SEPTIC TANK SLUDGES:
ACCUMULATION RATE AND
BIOCHEMICAL CHARACTERISTICS

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ABSTRACT

A three year field and investigative study carried out on 33 individual sanitation systems showed that the
frequency of septic tank emptying could be at least 5 years, corresponding to a sludge accumulation rate of
0.2 l/user.day. This value should be included in the calculation of septic tank sizing. Other data showed
within a septic tank the methanogenesis is only effective after 2 years of operation. Thereby a septic tank
should not be desludged before this period of time. At last, among all the physico-chemical parameters
monitored to study the sludge quality, the best indicators of system failures were both the solids (TS and VS)
and soluble matter (COD and some VFA). Then, biochemical study of septic tank sludge showed that the
main hydrolytic enzymes (cellulase, phosphatase, protease, lipase and urease) are present in septic tank
sludges and linked to the insoluble particles. Their solubilization with different solvents (buffers,
surfactants...) showed each enzyme was linked in a different way.

KEYWORDS

Anaerobic digestion; enzymatic activity; hydrolysis; methane; on site wastewater treatment; process design
and management; septic tank; sludge.

INTRODUCTION

Individual sanitation systems consisting of a septic tank followed by underground soil infiltration
percolation have long been used as palliative wastewater treatment. This type of treatment may, however,
also be an effective solution over a long period in dispersed housing areas and small communities (up to 300
P.E.) when it is well designed. The septic tank ensures the hydraulic settling of solid matter as well as
having a biological function in liquefying organic matter by methanogenic fermentation. Thus cleared of its
suspended solids, the pretreated wastewater is directed towards a system of percolation (the ground itself, a
sand filter, etc) which carries out both the disinfection and the microbiological oxidation of the organic
matter.

In France, almost 3 million installations are used by 10 million persons. Each year, a volume of 3 million m³
of sludge and septage removed from septic tanks has to be treated. Non collective wastewater treatment is

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now considered as a full treatment process by the Water Act of January 3rd 1992. Its regulation is administered by the municipal authorities. For practical reasons of inaccessibility to the percolation, only the septic tank part of the process can be controlled. However, the design and maintenance of septic tanks are still frequently established on arbitrary bases, and notable differences in practice are still observed between European countries. As shown in Table 1, one of the main issues is the time interval between tank emptying dates. This particular parameter depends directly on the efficiency of the tank since optimal anaerobic digestion reduces the sludge accumulation rate. The complex biochemical processes linked to methanogenic fermentation occur within the sludges themselves, as with all anaerobic digesters.

**TABLE 1. Differences of Septic Tank Sizing and Maintenance in Some European Countries (Philippi, 1992)**

<table>
<thead>
<tr>
<th>Countries</th>
<th>Rate of sludge removal (year)</th>
<th>Volume recommended m³/users</th>
</tr>
</thead>
<tbody>
<tr>
<td>Italy</td>
<td>0.3 to 1</td>
<td>1/5</td>
</tr>
<tr>
<td>Belgium</td>
<td>0.5 to 1</td>
<td>1/5</td>
</tr>
<tr>
<td>Great Britain</td>
<td>1</td>
<td>2.4/4</td>
</tr>
<tr>
<td>Germany</td>
<td>1</td>
<td>6/4</td>
</tr>
<tr>
<td>France</td>
<td>5 max</td>
<td>2/3</td>
</tr>
<tr>
<td>Switzerland</td>
<td>1</td>
<td>6/3</td>
</tr>
</tbody>
</table>

The aims of this study were to quantify the sludge accumulation rate, this in fact determining the need to clean the tank, and to define the biochemical nature of the sludge determining the behaviour of the wastes.

Firstly, a three year field and investigative study was carried out on approximately fifty septic tanks located in the South of France. Each year an important campaign of measuring and sampling in situ was undertaken in the selected sites. The results have enabled a distinction to be made between "good" and "bad" tanks.

The second part of this work deals with the biochemical nature of the septic tank sludge. As for all anaerobic digestors, the hydrolysis of organic macromolecules by extracellular enzymes initiates the process of the biodegradation of organic matter. Many hydrolytic assays were carried out firstly to evaluate the relations between the enzymes and their micro-environment, and also to enable a better understanding of the overall biodegradation process.

With the results obtained, it is possible to contemplate a 'scientific' management of individual or semi collective sanitation systems.

**MATERIALS AND METHODS**

**Sludge Accumulation in Septic Tanks** (Lesavre et al., 1993, Philippi et al., 1992).

**Systems, sites and assay schedules.** The sanitation systems studied were septic tanks spread over 12 municipalities in the Montpellier region (Hérault, France). The tanks treated complete domestic wastewater (i.e. grey and black water). 33 tanks were selected, each undergoing 3 measurement operations from 1988-89, 1989-90 and 1990-91 carried out in the months of December and January. At the first operation the tanks were aged from 3 to 33 months after the initial installation or the last emptying. The tank volumes ranged from 2 to 4 m³ with over 80% at 3m³. The number of users varied from 2 to 5 with an average of 3.7 per installation.

**Sampling and analysis.** At each annual campaign, samples and measurements of the height of the sludges were taken in each tank using a peristaltic pump. The thickness of the matter floating at the surface (scum layer) was noted at the same time. The volume of sludge is the sum of the volume of settled solids plus the volume of floating solids. The sludges withdrawn were analysed for the following parameters according to the AFNOR French standard methods: pH, Eh, TS (Total Solids), VS (Volatile Solids), soluble COD (Chemical Oxygen Demand), CH₄ (Methane) and VFA (Volatile Fatty Acids) were analysed by gas chromatography. Methane production was evaluated by placing a sludge sample at 20°C for 3 weeks.
To express the results, the tanks were divided into 7 six-month age groups (from 0.5 to 3.5 years of use). Each age group was given between 7 and 22 values for each parameter measured. There were 93 values in total. Thus the standard deviation of the mean values was calculated (Student's test at 95%), and a definition of significant evolution in the parameters measured or observed over the time periods.

Enzymatic Activities in Septic Tank Sludges (Maunoir et al., 1991).

Detection of hydrolases within septic tank sludges. After sampling of the sludges by means of a peristaltic pump, the pellet and the supernatant were separated by centrifugation (2460g - 15 mins.) The supernatant was ultracentrifuged (142000g - 1 hour) to eliminate all traces of suspended solids. Enzymatic activity was investigated in the pellet and in the interstitial liquid. The activities tested were as follows. Protease activity: protease activity at pH 8, 37°C, was evaluated by measuring the optical density at 280nm using casein as substrate. Phosphatase activity: it was evaluated by measuring the optical density at 400 nm of the paranitrophenol, a yellow compound, resulting from the transformation of paranitrophenyl phosphate at 37°C, pH 5.5. Cellulase activity: this was determined by incubating the samples (37°C) in the presence of carboxymethyl cellulose at pH 4.5. Liberated reducing sugars was assayed with a colorimetric method at 700 nm. Lipase activity: tributyrin was hydrolyzed at 25°C and pH 7.5; liberated butyric acid was measured at constant pH with 0.05 N NaOH using an automatic titrimer. Urease activity: urea was hydrolysed at 25°C and pH 7.5; the ammonium hydroxyde was titrated at constant pH with 0.01N HCl using an automatic titrimer. These activities are expressed in micromoles of product released per minute, except protease activities given in optical density.

Study of hydrolases - solid particles binding. After separation of the pellet and the supernatant by centrifugation (3800g, 15 mins), different fractions of the pellet were washed with the following solutions: distilled water; Tris-buffer / HCl 0.2 M pH 9; Triton X-100, 0.3 %, pH 9. The washing consisted in suspending the sludge pellets in a vibrated solution (1g of solid matter in 20ml, 800 vibrations.min-1). The supernatant is then recovered by centrifugation (7570g, 15 mins.), ultracentrifuged (142000g, 1hr) to eliminate all traces of solid matter and then dialysed overnight in running water to remove the salts. Residual enzymatic activity in the suspensions of washed pellets is determined according to the techniques described above.

RESULTS AND DISCUSSION

Sludge Accumulation in Septic Tanks

Clogging of septic tanks by sludges. The trend of sludge volumes per user is shown in Fig. 1.
After a growth phase up to approximately the 2nd year, the volume of sludge accumulated tends to stabilize then decrease with time. The trend is significant on a statistical level, with the maximum reached at the end of the 3rd year. In 3 years the real mean volume is 245 \( l \pm 94 \), i.e. 82 litres/person.year, then 60 litres/person.year after 3.5 years. These values can be compared with the data of the literature: 80 \( l \) (Brandes, 1978), 71 \( l \) (Jones, 1974), 69 \( l \) (Weibel, 1954, USA in Brandes, 1978); the Public Health Service of the USA however requires 40 \( l \) and the Swiss norm is 360 to 440 (in Edeline, 1983). 180 \( l \) can be found in Great Britain (Jones, 1974) and south Africa (Edeline, 1983).

**Trend of sludge accumulation rate.** With the number of users the sludge accumulation rate can be calculated according to the time the tank has been in operation (the interval between 2 emptyings). The results are represented in Fig. 2.

![Graph showing sludge accumulation rate over time](image)

Fig. 2. Evolution of the sludge accumulation rate.

It can be seen that the sludge accumulation rate stabilises in the tank's first year around the value of 0.2 \( l/\text{person.day} \). This figure tends to decrease from the third year. In six months (from 3 years to 3.5 years) the accumulation rate falls from 0.223 to 0.163 \( l/\text{person.day} \).

The fall in accumulation rates in time is a normal trend that is inherent to anaerobic digestion, a process occurring in successive phases (hydrolysis, acidogenesis, and methanogenesis). In a septic tank the biological reactions are quite slow in starting and until recently it was thought that the permanent level was reached only after 2 years of service. The biological balance of a septic tank may only be reached after 4 or 5 years, and in all cases, after 5 years of service the sludge accumulation rate should be estimated at 0.2 \( l/\text{person.day} \). On this basis the theoretical production of sludge per user in 5 years is 365 litres. The septic tank volume to be allocated to each user is 730 litres so as to maintain a 50\% minimum volume for the settling of wastewater.

We can thus recommend the following tank volumes, for a 5 year emptying cycle:
- up to 4 users: 3\( m^3 \)
- up to 6 users: 4\( m^3 \)

In the majority of cases the 50\% reserve volume margin for settling offers a high level of security. The sludge accumulation rate is the most representative operating parameter for the system, being the result of hydraulic, biological and physico-chemical mechanisms developed within the tank.

**The physico-chemical evolution of septic tank sludges.** Figures 3abc show the mean values for the main variables analysed in the samples of sludges taken during the 3 annual campaigns (99 values).
Septic tank sludges

Fig. 3a shows a rapid rise in the first year in the solid matter (TS) and the volatile solids (VS), which then slows down with a widening in the TS-VS ratio. Between 0.5 and 3.5 years the VS moves from 19 to 29 g.l⁻¹ while the TS increases from 27 to 42 g.l⁻¹. The mineralisation of the sludge is appreciable therefore after a year's service. These results are close to those of the literature (table 2).

### TABLE 2. Total and Volatile Solids of Septic Tank Sludges According to Different Authors

<table>
<thead>
<tr>
<th>Authors</th>
<th>TS g.l⁻¹</th>
<th>VS g.l⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brandes, 1978</td>
<td>33.6 - 35.4</td>
<td>-</td>
</tr>
<tr>
<td>Edeline, 1982</td>
<td>27.9</td>
<td>21.4</td>
</tr>
<tr>
<td>Philip, 1983</td>
<td>22.6 - 40.5</td>
<td>16.9 - 26.7</td>
</tr>
</tbody>
</table>

Fig. 3b clearly illustrates the rise in the soluble COD during the first two years followed by a rapid decline. In such a system soluble COD results from the concentration of organic matter dissolved in the interstitial liquids of the sludge by the exoenzymatic degradation of the solid particles. The decrease of the COD after the second year is therefore to be related to the increase of the CH₄ production resulting from the hydrolysed products and VFA consumption. In the course of time a more diversified bacterial community settles in and brings about a more thorough biodegradation. Methane production is indeed quite low (10 ml l⁻¹ d⁻¹) up to the 2nd year (Fig. 3c) and is only really significant after this period.

![Fig. 3a. TS and VS evolution.](image1)

![Fig. 3b. COD evolution.](image2)

![Fig. 3c. Methane Production.](image3)

**Physico-chemical parameter indicators of septic tank failure.** From the first year of service the sludge accumulation rate of a septic tank stabilises around the value of 0.2 l / person.day. This value enables us to distinguish 3 categories of tanks (Fig. 4): 'good' tanks for values below 0.175 l / person.day, 'middle' tanks for values between 0.175 and 0.225 l / person.day and 'bad' tanks for values above 0.225 l / person.day.

![Fig. 4. Accumulation rate as a function of time.](image4)
By comparing the characteristics of the extreme groups, it is possible to define the indicators of performance (Table 3).

### TABLE 3. Mean Values of the Physico-Chemical Parameters for the 'Good' & 'Bad' Tank Groups According to the Nominal Value of the Accumulation Rate (0.2 l/pers. day)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Septic tank &quot;good installation&quot;</th>
<th></th>
<th>Septic tank &quot;defective installation&quot;</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Standard deviation</td>
<td>Mean</td>
<td>Standard deviation</td>
</tr>
<tr>
<td>pH</td>
<td>6.73</td>
<td>0.27</td>
<td>6.62</td>
<td>0.24</td>
</tr>
<tr>
<td>Eh (mV)</td>
<td>-310</td>
<td>78</td>
<td>-339</td>
<td>37</td>
</tr>
<tr>
<td>TS (g.l⁻¹)</td>
<td>36.57</td>
<td>13.25</td>
<td>46.4</td>
<td>14.31</td>
</tr>
<tr>
<td>VS (g.l⁻¹)</td>
<td>25.81</td>
<td>8.93</td>
<td>31.57</td>
<td>9.34</td>
</tr>
<tr>
<td>CH₄ (ml.l⁻¹)</td>
<td>26.31</td>
<td>30</td>
<td>15.88</td>
<td>30</td>
</tr>
<tr>
<td>COD (mg.l⁻¹)</td>
<td>2502</td>
<td>1753</td>
<td>3873</td>
<td>2554</td>
</tr>
<tr>
<td>Acetic (mg.l⁻¹)</td>
<td>194</td>
<td>176</td>
<td>340</td>
<td>312</td>
</tr>
<tr>
<td>Propionic (mg.l⁻¹)</td>
<td>300</td>
<td>378</td>
<td>547</td>
<td>465</td>
</tr>
<tr>
<td>Isobutyric (mg.l⁻¹)</td>
<td>22</td>
<td>27</td>
<td>46</td>
<td>45</td>
</tr>
<tr>
<td>Butyric (mg.l⁻¹)</td>
<td>42</td>
<td>67</td>
<td>36</td>
<td>128</td>
</tr>
<tr>
<td>Isovaleric (mg.l⁻¹)</td>
<td>45</td>
<td>53</td>
<td>92</td>
<td>95</td>
</tr>
<tr>
<td>Valeric (mg.l⁻¹)</td>
<td>15</td>
<td>32</td>
<td>24</td>
<td>38</td>
</tr>
</tbody>
</table>

Comparison of the mean values (Fischer test at 95%) shows that the 'bad' tanks have significantly higher concentrations than the 'good' ones in both solids (TS and VS) and soluble matter (COD, acetic, propionic, isobutyric and isovaleric acids). The oxido-reduction potential is significantly lower in the 'bad' tanks. The result is surprising a priori: either there is an optimum, closer to -310 than -340 mV, or the difference is due to compounds limiting the anaerobic digestion. The other parameters do not enable differentiation of the systems.

**Extracellular Enzymatic Activities of Septic Tank Sludges: Study of Some Hydrolases**

The main parameter of septic tank performance is the sludge accumulation rate. This parameter incorporates all the operating conditions of the tank and thus of the process of anaerobic digestion. The initial phase of the process corresponds to the hydrolysis of the complex insoluble organic matter which is achieved by microbial exoenzymes. Localization and activity of these enzymes are useful to be determined (Sabil, 1991).

**Detection and localization of hydrolase in septic tank sludges.** The enzymatic activity was determined from the 2 components of the sludge: the solid part and the interstitial liquid. The results are shown in Table 4.

### TABLE 4. Hydrolytic Activities of Septic Tank Sludges

<table>
<thead>
<tr>
<th>Enzyme activity</th>
<th>Activity in the pellet (µM, min⁻¹, g⁻¹)</th>
<th>Activity in the supernatant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protease</td>
<td>0.028 ± 0.003</td>
<td>undetectable</td>
</tr>
<tr>
<td>Urease</td>
<td>2.30 ± 0.20</td>
<td>&quot;</td>
</tr>
<tr>
<td>Phosphatase</td>
<td>76.00 ± 8.00</td>
<td>&quot;</td>
</tr>
<tr>
<td>Cellulase</td>
<td>0.90 ± 0.09</td>
<td>&quot;</td>
</tr>
<tr>
<td>Lipase</td>
<td>24.00 ± 3.00</td>
<td>&quot;</td>
</tr>
</tbody>
</table>

* O.D. at 280 nm for 1 mg of solid matter. ml⁻¹.min⁻¹
The results show that all the activity was bound to the solid part of the sludge. Enzyme activity in the interstitial liquid was below the detection limit. Phosphatase and lipase activity were in the same order of magnitude (<100 mM. min⁻¹. g⁻¹ dry wt.) and were much higher than the urease and cellulase activity. We may conclude that all these enzymes are present and are not hydrosoluble but linked in one way or another to the solid part of the sludge.

Study of the binding of hydrolases on sludge particles. To study the type of linkage that exists between bound enzymes and the particular phase of the sludge, the pellet was subjected to 4 washes. Several authors have previously described the extraction of enzymes from soil (Ceccanti et al., 1978, Mayaudon et al., 1975, Nannipieri et al., 1980) or from anaerobic sludge (Thiel and Hattingh, 1967) and various extraction procedures have been proposed.

The results on Fig. 5 show that at least 50% of the activities remained strongly bound to the solids phase of the sludge regardless of the treatment used. Another part of the activities is bound to cell membranes and cell debris. This is the case for the fraction of phosphatase activities which are solubilized by washing in Triton, a non-ionic detergent known to solubilise bacterial cell wall and membranes. On the contrary, cellulase and urease activities appeared to be under the influence of ionic strength.

![Fig. 5. Percentage of binding on sludge particles after the action of different washing solutions.](https://iwaponline.com/wst/article-pdf/28/10/63/59346/63.pdf)

CONCLUSIONS AND PERSPECTIVES

The field and investigative study and the biochemical study carried out on many septic tanks enables us to draw the following conclusions about the sludge behaviour.

- During the first 2 years of septic tank operation the microbial hydrolytic activity produce soluble organic compounds (VFA and other metabolites) which tend to accumulate in the sludge.
- The methane formation is effective after 2 years of operation.
- The reduction of the sludge volume is optimal only after 2.5 - 3 years. Though the sludge removal is not recommended at this term.
- The sludge accumulation rate is the main parameter to be managed: a value ≤ 0.2 l day⁻¹. user⁻¹ indicates a good biological efficiency; this allows us to calculate a reactor volume knowing the sludge removal rate: a minimum five years cycle is a very reasonable challenge.

- The hydrolytic enzymes are associated with insoluble sludge particles. All the enzymes sought in the septic tank sludge were detected in the solid part. In the interstitial liquid they presented very weak, even negligible activity. The binding was very strong with regard to the values obtained: at least half the activities were unaffected by washing.

These facts clearly indicate that the rate-limiting step of sludge digestion is the methane formation. To solve septic tank problems, it is therefore unnecessary to add hydrolytic yeast, enzymes and bacteria. On the other hand, mineral insoluble additives were shown to have stimulating effects on the different stages of the
anaerobic digestion process (Maunoir et al., 1990a, 1990b). The last patented product (European no 90403338-8) issued from our works permits a reduction of the sludge volume of 60 % in treated systems compared to controls without additives, and research in progress gives hope of an increase of the efficiency up to 90 % of reduction. When operating under optimal conditions (good reactor design and sizing, effective additives) the period between two emptyings could be greatly increased (up to 15-20 years in real on-site cases). Problems of sludge and septage disposal could then be widely reduced.

REFERENCES


