td>1.6</td>
</tr>
<tr>
<td>C</td>
<td>130</td>
<td>15 + 2 ✷</td>
<td>1985</td>
<td>570</td>
<td>14.8</td>
<td>110</td>
<td>33.8</td>
<td>1.95</td>
</tr>
<tr>
<td>D</td>
<td>30</td>
<td>16 + 5 ✷</td>
<td>1983</td>
<td>500</td>
<td>11.5</td>
<td>81</td>
<td>25.9</td>
<td>2.75</td>
</tr>
<tr>
<td>E</td>
<td>88</td>
<td>9</td>
<td>1986</td>
<td>575</td>
<td>14.1</td>
<td>97</td>
<td>25</td>
<td>1.80</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td></td>
<td>1986</td>
<td>590</td>
<td>13.1</td>
<td>91</td>
<td>25.5</td>
<td>2.05</td>
</tr>
<tr>
<td>Max value</td>
<td></td>
<td></td>
<td>1998</td>
<td>3000</td>
<td>26</td>
<td>194</td>
<td>57</td>
<td>6.6</td>
</tr>
<tr>
<td>Min value</td>
<td></td>
<td></td>
<td>1977</td>
<td>120</td>
<td>5</td>
<td>17</td>
<td>3</td>
<td>0.4</td>
</tr>
<tr>
<td>standard deviation</td>
<td></td>
<td></td>
<td></td>
<td>4</td>
<td>4</td>
<td>37</td>
<td>13.7</td>
<td>1.36</td>
</tr>
<tr>
<td>Number of values</td>
<td></td>
<td></td>
<td></td>
<td>71</td>
<td>71</td>
<td>67</td>
<td>45</td>
<td>27</td>
</tr>
</tbody>
</table>

*number of ponds desludged twice
time between measurement and clearance is about a year due to financial constraints, it is not often provided for in the budget, and to technical aspects such as physico-chemical analysis and drawing up of land spreading plans. With the average loading conditions of the French WSPs, bathymetric measurements should therefore be taken after 10–12 years of operation.

During desludging wastewater is diverted to the second pond and various amounts of supernatant water remaining in the first pond are transferred to the following ponds by various means. The sludge is then removed by one of four techniques.

- Direct pumping out without emptying the pond. This method is discouraged as it does not permit the quality of the work to be seen.
- Supernatant water is partially removed leaving a depth of about 20 cm and a floating platform is used to guide the pump according to the texture of the evacuated sludge. A pipe takes the sludge directly to a liquid manure tanker which transports it to the chosen land-spreading area. This method is used in 35% of cases, even though it is difficult at the edges where sludge usually accumulates. It should always be used where a membrane could be damaged by use of machinery in the pond. There are no data related to this type of pond as they are too recent.
- Supernatant water is evacuated until the sludge is visible. A wetland bulldozer with large caterpillar tracks is then used inside the pond to push the sludge towards a pump. This is a well favoured method (38% of cases) as the results are visible.
- The above method is used but the sludge, instead of being pumped out, is left to dry for a considerable time in order to reduce its volume. This prevents the use of the pond for a long time so this technique is seldom used (5% of cases).

Usually the sludge is spread on the nearest available agricultural land, which has been clearly identified in the clearance plan, as it is removed. Several tankers are used in rotation. It is not always possible to organise this so in 10% of cases the sludge is temporarily left in a zone marked by small dykes to dry out for at least 6 months. The well dehydrated sludge is then spread on agricultural land.

To calculate the actual volume of sludge removed the technical services count the number of tankers filled and measure the surface area of the pond. The average depth of sludge measured was 25.5 cm. The large coefficient of variation (55%) shows the differences between departments. By taking the age of the plant into account the annual increase in sludge in the first pond was found to be 2 cm, in line with current estimations.

If this annual volume of sludge is compared to the nominal capacity of the plant the average accumulated volume of sludge is 110 L(p.e.)\(^{-1}\)y\(^{-1}\). Unfortunately these values do not take the increase in organic loading into account for which figures are not available. Whatever unit is used to express the volume, the large standard deviation clearly demonstrates the variability. These results are from 27 clearances of 1st ponds only.

There were only 12 whole WSP system desludging operations. Here the annual accumulation was large (2.3 cm y\(^{-1}\)) corresponding to a much higher volume, 200 L(p.e.)\(^{-1}\)y\(^{-1}\). This surprising result can be explained by the following: in one case accumulated duckweed was not removed in the previous desludging 10 years before, and in the other case the desludging happened after 15.5 years of operation. It is therefore possible that very large hydraulic loadings had swept sludge out of the first pond into the others.

There were 19 mixed clearances where the sludge was removed from the whole first pond and a part of the others. Here the average sludge volume was 140 L(p.e.)\(^{-1}\)y\(^{-1}\).

The sludge is systematically analysed to ensure it complies with regulations on land spreading. Such analyses should be viewed with caution, however, as samples could be taken: before evacuation of the water, during desludging when one cannot be sure that it
is entirely representative or according to a protocol, after storage and before spreading. Data on dry weight in the first two cases is only based on 12 samples. The average DM of this small sample was 8.5%, ranging from 0.8% to 14.2%, with a standard deviation of 4.1. In the last case, before spreading, dry weight was more than 200 g kg⁻¹, i.e. 20% dry matter content (DM).

It is impossible to equate the DM to the method of desludging. Despite all these reservations it is possible to give an annual accumulation of sludge of about 12 kg DM(p.e.)⁻¹ approximately as the SS entering. This can be explained by the fact that the reduction due to anaerobic mineralization is balanced by the addition of the degrading algae and bacteria.

It is also difficult to calculate the average cost of desludging. Figures given usually include the cost of preliminary and spreading plans plus the whole clearance operation but not the chemical analyses. Sometimes the banks are repaired at the same time and this cost is included. The average cost of desludging and land spreading thus calculated was 24 € per m³ before tax (Table 4). The annual budget should allow for 3.20 €.(p.e.)⁻¹ before tax. The factors already mentioned explain the large differences (coefficient of variance of 60%). In the year 2000 the investment cost, depending on the size of the plant, was 100–160 €.(p.e.)⁻¹ before tax and desludging represented an operating annual cost equivalent to 2–3% of this amount.

Future developments
The increased quality necessary for sensitive receiving bodies has led to the need for complementary treatments. At present research focuses on the use of intermittent sand filter (ISF) systems at the output of WSP plants. This system brings together the hydraulic capacities of WSP and the useful properties of ISF in the removal of residual organic matter and complementary nitrification. A quality of level D4 (Table 1) should be obtained. In the framework of a European Union LIFE programme, we set up a demonstration plant to try to solve the problems of small rural communities that are already equipped with networks, part of which are combined (Boutin and Liénard, 2004). The objective is to demonstrate a treatment system simple enough to be run by local people who have no specialist knowledge in the field of wastewater treatment but who are willing to invest some time. However, it must be noted that such a result can only be obtained by keeping strictly to alternate feeding of the filters which necessitates 2 visits a week, which a classical third pond does not. At the end of 2005, we hope to be able to define: the technical characteristics of new systems based on WSPs in combination with ISFs (one or two ponds, etc.) in terms of the quality of effluent. The hydraulic limitations of such plant. And the operation and maintenance costs of such plants.

Adding a vertical flow constructed wetland (VFCW) at the entry of an existing WSP should be considered when there is an organic overload of the first pond. Such a modification was studied by Liénard et al. (1993) and a quality of level D4 was obtained. Studies should be performed to confirm that algae discharge using these installations, 5 m²(p.e.)⁻¹ pond after a 1 m²(p.e.)⁻¹ VFCW, does not adversely affect COD and SS of effluent and that D4 quality levels can be maintained.

Conclusion
Waste stabilisation pond systems remain a widely used technique for the treatment of wastewater for rural areas in France. Recent data confirm that on average the plants receive an organic loading clearly lower than the one on which their design is based. Their performance in terms of removal calculated in flux achieves the D3 level of the French regulations. Nevertheless, there have been modifications of the design in the last
few years to redress malfunctions observed. These changes are most notably the increase
in size of the first pond to 6 m$^2$(p.e.)$^{-1}$ which should not receive a BOD loading of more
than 70 kg BOD$_5$d$^{-1}$. Also it seems that ponds function more reliably with a diluted influ-
ent which means that their use for sewerage networks which are totally separated, without
any infiltration or inflow, is not recommended.

Sludge removal is still a major maintenance operation whose annual cost may rep-
resent 2–3% of the investment cost. Taking the low loadings received during the first
few years of operation into account, the first sludge removal is usually after about 13
years of operation when the organic loading is reaching its nominal value. Statistical
analysis shows a large variability of results despite which it is possible to estimate a
figure of about 110 L(p.e.)$^{-1}$ which represents a dry matter value of 12 kg SS(p.e.)$^{-1}$.
A second sludge removal seems to be necessary after about 10 years when sludge is
removed from all ponds giving a possible total volume of 200 L(p.e.)$^{-1}$.

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